

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ENERGY SOLUTION, LTD.,
Petitioner

v.

MOLECULAR REBAR DESIGN, LLC,
Patent Owner

Case IPR2024-01011
U.S. Patent 8,968,924

DECLARATION OF DEBORAH D.L. CHUNG, PH.D.

MRD EX. 2006 LGES v MRD IPR2024-01011
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EXHIBIT LIST

Exhibit No.	Description
MRD-2006	Declaration of Dr. Deborah D.L. Chung, Ph.D.
MRD-2007	WEBSTER'S NEW WORLD COLLEGE DICTIONARY (4th ed. 1999), various definitions
MRD-2008	U.S. Patent No. 8,703,009 ("Liu-009")
MRD-2009	Mengxuan Zhang et al., <i>Binder Assisted Dispersion of Agglomerated Carbon Nanotubes for Efficiently Establishing Conductive Networks in Cathodes of Li-Ion Batteries</i> , 8 ENERGY TECHNOLOGY 2000589 (2020).
MRD-2010	Varrla Eswaraiah et al., <i>Morphological, Thermal, Electrical and Electromechanical Properties of Polyvinylidene Fluoride (PVDF)-Functionalized Carbon Nanotube Composites (Preprint)</i> , AFRL-RX-WP-TP-2012-0277 INDIAN INSTITUTE OF TECHNOLOGY CHENNAI (2012).
MRD-2011	B. V. Bahaskara Rao et al., <i>Fabrication and Evaluation of Thin Layer PVDF Composites Using MWCNT Reinforcement: Mechanical, Electrical and Enhanced Electromagnetic Interference Shielding Properties</i> , 6 AIP ADVANCES 065107 (2016).
MRD-2012	Viraj Bhingardive et al., <i>Polyvinylidene Fluoride Based Lightweight and Corrosion Resistant Electromagnetic Shielding Materials</i> , 5 RSC ADV. 35909 (2015).
MRD-2013	Ming Wang et al., <i>The Influence of Polyvinylidene Fluoride (PVDF) Binder Properties on LiNi_{0.33}Co_{0.33}Mn_{0.33}O₂ (NMC) Electrodes Made by a Dry-Powder-Coating Process</i> , 166 JOURNAL OF THE ELECTROCHEMICAL SOCIETY A2151 (2019).
MRD-2014	Soumyaranjan Mishra et al., <i>Synthesis of PVDF/CNT and Their Functionalized Composites for Studying Their Electrical Properties to Analyze Their Applicability in Actuation & Sensing</i> , 509 COLLOIDS AND SURFACES A: PHYSICOCHEMICAL AND ENGINEERING ASPECTS 684 (2016).

Exhibit No.	Description
MRD-2015	U.S. Patent No. 6,869,724
MRD-2016	Lizhi Wen et al., <i>Effect of Conductive Material Morphology on Spherical Lithium Iron Phosphate</i> , 8 NANOMATERIALS 904 (2018).
MRD-2017	U.S. Patent Application Publication No. 2014/0319429 (“Nicolas-429”)
MRD-2018	U.S. Patent Application Publication No. 2011/0256454 (“Nicolas-454”)
MRD-2019	RESERVED
MRD-2020	Wener Bauer et al., <i>Rheological Properties and Stability of NMP Based Cathode Slurries for Lithium Ion Batteries</i> , 40 CERAMICS INTERNATIONAL 4591 (2013).
MRD-2021	RESERVED
MRD-2022	RESERVED
MRD-2023	Declaration of Dr. Yu Zhu in IPR2024-01013, dated June 12, 2024
MRD-2024	Deposition Transcript of Dr. Yu Zhu in IPR2024-01013, dated March 14, 2025
MRD-2025	Deposition Transcript of Dr. Yu Zhu in IPR2024-01006, dated March 21, 2025
MRD-2026	Deposition Transcript of Dr. Yu Zhu in IPR2024-01011, dated March 21, 2025
MRD-2027	RESERVED
MRD-2028	U.S. Patent Application Publication No. 2024/0274804

Exhibit No.	Description
MRD-2029	Niurka Barrios-Bermúdez et al., <i>Amino-Functionalized Multiwall Carbon Nanotubes as Efficient Basic Catalysts for the Formation of γ-Lactams: Synthesis of N-1-Heptenyl-2-pyrrolidinone</i> , 12 NANOMATERIALS 684 (2022).
MRD-2030	Shankhamala Kundu et al., <i>Thermal Stability and Reducibility of Oxygen-Containing Functional Groups on Multiwalled Carbon Nanotube Surfaces: A Quantitative High-Resolution XPS and TPD/TPR Study</i> , 112 J. PHYS. CHEM. 16869 (2008).
MRD-2031	S.A. Chernyak et al., <i>Mechanism of Thermal Defunctionalization of Oxidized Carbon Nanotubes</i> , 120 THE JOURNAL OF PHYSICAL CHEMISTRY 17465 (2016).
MRD-2032	Nathan Hordy et al., <i>Thermal Stability of Plasma Generated Oxygenated Functionalities on Carbon Nanotubes</i> , 12 PLASMA PROCESS. POLYM. 533 (2015) 533.
MRD-2033	ICSC: 1577 – FERRIC OXIDE (2004)
MRD-2034	Haitao Wang et al., <i>In Situ TiC-Reinforced Ni-Based Composite Coating Prepared by Flame Spraying Using Sucrose as the Source of Carbon</i> , 18 JOURNAL OF THERMAL SPRAY TECHNOLOGY, 103 (2009).
MRD-2035	RESERVED
MRD-2036	RESERVED
MRD-2037	Aleksander Cholewinski et al., <i>Polymer Binders: Characterization and Development toward Aqueous Electrode Fabrication for Sustainability</i> , 13 POLYMERS 631 (2021).
MRD-2038	Xiaoping Shui et al., <i>High-Strength High-Surface-Area Porous Carbon Made From Submicron-Diameter Carbon Filaments</i> , (2016).
MRD-2039	RESERVED

Exhibit No.	Description
MRD-2040	R. Piat et al., <i>Identification of Coefficients of Thermal Expansion of Pyrolytic Carbon with Different Texture Degrees</i> , 251-252 KEY ENGINEERING MATERIALS 333 (2003).
MRD-2041	Keiichi Shirasu et al., <i>Negative Axial Thermal Expansion Coefficient of Carbon Nanotubes: Experimental Determination Based on Measurements of Coefficient of Thermal Expansion for Aligned Carbon Nanotube Reinforced Epoxy Composites</i> , 95 CARBON 904 (2015).
MRD-2042	Tobias Gensch et al., <i>Approach to Comparing Functional Group Tolerance of Reactions</i> , 82 THE JOURNAL OF ORGANIC CHEMISTRY 9154 (2017).

I. INTRODUCTION

1. I have been retained as a technical expert by Molecular Rebar Design, LLC (“Molecular” or “Patent Owner”) and asked to provide my objective and unbiased opinions concerning the patentability of U.S. Patent No. 8,968,924 (“the ’924 Patent”). Specifically, I have been asked to provide my opinions on the patentability of the challenged claims of the ’924 Patent in view of the grounds advanced in the pending Petitions for *Inter Partes* Review filed by LG Energy Solution Ltd. (“LG” or “Petitioner”) against the ’924 Patent (IPR2024-01011), the state of the art at the time of the claimed inventions, and the knowledge of a person of ordinary skill in the art at the time of the claimed inventions.

II. BACKGROUND AND QUALIFICATIONS

2. My Curriculum Vitae is attached hereto as Appendix A.

3. In forming the opinions expressed in this Declaration, I have considered and relied upon my education, background, and experience. In addition, I have reviewed and relied upon materials in preparation of this Declaration, as described herein.

4. I earned a Bachelor’s (B.S.) Degree in Engineering and Applied Science in 1973 from the California Institute of Technology in Pasadena, California. I also earned a Master’s (M.S.) Degree in Engineering Science in 1973 from the California Institute of Technology. I earned a Master’s (S.M.) Degree in Materials

Science in 1975 from the Massachusetts Institute of Technology in Cambridge, Massachusetts. I also earned a Doctorate (Ph.D.) degree in Materials Science in 1977 from the Massachusetts Institute of Technology.

5. I am currently a SUNY Distinguished Professor of Mechanical and Aerospace Engineering at University at Buffalo, The State University of New York, in Buffalo, New York. I am also the Founding Director of the Composite Materials Research Laboratory at the University at Buffalo, The State University of New York.

6. Prior to joining the University at Buffalo, The State University of New York, I was a Teaching Assistant in the Department of Materials Science and Engineering at the Massachusetts Institute of Technology from 1973 to 1974. I was a Research Assistant in the Department of Materials Science and Engineering and the Department of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology from 1974 to 1977. I was an Assistant Professor of Metallurgical Engineering and Materials Science and Electrical Engineering at Carnegie–Mellon University in Pittsburgh, Pennsylvania from 1977 to 1982. I was an Associate Professor of Metallurgical Engineering and Materials Science at Carnegie–Mellon University from 1982 to 1986. I was a Professor of Mechanical and Aerospace Engineering at University of Buffalo, The State University of New York (SUNY), from 1986 to 2024. In 2024, I became a SUNY Distinguished Professor at University at Buffalo, The State University of New York.

In addition, I became a Founding Director of the Composite Materials Research Laboratory at University of Buffalo, The State University of New York, in 1989.

7. I am a Member (Fellow) of the American Academy of Arts and Sciences (elected in 2023). This Academy was founded by the Founding Fathers of the U.S.A. in 1780, with members including Washington, Kennedy and Einstein.

8. I hold an Honorary Doctorate Degree from University of Alicante, Alicante, Spain (2011).

9. I am Fellow of ASM International (1998), and Fellow of American Carbon Society (2001).

10. In 2004, I received the Pettinos Award from the American Carbon Society. This is an international award for outstanding achievement in research in the field of carbon materials. An award is given once every three years to one person (or one research group) in the world.

11. I received the University at Buffalo President's Medal (2024) and the SUNY Chancellor's Award for Excellence in Scholarship and Creative Activities (2003). In addition, I was recognized as a SUNY Outstanding Inventor (2002).

12. In 2024, I received a Special Congressional Recognition from the U.S. Congress.

13. Through my professional work, and as reflected in my curriculum vitae (CV), I am an expert in the field of carbon materials and composite materials,

including materials for electrical functions, materials for electrochemical functions, materials for mechanical functions, and materials for thermal functions. For example, I authored the following books on carbon materials and composite materials:

- a. “Carbon Materials” published in 2019 by World Scientific Publishing Company;
- b. “Functional Materials”, 2nd Edition, published in 2021 by World Scientific Publishing Company;
- c. “Carbon Composites: Composites with Carbon Fibers, Nanofibers and Nanotubes”, 2nd Ed., published by Elsevier in 2017.

14. I am the author or co-author of over 600 peer-reviewed journal papers on varying topics related to the relationship among the processing (fabrication and modification), structure (internal structure in the microscopic level and macroscopic level) and properties (behavior) of materials, said materials including carbon materials, nanomaterials, composite materials, electrically conductive materials, polymeric materials, and ceramic materials, with their impact indicated by 49,718 citations, h factor = 115, according to Google Scholar (viewed on 3/30/2025).

15. Specific to the field of carbon and composite materials for electrical/electrochemical functions, I have authored or co-authored hundreds of

peer-reviewed journal publications, all of which are listed in Appendix 1.

Specifically, I have authored or co-authored:

- a. 12 peer-reviewed archival journal publications on carbon materials for electrochemical functions, which include the functions related to electrodes, binders, electrically conductive additives, current collectors, electrical contacts, thermal management, and electromagnetic interference shielding,
- b. 36 peer-reviewed archival journal publications on carbon nanomaterials, which include carbon nanotube, carbon nanofiber, carbon black, and graphite nanoplatelet,
- c. 15 peer-reviewed archival journal publications on exfoliation of carbon materials, which include graphite and carbon fiber,
- d. 17 peer-reviewed archival journal publications on intercalation, particularly the intercalation of graphite,
- e. 6 peer-reviewed archival journal publications on binders, which include polymeric, ceramic and carbon materials,
- f. 22 peer-reviewed archival journal publications on electrical contacts, which include those between carbon fiber composites, between metals, and between ceramic materials,

g. 33 peer-reviewed archival journal publications on electrical resistance, particularly the effect of mechanical and thermal stimuli on the electrical resistance of materials.

16. I also have considerable experience studying and working with carbon nanotubes. Specifically, I pioneered and provided international leadership in research on carbon nanofiber, which was originally known as carbon filament (prior to nanomaterials becoming “fashionable”). Carbon nanotube is a type of carbon nanofiber and was also originally known as carbon filament. Below are some of my peer-reviewed journal publications in this field. These publications pertain to the processing, structure, properties and applications of carbon nanotube and related materials.

- Xiaoping Shui, Christine A. Frysz, and D.D.L. Chung, "Solvent Cleansing of the Surface of Carbon Filaments and Its Benefit to the Electrochemical Behavior," Carbon 33(12), 1681-1698 (1995).
- Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Carbon Filaments and Carbon Black as a Conductive Additive to the Manganese Dioxide Cathode of a Lithium Electrolytic Cell," J. Power Sources 58(1), 41-54 (1996).
- Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Use of Carbon Filaments in Place of Carbon Black as the Current Collector of a Lithium

Cell with a Thionyl Chloride-Bromine Chloride Catholyte," J. Power Sources 58(1), 55-66 (1996).

- Xiaoping Shui and D.D.L. Chung, "High-Strength High-Surface-Area Porous Carbon Made From Submicron-Diameter Carbon Filaments," Carbon 34(6), 811-814 (1996); 34(9), 1162 (1996).
- Weiming Lu and D.D.L. Chung, "Mesoporous Activated Carbon Filaments," Carbon 35(3), 427-430 (1997).
- Christine A. Frysz and D.D.L. Chung, "Improving the Electrochemical Behavior of Carbon Black and Carbon Filaments by Oxidation," Carbon 35(8), 1111-1127 (1997).
- D.D.L. Chung, "Comparison of Submicron Diameter Carbon Filaments and Conventional Carbon Fibers as Fillers in Composite Materials", Carbon 39(8), 1119-1125 (2001).
- Weiming Lu and D.D.L. Chung, "Anodic Performance of Vapor-Deprived Carbon Filaments in Lithium-Ion Secondary Battery", Carbon 39(4), 493-496 (2001).
- Junhua Wu and D.D.L. Chung, "Improving Colloidal Graphite for Electromagnetic Interference Shielding by the Use of 0.1 μm Diameter Carbon Filaments", Carbon 41(6), 1313-1315 (2003).

- Xuli Fu and D.D.L. Chung, "Submicron Carbon Filament Cement-Matrix Composites for Electromagnetic Interference Shielding," *Cem. Concr. Res.* 26(10), 1467-1472 (1996); 27(2), 314 (1997).
- Xiaoping Shui and D.D.L. Chung, "Submicron Nickel Filaments Made by Electroplating Carbon Filaments as a New Filler Material for Electromagnetic Interference Shielding," *J. Electron.Mater.* 24(2), 107-113 (1995).
- Xiaoping Shui and D.D.L. Chung, "Piezoresistive Carbon Filament Polymer-Matrix Composite Strain Sensor," *Smart Mater.Struct.* 5, 243-246 (1996).
- Steven W. Hudnut and D.D.L. Chung, "Use of Submicron Diameter Carbon Filaments for Reinforcement between Continuous Carbon Fiber Layers in a Polymer-Matrix Composite," *Carbon* 33(11), 1627-1631 (1995).
- Martin Segiet and D.D.L. Chung, "Discontinuous Surface-Treated Submicron-Diameter Carbon Filaments as an Interlaminar Filler in Carbon Fiber Polymer-Matrix Composites for Vibration Reduction", *Composite Interfaces* 7(4), 257-276 (2000).
- Xinghua Hong and D.D.L. Chung, "Carbon nanofiber mats for electromagnetic interference shielding", *Carbon* 111, 529-527 (2017).

- Seungjin Han and D.D.L. Chung, "Strengthening and stiffening carbon fiber epoxy composites by halloysite nanotubes, carbon nanotubes and silicon carbide whiskers", Applied Clay Science, 83-84, 375-382 (2013).
- Yan Chen, David T. Shaw and D.D.L. Chung, "Hydrogen Storage in Aligned Carbon Nanotubes", Appl. Phys. Lett. 78(15), 2128-2130 (2001).
- Yunsheng Xu, Chia-Ken Leong and D.D.L. Chung, "Carbon Nanotube Dispersions as Thermal Pastes", J. Electron. Mater. 36(9), 1181-1187 (2007).

17. I have no financial interest in Molecular Rebar or the '924 Patent. I am being compensated for my time spent in connection with these proceedings at an hourly rate. I am also being reimbursed for reasonable expenses, such as travel expenses. My compensation is not contingent on my opinions, on the outcome of any matter, or on any of the technical positions I explain in this declaration.

III. LEGAL STANDARDS

18. I am not an attorney. For purposes of this Declaration, I have been informed about certain aspects of the law that are relevant to my opinions, as set forth below.

A. Patentability

19. I understand that for an invention claimed in a patent to be valid and patentable, it must be, among other things, new and not obvious in light of what was known and came before it. That which was known or came before the invention claimed is generally referred to as “prior art.”

20. I understand that there are two ways in which prior art may render a patent claim unpatentable. First, the prior art can be shown to “anticipate” the claim. Second, the prior art can show that the claim was obvious to a person of ordinary skill in the field of the invention at the time the invention was made.

21. I understand that, for a patent claim to be “anticipated” by the prior art, each and every element or requirement of the claim must be found, expressly or inherently, in a single prior art reference. Further, I understand that anticipation requires that the single prior art reference must disclose the elements of the claim arranged or combined in the same way as in the claim.

22. It is my understanding that whether a claimed invention is obvious is a question of law, with underlying factual inquiries that are determined from the perspective of a person of ordinary skill in the art at the time of the claimed invention.

23. It is my understanding that a claimed invention is obvious if the differences between the claimed invention and the prior art are such that the claimed

invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art (a “POSITA”).

24. It is my understanding that obviousness requires consideration of the following underlying factual inquiries:

- determining the scope and content of the prior art
- ascertaining the differences between the claimed invention and the prior art;
- resolving the level of ordinary skill in the art; and
- evaluating objective evidence or “secondary considerations” of non-obviousness, such as experimental results, commercial success, long-felt but unresolved needs, failure of others, industry praise, and unexpected results.

25. It is my understanding that a reference must be analogous art to the claimed invention in order to be properly considered for use in an obviousness inquiry. It is my understanding that a reference is analogous art to the claimed invention if:

- The reference is from the same field of endeavor as the claimed invention (even if it addresses a different problem); or
- The reference is reasonably pertinent to the problem faced by the inventor (even if it is not in the same field of endeavor as the claimed invention).

26. It is my understanding that whether a reference is reasonably pertinent depends on how the problem faced by the inventor is reflected, either explicitly or implicitly, in the specification.

27. It is my understanding that the following are exemplary rationales that may support a conclusion of obviousness:

- Combining prior art elements according to known methods to yield predictable results;
- Simple substitution of one known element for another to obtain predictable results;
- Use of known techniques to improve a similar method or product in the same way;
- Applying a known technique to a known method or product ready for improvement to yield predictable results;
- Obvious to try – choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- Known work in one field of endeavor may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations are predictable to one of ordinary skill in the art; and
- Some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

28. In addition to the above, I understand that a person of ordinary skill in the art may resort to logic, judgment and common sense available to him or her at the time of the invention or prior to the invention to find a claim feature obvious, even if the prior art relied on does not explicitly state or teach that feature. I understand that when common sense is relied on to find a feature obvious, the reasoning for that conclusion must be articulated with sufficient clarity.

29. I also understand that a patent claim is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art. An obviousness determination requires finding both that a skilled artisan would have been motivated to combine the teachings of the prior art references to achieve the claimed invention, and that the skilled artisan would have had a reasonable expectation of success in doing so. I understand that it is important to be careful not to allow hindsight reconstruction of references to produce the claimed invention, without any explanation as to how or why the references would be combined to produce the claimed invention.

30. I understand that where claim element discloses a narrow range of a characteristic of a chemical compound, a prior art reference disclosing an overlapping, but much larger range, does not necessarily render the limitation obvious if the broader range encompasses versions of the compounds that would have distinct structures or behaviors different from than those in the claimed range.

I understand that a POSITA would thus not be motivated to attempt to optimize the broader disclosed range because of those distinct differences in structure and behavior.

31. Regarding “objective evidence” or “secondary considerations,” I understand that for such evidence to be relevant to the obviousness of a claim, there must be a causal relationship (called a “nexus”) between the claim and the evidence. I also understand that such objective evidence may include: commercial success of products covered by the patent claims; long-felt need for the invention; failed attempts by others to solve the problem addressed by the invention; copying of the invention by others in the field; unexpected results achieved by the invention; praise of the invention; the taking of licenses under the patent by others; expressions of surprise by experts and those skilled in the art at the making or use of the invention; and that the patentee proceeded contrary to the accepted wisdom of the prior art.

32. I understand that a person of ordinary skill is also a person of ordinary creativity. I further understand that the obviousness analysis need not seek out precise teachings directed to the specific subject matter of the challenged claim, but instead can take into account “ordinary innovation” that does no more than yield predictable results, which are inferences and creative steps that a person of ordinary skill in the art would be understood to employ.

33. I understand that sometimes it will be necessary to look to interrelated teachings of multiple patents and publications; the effects of demands known to the relevant field or present in the marketplace; and the background knowledge possessed by a person having ordinary skill in the art. I understand that all these issues may be considered to determine whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue.

B. Prior Art

34. I understand that for purposes of this proceeding, prior art includes patents and printed publications (e.g., journal articles) in or outside the United States before the effective filing date of the claimed invention. I also understand that prior art includes U.S. patents, published U.S. patent applications, and published international applications (pursuant to the Patent Cooperation Treaty) that themselves have an effective filing date before the effective filing date of the claimed invention, as long as they name another inventor.

C. Inherency

35. I understand that if a prior art reference does not expressly set forth a particular claim element, the prior art may still disclose that element if it is “inherent” in its disclosure. To establish inherency, it is my understanding that evidence must make clear that the missing descriptive matter is necessarily present in the thing described in the reference. It is my understanding that inherency may not be

established by probabilities or possibilities. In other words, it is my understanding that the mere fact that a certain thing may result from a given set of circumstances is not sufficient to establish inherency.

36. I understand that under the principles of inherency, if a prior art device, in its normal and usual operation, would necessarily perform a claimed method, then the method will be considered to be anticipated by the prior art device. I also understand that when the prior art device is the same as a device described in the specification for carrying out the claimed method, it can be assumed that the device will inherently perform the claimed process.

D. Person of Ordinary Skill In The Art

37. I understand that “a person of ordinary skill in the art” or POSITA is a hypothetical person who is presumed to have known the relevant art at the time of the invention. Such a person would necessarily have the capability of understanding any scientific and engineering principles applicable to the pertinent art.

38. I understand that factors that may be considered in determining the level of ordinary skill in the art include, but are not limited to, the following:

- a. the educational level of the inventor;
- b. the type of problems encountered in the art;
- c. prior art solutions to those problems;

- d. the rapidity with which innovations are made;
- e. the sophistication of the technology; and
- f. the educational level of active workers in the field.

39. I understand that a person of ordinary skill in the art is not a real person, but rather is a hypothetical individual having the qualities reflected by the factors above. This hypothetical person has knowledge of all prior art in the relevant field as if it were arranged on a workshop wall and takes from each reference what it would teach to a person of ordinary skill in the art.

40. I understand that a person of ordinary skill in the art is a person of ordinary creativity, not an automaton. In many cases a person of ordinary skill will be able to fit the teachings of multiple prior art references together like pieces of a puzzle.

41. I understand that a person of ordinary skill in the art can collaborate with one or more other persons of ordinary skill in the art for one or more aspects with which the other person may have superior expertise, experience, and/or knowledge.

E. Claim Construction

42. It is my understanding that claim construction, or the interpretation of the claims of a patent, is ultimately a question of law. I have been informed that

claim terms are generally presumed to carry their ordinary and customary meaning. However, I understand that a patent applicant is his own lexicographer and is entitled to provide alternate definitions of words in common usage, but if the patent applicant uses a term that is in common usage without providing an alternate definition, then that term should generally be understood as having its common meaning.

43. I understand that a person of ordinary skill in the art is deemed to read a claim term not only in the context of the particular claim in which the disputed term appears, but in the context of the entire patent specification and the “file history” of the patent developed during examination by the Patent Office.

44. I understand that the claims, the specification, and the file history are referred to as “intrinsic evidence,” and are to be read as a person of ordinary skill in the art at the time of the invention would have done at the time of the alleged invention.

45. In addition to the intrinsic evidence, I understand that the court or tribunal may also consider other relevant evidence, which is called “extrinsic evidence,” concerning relevant scientific principles, the meaning of technical terms, and the state of the art. Such evidence includes the testimony of qualified expert witnesses. Although extrinsic evidence may be used to resolve ambiguities that may exist after reviewing the intrinsic evidence, I understand that extrinsic evidence

cannot be used to contradict a claim construction that is clear from the intrinsic evidence.

46. I understand that some claims are independent, and that those independent claims are complete by themselves. Other claims refer to these independent claims, or other dependent claims, and are “dependent” on those claims. The dependent claims include all of the limitations of the claims on which they depend.

IV. BASES FOR OPINIONS

47. The opinions set forth in this Declaration are my own. In forming the opinions herein, I have considered the Petition for *Inter Partes Review* filed in the IPR proceedings referenced above and exhibits thereto, as well as the additional materials cited in this Declaration (including the exhibits to the Patent Owner’s Response cited herein), and my education, training, and experience.

48. My analysis of the materials relating to this matter is ongoing and I will continue to review any new material that is provided to me. This Declaration represents certain opinions that I have formed to date and the bases for those opinions. I reserve the right to revise, supplement, and/or amend my opinions based on new information presented to me and on my continuing analysis of the materials cited herein or later provided to me.

V. LEVEL OF ORDINARY SKILL IN THE ART

49. I understand that Petitioner's expert, Dr. Yu Zhu, provides his opinion that a POSITA would have at least a Master's degree in materials science, chemistry, chemical engineering, a field relevant to polymer science and engineering, or the equivalent, and at least three years of experience in nanomaterials, electrochemistry, batteries, or polymer related activities. LGES-1003 ¶11.

50. My education and experience exceed that of a POSITA as described above and qualify me to testify as to the knowledge of a POSITA under any reasonable definition. *Supra* Section II ("Background and Qualifications").

51. With these understandings, my testimony herein relates to the knowledge and understanding of a POSITA as of June 23, 2011. I understand this is the alleged "Critical Date" date applied by Petitioner, and I have been asked to use this date for the purposes of my testimony. I have formed no opinion on whether this date is the appropriate date, nor have I been asked to do so. Moreover, even assuming the Critical Date were to be June 21, 2012, my opinions in this Declaration would not change with respect to the understanding of a POSITA at the time of the invention.

VI. CLAIM CONSTRUCTION

52. I understand that Petitioner has not expressly proposed any terms for construction. Consequently, for purposes of this declaration, I apply the plain and ordinary meaning of the disputed terms as they would be understood by a POSITA.

VII. ASSERTED GROUNDS

53. I understand that in IPR2024-01011, Petitioner has asserted two grounds of unpatentability.

54. In Ground 1, I understand that Petitioner has asserted that Claims 1, 4, and 5 are obvious over the combination of Ohata and Kavan. Specifically, Petitioner contends that it would have been obvious to modify the process described in Ohata based on Kavan, by oxidizing the CNTs of Ohata at the levels taught by Kavan and using an active material that is LiMnPO_4 or LiFePO_4 as taught by Kavan.

55. In Ground 2A, I understand Petitioner has asserted that Claims 1, 4, and 5 are obvious over the combination of Cheng and Gan. Specifically, Petitioner contends that it would have been obvious to modify the process described by Cheng to use CNTs that are functionalized or oxidized with carboxyl or hydroxyl groups using the methods and weight percentages taught by Gan.

56. In Ground 2B, I understand Petitioner has asserted that Claims 2 and 3 are obvious over the combination of Cheng, Gan, and Zhao. Specifically, Petitioner

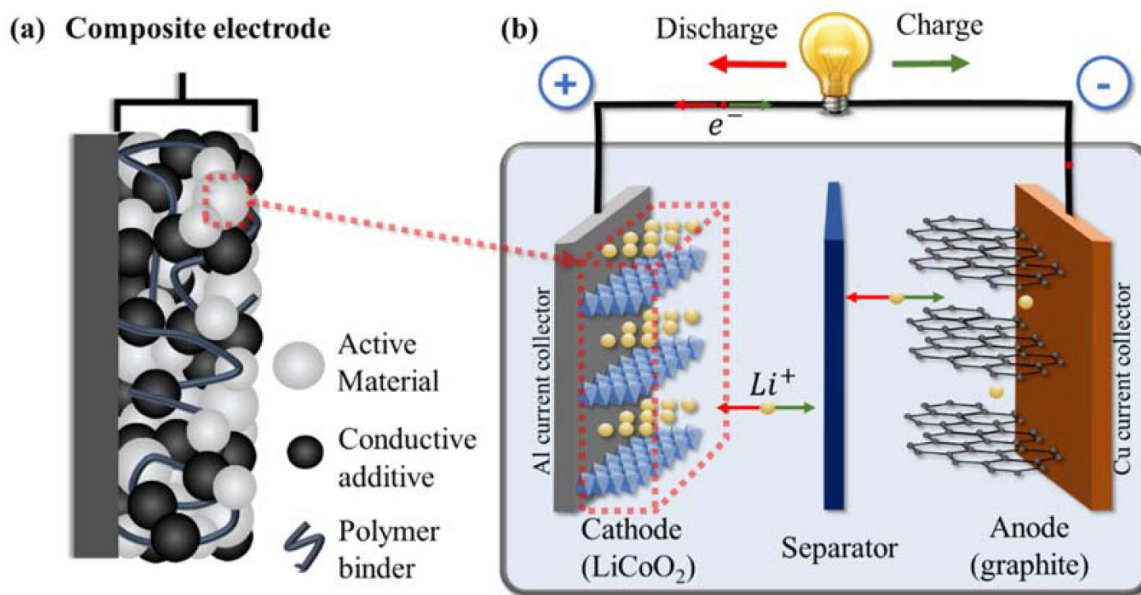
contends that it would have been obvious to use graphene in the Cheng-Gan combination based on Zhao.

VIII. TECHNOLOGICAL BACKGROUND

57. Before addressing the specific grounds asserted by Petitioner, I provide a brief background of the '924 Patent and relevant technology. The '924 Patent is directed toward lithium-ion batteries, particularly compositions that makeup the electrode (either the cathode or anode) of lithium-ion batteries. LGES-1001, 2:37-47.

A. Overview of Electrodes

58. In reference to the schematic below, an electrode (cathode or anode) comprises three key parts: (1) the active material, (2) a binder, and (3) a conductive additive. MRD-2037, 2. The depicted cathode is on a current collector.



Id. The active material (1) is the electrochemically active component that directly participates in the reactions that allow the battery to store and release energy. During discharge, oxidation reaction occurs at the anode, which releases electrons to the cathode via the outer circuit. Thus, the cathode receives electrons from the outer circuit, thereby resulting in a reduction reaction at the cathode. During charge, a voltage is applied at the outer circuit, so that the reverse reactions occur at the two electrodes, i.e., reduction reaction occurs at the anode and oxidation reaction occurs at the cathode. Both electrodes must be in direct contact with the electrolyte, which is a fluid that the two electrodes are immersed in. Preferably, the electrodes are porous, so that the electrolyte can enter the pores in both electrodes, thereby enabling the area of the electrode-electrolyte interface to be high. Alternatively, the electrolyte is a solid, but this is not common. During charging and discharging, the active material expands and contracts.

59. The binder (2) acts as a “glue” to hold the active material particles and electrically conductive agent together, as well as to attach the active material to the current collector. The binder thus enables the composition to be an integral mass (rather than loose particles) and provides sturdiness and handleability to the mass.

60. A conductive agent (3) is typically included in the electrode composition to help provide a continuous electrically conductive path in the electrode composition. This path helps ensure that electrons are able to flow from

the anode to the external circuit (not shown), and for the electrons to flow from the external circuit to the cathode during discharge. If the active material is not conductive or poorly conductive, as in the case of active materials in the form of oxides, a conductive agent is indispensable for increasing the electrical conductivity of the electrode. In the typical case where the binder is not conductive, the binder cannot contribute to the formation of a conductive path and a conductive agent is key to forming a conductive path. The binder also serves to hold the units of the conductive agent together and to hold the conductive agent and the active material particles together. Therefore, a mixture of active material particles, binder and conductive agent is widely used in forming an electrode that is electrically conductive and mechanically sturdy.

61. The conductive agent is typically in the form of particles, discontinuous fibers, discontinuous nanofibers, or discontinuous nanotubes. The discontinuous nature facilitates the mixing of the constituents in the electrode composition. In order to form a continuous conductive path using such discontinuous units, the units must touch one another. The phenomenon in which the units touch one another to form continuous conductive path is known as “percolation.” It is helpful to have multiple paths, so that any discontinuity in one of the paths would not destroy the conduction feasibility in the overall composition. An assembly with multiple conductive paths is typically in the form of a network that involves a large number of contact points

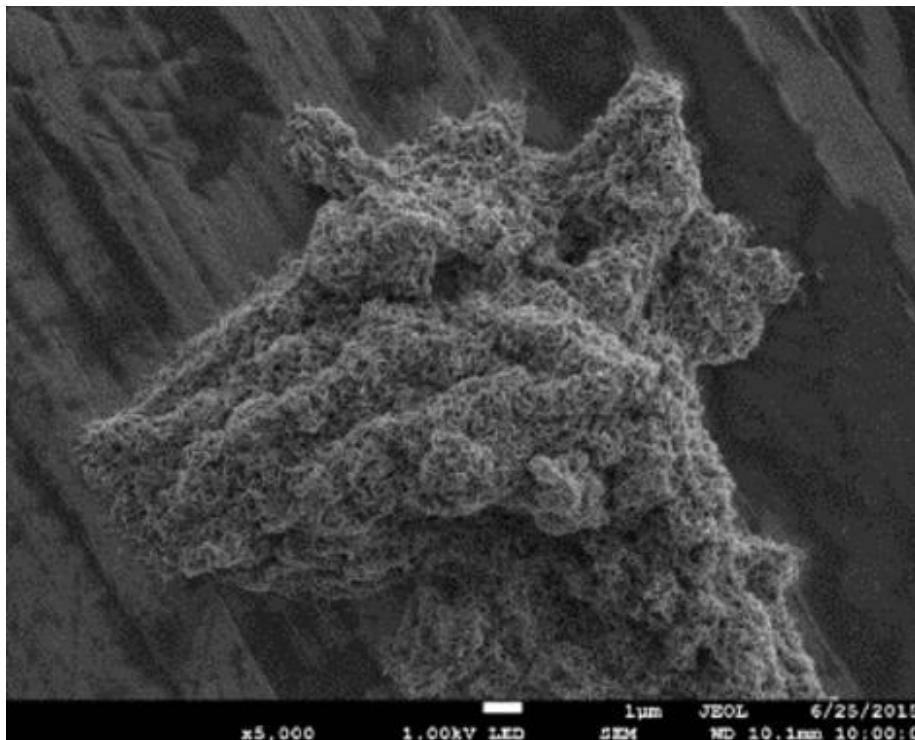
among the units of the conductive agent. Each contact point is associated with an electrical resistance, which is undesirable. Having a plurality of conductive paths helps to reduce the overall resistance of the network, but results in more contact points.

B. Efforts to Improve Electrical Conductivity

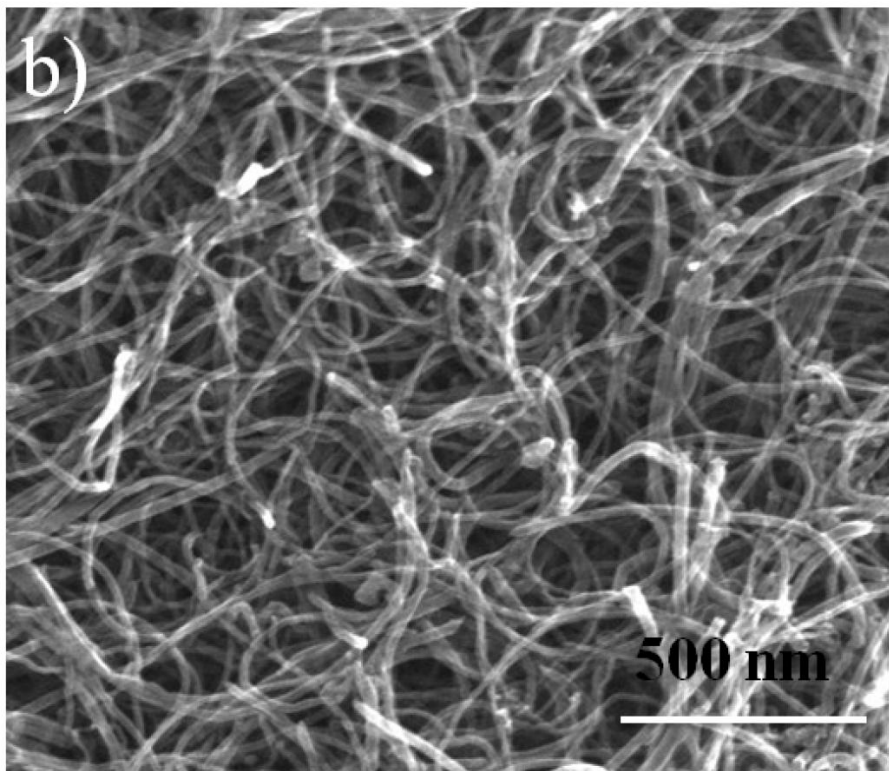
62. At the time of the invention, it was common to use carbon black as the conductive agent to try and form a continuous conductive network in lithium-ion battery electrodes. LGES-1004 ¶[0002]-[0003]. While carbon black particles are inexpensive and can be naturally chained together through Van der Waals forces to form a conductive network, it was known that the chains were susceptible to breaking apart, particularly during the mixing of the constituents in the composition comprising the carbon black. *Id.* ¶[0003] (explaining that it was known that the shear force applied to carbon black during mixing could break the conductive chain). For this and other reasons, carbon nanotubes (“CNTs”) were being explored as an alternative conductive agent. LGES-1007 ¶[0009] (explaining that in prior art methods “carbon nanotubes are used as an electrically conductive additive instead of carbon black”).

63. CNTs were of particular interest because of their high electrical conductivity and mechanical strength, making them prime candidates for use as conductive agents. *Id.* ¶¶[0005]-[0006]. Unlike carbon black particles, CNTs are

formed as tubes held together by internal bonds that are much more resilient to shear forces and which can more readily provide a continuous conductive path through the composition. However, one of the key challenges with CNTs is that they are created as highly entangled bundles (also called “raw” bundles). *Id.* ¶[0009] (explaining that “the dispersion problem of the carbon nanotubes cannot be completely solved”). A scanning electron microscopy (“SEM”) image is provided below as an example of how CNTs present as a highly entangled mass in their raw state.



Another example SEM image is provided below showing how highly entangled raw CNTs present themselves:



MRD-2010, 15 (Fig. 2(b)).

64. This excessive bundling presented several problems, including higher resistance due to the number of CNT-to-CNT contact points and considerable difficulty in dispersing the CNTs throughout the electrode composition. The inability to adequately disperse CNTs throughout the electrode composition can result in agglomeration, leading to local discontinuities (e.g., voids) in the conductive network of the composition. The discontinuities can hinder the formation of a continuous conductive path, thereby degrading the electrical conductivity of the assembly. LGES-1021 ¶[0027] (explaining that agglomeration of CNTs “is undesirable because it results in the formation of voids and aggregates in the

composite which adversely affects the electrical conductivity properties of the composite as well as the physical properties of the composite”).

65. At the time of the invention, a key focus of those seeking to leverage CNTs as a conductive agent was trying to form the most effective continuous (also called “percolated”) conductive network. For example, a Chinese patent application publication (“Cheng”) explains that CNTs “can better connect electrode active materials into a continuous ‘network’ that is electrically conductivity, thereby improving the electrical conductivity of the electrode and utilization rate of the active material.” LGES-1007 ¶[0005]. More specifically, Cheng sought to “form a continuously connected three-dimensional electrically conductive network or [p]ore structure both in the bulk phase and on surfaces of the electrical material.” *Id.* ¶¶[0009]-[0010].

66. Similarly, U.S. Patent Publication No. 2012/0058255 (“Gan”) likewise teaches that its goal is to achieve a “percolated network” of CNTs that “form a continuous conductive path extending through the composite,” which is “believed to be a reason why the electrical conductivity ... increases when CNTs are present.” LGES-1021 ¶[0041]. Figure 5 of Gan, reproduced below, depicts CNTs that have been dispersed to form a continuous network:

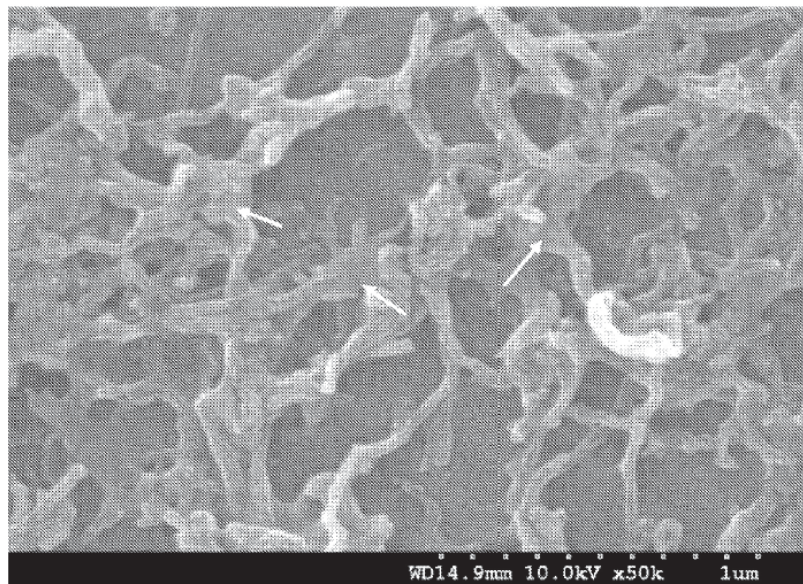


FIG.5

Id., 5. As clearly shown, the CNTs are considerably less entangled than they would be in their raw bundled form, and they are interconnected to form a continuous network, as was widely sought at the time of the invention. To achieve these continuous networks of CNTs, efforts were made to disentangle and improve the dispersion of CNTs, resulting in a less entangled network of CNTs that was better distributed throughout the overall composition. LGES-1021 ¶¶ [0019]-[0021], [0041] (explaining that oxidizing CNTs helps improve their solubility and dispersibility to form a better conductive network); LGES-1007 ¶[0010] (explaining that “uniform dispersion of carbon nanotubes” can help form a “continuously connected three-dimensional electrically conductive network structure”). Thus, a primary goal of those of skill in the art prior to the invention was to improve CNT

dispersion to achieve a continuous network of CNTs, providing improved conductivity throughout the electrode composition.

C. The '924 Patent

67. While the conventional wisdom at the time was to seek to achieve a network of interconnected CNTs (i.e., a “continuous” network) among active material particles, the inventors made the unconventional discovery that discrete CNTs provide major advantages, particularly when the active material crystals are attached (e.g., ionically or covalently bonded) to the surface of the CNTs via oxidation. LGES-1001, 1:52-64. As the patent explains, “discrete” CNTs are those that are individually dispersed and separate from other CNTs. *Id.* at 1:45-49 (describing “discrete carbon nanotubes” as “individual uniformly dispersed tubes”), 3:52-54 (explaining that “discrete carbon nanotubes” refers to CNTs being “separated to give individual tubes”), FIG. 1 (depicting individual tubes separate from any other tube); *See also* MRD-2007, 8 (defining “discrete” as “separate and distinct; not attached to others; unrelated”); MRD-2024, 11:4-8 (Dr. Zhu testifying that CNTs are discrete “because” they are “fully isolated” from one another), 12:17-13:22 (testifying that “discrete” CNTs are “separated from each other”); MRD-2025, 11:7-12:1.

68. They discovered that the microcracking of active material crystal—due to expansion and contraction during charging and discharging, severe mechanical

vibration, and bending—could be “retarded” by bounding the active material crystals to the surface of discrete CNTs. LGES-1001, 1:52-63. In other words, when the active material (such as a silicon-based active material) undergoes expansion/contraction during charge/discharge, it tends to crack. The discrete CNTs attached to the surface can provide mechanical strengthening, helping to prevent the cracking from occurring. Additionally, having CNTs attached to the surface of the active material particles may also provide a linkage between the fractured parts of an active material particle, thereby promoting the mechanical integrity of the assembly even when cracking has occurred in one or more of the active material particles. MRD-2028 ¶[0042] (explaining how CNTs can provide a “crosslink” on cracked silicon-based particles). A POSITA would also understand that discrete CNTs on the surface of the active material particles are able to more freely mechanically interact with the active material than CNTs that are a part of a continuous CNT network, since the CNTs in the continuous network are more mechanically constrained than the discrete CNTs. The inventors also discovered that attaching discrete CNTs to the surface of active material could be used instead of coating the active material with carbon. LGES-1001, 1:64-2:8.

69. Thus, while those in the art at the time were seeking to achieve a continuous network of CNTs for electrodes, the inventors took the opposite approach by seeking to achieve discrete CNTs with the active material particles attached to

their surfaces. The '924 Patent teaches that this provides “improved capacity, electron and ion conductivity and mechanical strength,” “support and spatial stabilization of” active material particles, “improved heat transfer media to avoid thermally-induced runaway,” “structural strength to the paste during manufacturing and high surface area per weight of” active material “to provide good energy density.” *Id.* at 2:9-28. “The uniform dispersion of discrete tubes will also provide a more uniform voltage gradient across the cathode or anode layer.” *Id.* at 2:29-33.

70. The specification explains how discrete CNTs may be formed. “During the process of making discrete carbon nanotubes ..., the nanotubes are cut into segments and the residual catalyst particles that are interior to the carbon nanotubes as received from the manufacturer are dissolved.” LGES-1001, 4:4-11. The cutting of the tubes “helps with exfoliation,” which refers to disentangling as between CNTs. *Id.* The inventors also explain that “[p]roper selection of the carbon nanotube feed stock related to the catalyst particle type and distribution in the carbon nanotubes allows more control over the resulting individual tube lengths and overall length distribution.” *Id.* at 4:11-15. The inventors discovered that the preferred selection “is where the internal catalyst sites are evenly spaced and where the catalyst is most efficient.” *Id.*, 4:15-17.

71. After applying this unique process, CNTs having an aspect ratio of 10-500 are subsequently oxidized to add functional groups to their surface, and then the

oxidized CNTs are mixed directly with an active material (along with other materials), so that the active material can chemically attach to the added functional groups. LGES-1001, 4:23-47 For instance, in the '924 Patent, Examples 2 and 3 directly mix oxidized CNTs with lithium iron phosphate as the active material, Example 4 directly mix oxidized CNTs with lithium manganese phosphate, and Example 5 directly mix oxidized CNTs with titanium dioxide. *Id.* at 5:9-7:5. In each example, the surface of the oxidized CNTs is fully exposed to the active material, which allows for the active material to attach to the surface of the CNTs via the added functional groups. A POSITA would understand that this forms a strong bond between the active material and discrete CNTs.

72. Thus, the '924 Patent discloses a process for creating well-dispersed, discrete, oxidized CNTs with active material particles attached to their surface. While improved dispersibility is one factor to achieving discrete CNTs, dispersibility and discreteness are fundamentally different concepts. Indeed, much of the cited prior art focuses heavily on improved dispersibility to achieve a **continuous** network of CNTs, which are by definition not discrete because they are interconnected. The inventors' discovery—discrete CNTs having active material attached their surface, as well as the benefits associated therewith—ran contrary to this conventional wisdom. This is fundamentally different than the prior art concept

of interconnecting CNTs to form a continuous or percolated conductive network comprising active material particles.

IX. OPINIONS ON GROUND 1: OHATA-KAVAN

A. Whether Ohata-Kavan Discloses or Renders Obvious Independent Claim 1

73. As explained in further detail below, it is my opinion that the combination of Ohata-Kavan does not render obvious claim 1 of the '924 Patent for various reasons.

1. Overview of Ohata-Kavan

74. I understand that Petitioner describes Ohata as preparing “composites of carbon nanotubes and either positive or negative electrode active materials for use as electrodes in lithium ion batteries.” Pet., 9. While that is true, Ohata is specifically trying to create an improved resin binder by embedding CNTs within the resin matrix to form its masterbatch. LGES-1004 ¶¶[0005]-[0006], [0030]; MRD-2024, 58:5-10 (testifying that Ohata is “embedding” conductive material “within the resin”). Based on Ohata’s teachings, it is only after the carbon nanotubes (CNTs) are embedded in the masterbatch resin binder that they are mixed with the active material to prepare the electrodes for the lithium-ion battery. LGES-1004 ¶¶[0002], [0005], [0032], [0046]).

75. I begin first with the “Background of the Invention” of Ohata, which teaches:

An electrode of non-aqueous electrolyte secondary batteries as typified by a lithium ion secondary battery and a lithium ion polymer secondary battery is typically produced by mixing an electrode active material with a conductive material and **a binder** to form a paste, which is then applied onto a current collector made of aluminum, titanium, stainless steel or the like, followed by rolling. A conductive material is used to secure the conductivity of an electrode. If the amount of conductive material is large, however, the battery capacity will be decreased.

LGES-1004 ¶[0002].

76. To address the drawback of decreased capacity, Ohata teaches that it was known to perform a “a masterbatch process, whereby a conductive material [e.g., carbon black] is uniformly predispersed **in a binder**, in the production of a positive electrode.... As a conductive material, carbon black such as furnace black or acetylene black, and powdered graphite are used.” *Id.* The “conductive material,” for example carbon black, is pre-dispersed in the “binder” (e.g., resin) to render the binder more electrically conductive. *Id.* The binder is then mixed with the active material to bind the active material together as part of an electrode mixture material paste. *Id.* Thus, the “masterbatch” in Ohata refers to a binder with embedded conductive material. Notably, Ohata does not describe “uniformly dispers[in]g” the carbon black in the electrode material mixture paste, but rather in the binder that is later mixed with active material. LGES-1004, ¶¶[0002], [0017], [0019], [0022].

77. A POSITA would have been very familiar with binders, which is essentially used as a “glue” that hold the constituent parts of the electrode together, including the active material particles. Because binders are typically resins with high resistivity (i.e., low conductivity), it was common to embed a conductive material (e.g., carbon black) in the resin matrix to increase its electricity conductivity.

78. U.S. Patent No. 8,703,009 (MRD-2008, “Liu-009”) provides an example of the type of conductive-glue-like “masterbatch” process that Ohata describes. MRD-2008. The cartoon FIG. 6 of Liu shows “how ... active material is glued together by conductive glue” comprising carbon black as the embedded conductive material in PVDF. *Id.*, 4:16-17, 11:28-32.

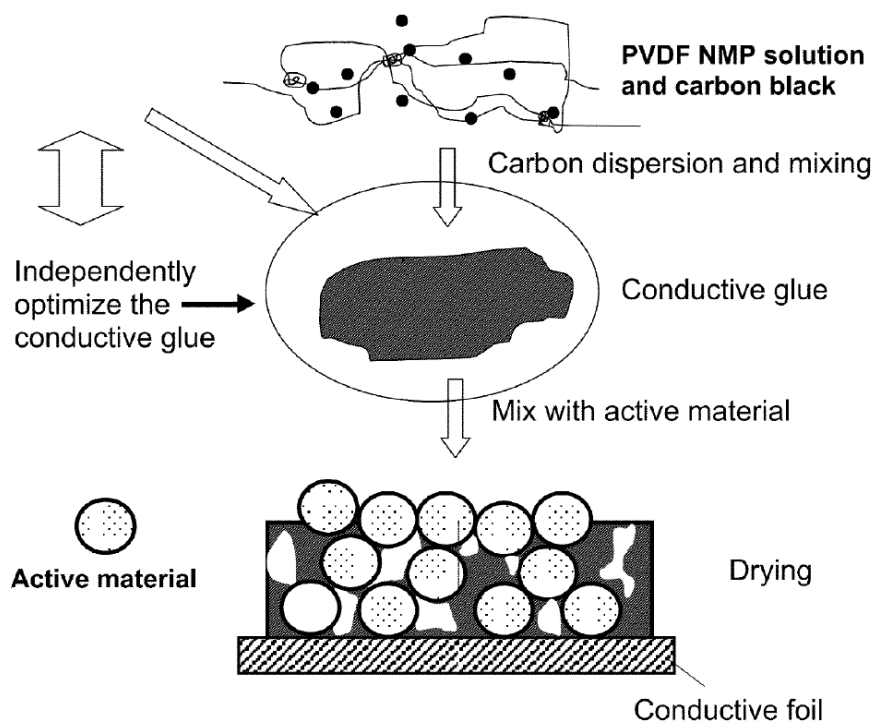


FIG. 6

Liu-009 explains that “[w]hen the carbon conductor and binder are mixed with the solvent NMP, it creates a conductive carbon glue (see Figure 6).” *Id.*, 6:25-29; MRD-2024, 33:21-34:1.

79. A POSITA would understand that having conductive material in the binder, such as carbon black, improves the binder’s electrical performance, provided that the units of the conductive material are sufficiently in contact to form a network that provides a continuous electrically conductive path in the binder. MRD-2010, 8. Uniform distribution does not necessarily mean that a continuous network is formed. Ohata teaches that the continuous conductive paths are adversely affected by the local breakage in the paths, thereby degrading the continuity of the conductive paths. For example, the local breakage of a carbon black network (which consists of carbon nanoparticles, known as primary particles, that are weakly bonded to one another) can occur during blending. LGES-1004 ¶[0003].¹

80. A POSITA would understand, based on Ohata’s teachings, that its primary goal is to address a drawback associated with dispersing carbon black and powdered graphite in a binder. LGES-1004 ¶¶[0002]-[0003]. Ohata teaches that in a masterbatch binder comprising carbon black and powdered graphite, the primary

¹ Increasing the aspect ratio of the units of the conductive material (e.g., the aspect ratio of CNTs) increases the chance of touching among these units, thereby increasing the chance of continuous network formation.

particles of the carbon black “are linked into a chain to form a conductive path,” which “is likely to be damaged by shearing force” during the masterbatch process. LGES-1004 ¶[0003]. In other words, the carbon black primary particles are chained together to form a continuous conductive network within the binder. *Id.* A POSITA would understand that the “chaining” referenced involves Van der Waals forces and, due to the weakness of those forces, the shearing associated with blending may break up the chains in the network of carbon black particles.

81. Ohata teaches that “[f]or this reason, the use of the masterbatch process to uniformly disperse the conductive material in a binder does not yield an electrode superior in conductivity.” LGES-1004 ¶[0003]. Ohata thus teaches that the problem it attempts to address involves the breakage of the carbon black chains that are used in the binder that glues the active material particles together. *Id.*

82. “In view of this” drawback, Ohata discloses the steps of “producing a masterbatch: (a) producing a masterbatch comprising at least carbon nanotubes and a resin; (b) blending an electrode material mixture containing at least the masterbatch and an electrode active material with a dispersion medium to prepare an electrode material mixture paste.” *Id.* ¶¶[0004]-[0005]. Ohata explains that “[u]nlike carbon black and powdered graphite, a conductive path to be formed by carbon nanotubes is not damaged by shearing force. Thus, even if high sh[e]aring (*sic*) force is applied

to the carbon nanotubes during the preparation of a masterbatch, it is possible to obtain an electrode superior in conductivity.” *Id.* ¶[0015].

83. This statement from Ohata is consistent with the fact that the carbon-to-carbon bonding along the length of a CNT is a covalent bond, rather than one involving merely Van der Waals forces. Due to this covalent bonding, a CNT is mechanically stronger than a chain of carbon black particles, which are held together by weaker Van der Waals forces. In other words, due to the internal covalent bonding of CNTs, CNTs are physically stronger than carbon black particle chains.

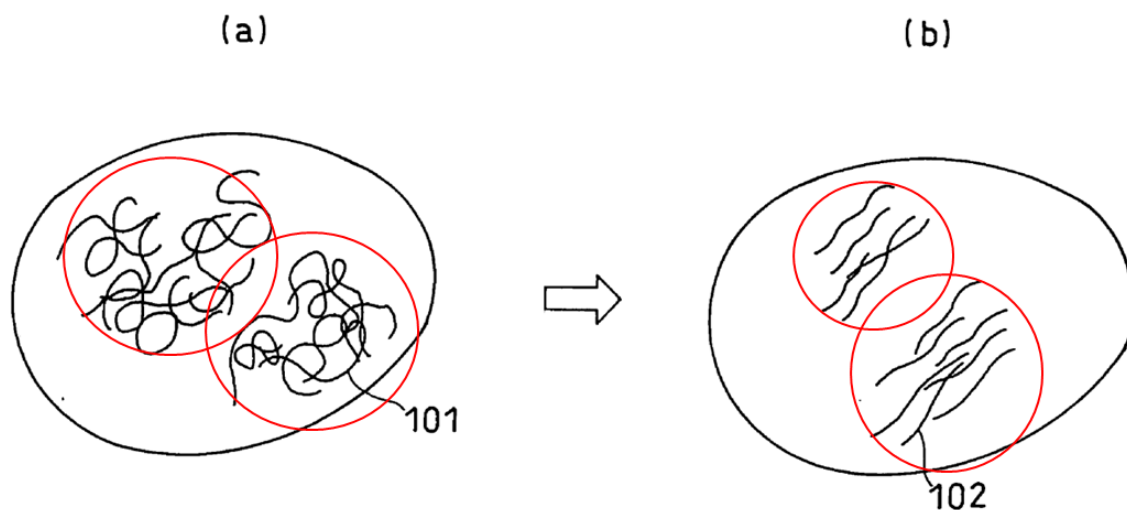
84. In view of the above, a POSITA would understand that Ohata is attempting to create an improved binder—referred to as the “masterbatch”—by pre-dispersing electrically conductive carbon nanotubes in a resin. LGES-1004 ¶¶[0004]-[0005], [0015]. The binder is then further mixed with an electrode active material to bind the active material together and form an electrode active material paste. *Id.* ¶¶[0005], [0023].

85. Consistent with these teachings, the first step in all embodiments of Ohata is to prepare the “masterbatch” (i.e., the binder), which is “5 to 20 parts by weight [of carbon nanotubes] per 100 parts by weight of the resin.” LGES-1004 ¶¶[0005]-[0006]. In other words, the lowest end of the range is 5% by weight of CNTs to 95% by weight of resin and the highest end of the range is 20% by weight

of CNTs to 80% by weight of resin. *Id.* Resin thus makes up the overwhelming majority of the masterbatch binder. *Id.*

86. In reference to annotated FIG. 1(a), which depicts two groups (red circles) of CNTs, Ohata teaches that “carbon nanotubes 101 are tangled and twisted with one another before they are blended with a resin” as part of the masterbatch process. *Id.* ¶[0016]. Ohata contends that during the masterbatch process, the CNTs are “unraveled and straightened by blending them with a resin, as shown in FIG. 1(b).” *Id.* Annotated FIG. 1(b) depicts the two groups of CNTs as having CNTs that have been unraveled, straightened, and individually dispersed. *Id.*

FIG. 1



Ohata, FIG. 1 (annotated by Patent Owner)

87. According to Ohata, one of the purposes of blending CNTs with resin is to unravel and straighten them, which are “expected to form an excellent

conductive path,” “serve[] to increase the mechanical strength of the electrode plate,” and may “produce a secondary battery excellent in cycle characteristics.” LGES-1004 ¶¶[0016]-[0017], [0021]. However, a POSITA would understand that there is another very important reason for the masterbatch process—namely to use the masterbatch as a binder with embedded conductive material (i.e., the CNTs).

88. While Ohata provides 15 examples of a positive and/or negative electrode prepared using the masterbatch, **Example 1** serves as the basis for most examples. LGES-1004 ¶¶[0029]-[0047].

89. In **Example 1**, the masterbatch is prepared by blending 15 parts by weight of CNTs and 85 parts by weight of polyvinylidene fluoride (“PVDF”) using an extruder. LGES-1004 ¶[0030]. The nanotubes have an average aspect ratio of 100. *Id.* The masterbatch—again consisting largely of resin—is then used to prepare a “positive electrode material mixture paste” by mixing 3.3 parts by weight of the masterbatch with LiCoO_2 as an active material and 45 parts by weight of N-methyl-2-pyrrolidone (abbreviated “NMP”), which is used to disperse the masterbatch into the mixture paste. *Id.* ¶¶[[0030], [0032]. The paste is then applied to a substrate to create the electrode plate, which is cut into a predetermined shape to create the positive electrode. *Id.* ¶[0032]. Ohata does not teach mixing additional resin as part of the positive electrode material mixture in this example, but instead relies solely on the masterbatch as the binder. *Id.*

90. The negative electrode is also created, but without using the masterbatch as a binder. LGES-1004 ¶[0034]. Instead, “3 parts by weight of styrene butadiene rubber” is instead used “as a binder.” *Id.* A POSITA would thus understand that in Example 1, the positive electrode uses the masterbatch as the binder and the negative electrode uses a different resin binder.

91. **Examples 2 to 8** follow the steps of Example 1, except for the differences reflected in Table 1. *Id.* ¶[0040]. As shown in the table, these examples also include a masterbatch comprising at least 80 parts resin and at least 15 parts CNTs. *Id.* ¶¶[0006], [0040]).

92. **Example 9** follows Example 1, except that vinylidene fluoride-hexafluoropropylene copolymer is used as a resin for the masterbatch instead of PVDF. *Id.* ¶[0041].

93. **Examples 10 to 14** follow Example 1, except that the CNTs used have different diameters and aspect ratios as reflected in Table 2. *Id.* ¶[0042].

94. **Example 15** prepares a negative electrode using the same masterbatch from Example 1. LGES-1004 ¶[0046]. The corresponding positive electrode is created using PVDF alone as the binder, instead of the masterbatch. *Id.* ¶[0044].

95. Therefore, Ohata teaches that its “masterbatch,” the binder with embedded CNTs, is used to hold the active material together. Indeed, in Example 1 of Ohata, 3.3 parts by weight of masterbatch is used as the binder for the positive

electrode material mixture. LGES-1004 ¶[0032]. However, for the negative electrode material mixture, the masterbatch is not used at all. *Id.* ¶[0034]. Instead, 3 parts by weight of styrene butadiene rubber is used as the “binder,” in lieu of the masterbatch. *Id.* A POSITA would understand that this is because the masterbatch is the binder in the positive electrode of Example 1, while another binder (styrene butadiene rubber) is used for the negative electrode. MRD-2017 ¶[0009] (discussing Ohata and explaining that its “masterbatch” is the binder for the active material).

96. A POSITA would understand that Ohata’s process is fundamentally different than the process described in Kavan. Unlike Ohata, Kavan does not (i) immerse its oxidized CNTs in resin to form a binder as an initial step, and then (ii) mix the resin-covered CNTs with the active materials. Instead, Kavan prepares a “powder precursor material” by first mixing its oxidized CNTs with *water* and an active material powder (TiO_2 , LiMnPO_4 , or LiFePO_4) and stirring overnight, which leaves the CNT surfaces exposed (or “naked”). LGES-1005, 2 (“Nanotubes were dispersed in water under short sonication. To this solution a powder material ... was added ... and stirred overnight. The suspension was subsequently evaporated to dryness. The electrodes were prepared as follows: powder precursor material, either pure or carbon-containing (see above) was mixed with 5 wt% of polyvinylidene fluoride (PVDF) dissolved in N-methyl-2-pyrrolidone.”). A POSITA would understand that Kavan mixes naked CNTs with the active material so that the active

material can attach to the surface of the CNTs, providing the “anchoring” benefits described by Kavan. *Id.*

97. Thus, in Kavan, the naked oxidized CNTs and active material are pre-mixed into a powder before mixing that powder with the binder, so that the active material can take advantage of the functional groups of the oxidized CNTs. *Id.* This is also true in the '924 patent. LGES-1001, 5:11-24 (Example 1 mixing naked oxidized CNTs with the active material to allow for attachment); LGES-1001, 5:30-50, 5:55-6:4, 6:17-35, 6:49-67 (same in Examples 2, 3, 4, 5, and 6, respectively)). Specifically, by leaving the functional groups of the CNTs exposed when mixed with the active material, the active material can “anchor” to the CNTs surface as described in Kavan.

98. In contrast to both Kavan and the '924 patent, the “masterbatch” process of Ohata involves initially embedding the CNTs in a resin as a binder (which prevents the surface of the CNTs from being exposed to the active material), and then mixing the binder (i.e., the masterbatch) with the active material. A POSITA would understand that Ohata considered this to be an important process, because Ohata believed that dispersing naked CNTs with the active material is “difficult taking the dispersibility of the carbon nanotubes in the resin into consideration.” LGES-1004, ¶[0021]. Thus, Ohata chose a much different approach to dispersibility that involves embedding the CNTs in the resin binder and then mixing the binder

with the active material to achieve better dispersion. *Id.* This is an important fact to keep in mind for purposes of certain of my opinions discussed below.

2. Whether Ohata-Kavan teaches or renders obvious active material that is “attached to the surface” of discrete CNTs.

99. I understand that the Petitioner alleges that the Ohata-Kavan combination results in CNTs with lithium-ion active material “attached to their surface.” Pet., 23, 25. Specifically, Petitioner argues that the oxidation of the CNTs creates functional groups on the surface of the CNTs, resulting in covalent bonding between the active material and the surface of the CNTs. Pet., 23-24. I understand that the Petitioner argues, additionally or alternatively, that there are Van der Waals forces and hydrogen bonding between the TiO₂ particles and the functional groups on the CNT surfaces resulting in the claimed attachment. *Id.*, 23-24. I understand that Petitioner cites to Kavan to support both assertions. *Id.* Thus, I understand that Petitioner relies on the teachings of Kavan alone to support its position that the active material of the Ohata-Kavan combination is “attached to the surface” of the CNTs.

100. I disagree with these assertions, because there is an important and meaningful difference between how Kavan (by itself) and the proposed combination of Ohata-Kavan prepare their electrode material mixtures.

101. In the Ohata-Kavan combination, Petitioner relies on the masterbatch process of Ohata, with the CNTs oxidized pursuant to Kavan. Pet., 10. Therefore,

the proposed Ohata-Kavan combination begins with the masterbatch process to initially create a binder with embedded CNTs as taught by Ohata.

102. Kavan, on the other hand, does not teach or suggest any form of masterbatch process, and certainly does not fully submerge its nanotubes in resin as is done in Ohata. Instead, Kavan mixes its naked oxidized CNTs with active material and water, so that the CNTs are fully exposed to the active material to allow the active material to attach to the functional groups of the CNTs. LGES-1005, 2 (“Nanotubes were dispersed in water under short sonication. To this solution a powder material ... was added ... and stirred overnight. The suspension was subsequently evaporated to dryness. The electrodes were prepared as follows: powder precursor material, either pure or carbon-containing (see above) was mixed with 5 wt% of polyvinylidene fluoride (PVDF) dissolved in N-methyl-2-pyrrolidone.”).

103. Petitioner’s invalidity theory does not account for the fact that the Ohata-Kavan masterbatch fully immerses and blends the CNTs in fluorocarbon resin as an initial step, which forms the binder used to bind the active material of the electrode mixture together in a paste. LGES-1004 ¶¶[0005], [0022]-[0023]. It appears that the Petitioner and its expert believe that the only reason Ohata is creating the masterbatch is to straighten and unravel the CNTs. Pet., 10, 12, 14, 22; *see also* MRD-2024, 42:25-44:22 (Dr. Zhu identifying several purposes of the

masterbatch, but not identifying serving as a binder as one of those purposes). However, when Ohata is read in the full context of its teachings and the problem it attempts to solve from the prior art, it is clear that the primary purpose of the masterbatch is to act as a conductive binder for subsequent use in holding the active material together.

104. A POSITA would understand that the masterbatch process of Ohata-Kavan results in resin coating the surface of the oxidized CNTs. This coating would prevent the active material from “attach[ing] to the[] surface” of the oxidized CNTs as claimed. Specifically, the coating would prevent the active material from “anchoring” to the functional groups of the oxidized CNTs, and likewise prevent any form of bonding (including primary bonding and secondary bonding, with the primary bonding including ionic, covalent and metallic bonding, and the secondary bonding including Van der Waals forces and hydrogen bonding) between the active material and the surface of the oxidized CNTs. The resin would be an interposed layer that prevents any type of bonding from occurring. I address this concept extensively in the following passages.

105. A POSITA would understand that when a small proportion of nanotubes (e.g., 5-20 parts by weight) are mixed with a large proportion of fluorocarbon resin (e.g., 100 parts by weight) as taught by Ohata, the nanotubes become embedded within, and are fully coated by, the fluorocarbon resin. LGES-

1004 ¶[0006]; MRD-2009, 2 (“In a CNT–PVDF–NMP suspension, PVDF molecular chains would *coat onto CNT surface due to the strong interaction between PVDF and CNTs.*”); LGES-1014, 3 (explaining that functionalized CNTs become “***completely covered*** with matrix” when mixed with resin)); MRD-2024, 65:21-66:9 (Dr. Zhu testifying that the resin covers a “significant amount” of CNT surface). Numerous objective references prove this point as set forth below.

106. As one example, field emission scanning electron micrographs (FESEM) of a composite of 2% by weight functionalized multi-wall CNTs (“f-CNT”) to 98% by weight polyvinylidene fluoride (“PVDF”) are depicted below in the excerpt of Figure 2(c)-(d) from MRD-2010:

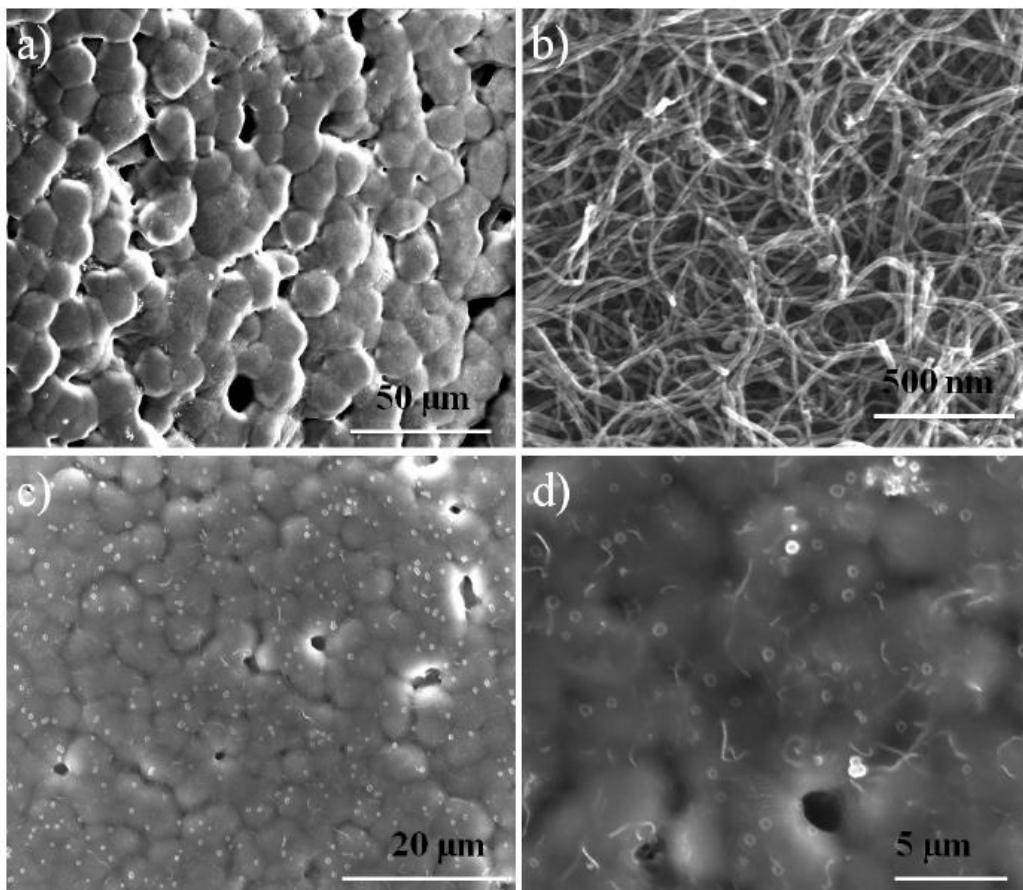


Figure 2 (MRD-2010)

MRD-2010, 15.

107. I first note that PVDF is a fluorocarbon resin used in the masterbatch of Ohata. LGES-1004 ¶[0022]. In Ohata, the fluorocarbon resin is the binder material that the CNTs are embedded within. Figure 2(a) depicts the PVDF. MRD-2010, 12. Figure 2(b) depicts the functionalized CNTs. *Id.* Figures 2(c) and (d) depict the functionalized CNT-PVDF composite, which shows the nanotubes in contact with the PVDF and dispersed by the PVDF. *Id.*, 11-12 (“When sufficient concentration is there, CNTs start forming network and connectivity ***in the matrix***”).

so that drastic rise in conductivity was observed in the composite.”) (Emphasis added). The dark areas (somewhat circular for some of them) in Figures 2(c) and (d) are voids in the PVDF matrix.

108. The CNT networking is not visible due to the resin covering it, but some of the CNTs in the network that are relatively close to the surface of the examined specimen are partly visible, being clearly embedded within the PVDF matrix. *Id.*, 11-12 (explaining that at 2 wt% of CNTs a “conductive network” is formed due to the “percolation behavior”); MRD-2010, 12 (“microspheres of polymer have been formed throughout the composites and carbon nanotubes are homogeneously dispersed within the polymer 3D scaffold with end to end connections in the polymer.”). Additionally, Figures 2(c) and 2(d) are at a fairly low magnification further obfuscating the CNT network just beneath the resin surface that is formed throughout the PVDF.

109. The visibility of those CNTs is likely due to the partial pull-out of the CNTs from the resin surface during the peeling of the composite from its substrate prior to SEM examination of the composite. The pull-out of a CNT causes the protrusion of a limited length of the CNT while the remaining length remains embedded in the PVDF matrix. The pull-out is an artifact resulting from the specimen preparation that involves peeling; it does not reflect the real structure, which is the structure prior to the peeling. At any rate, only a small number of CNTs

experienced the pull-out, indicating that the vast majority of the CNTs are not observed by SEM, due to their being fully embedded in the PVDF matrix. Note that an SEM can only observe what is on the surface, not what is under the surface.

110. In another example, multi-wall CNTs were ultrasonically dispersed and then mixed with a solution of PVDF in dimethyl sulfoxide² to obtain 3%, 5% and 9% by weight of CNTs in PVDF. MRD-2011, 2-3. The 5% and 9% weight percentages fall within the 5 to 20 parts by weight range of Ohata. LGES-1004 ¶[0021]. The FESEM results are depicted below in FIG. 1:

² Dimethyl sulfoxide is a solvent, similar to the NMP solvent used in Ohata. LGES-1004 ¶¶[0024], [0032], [0046].

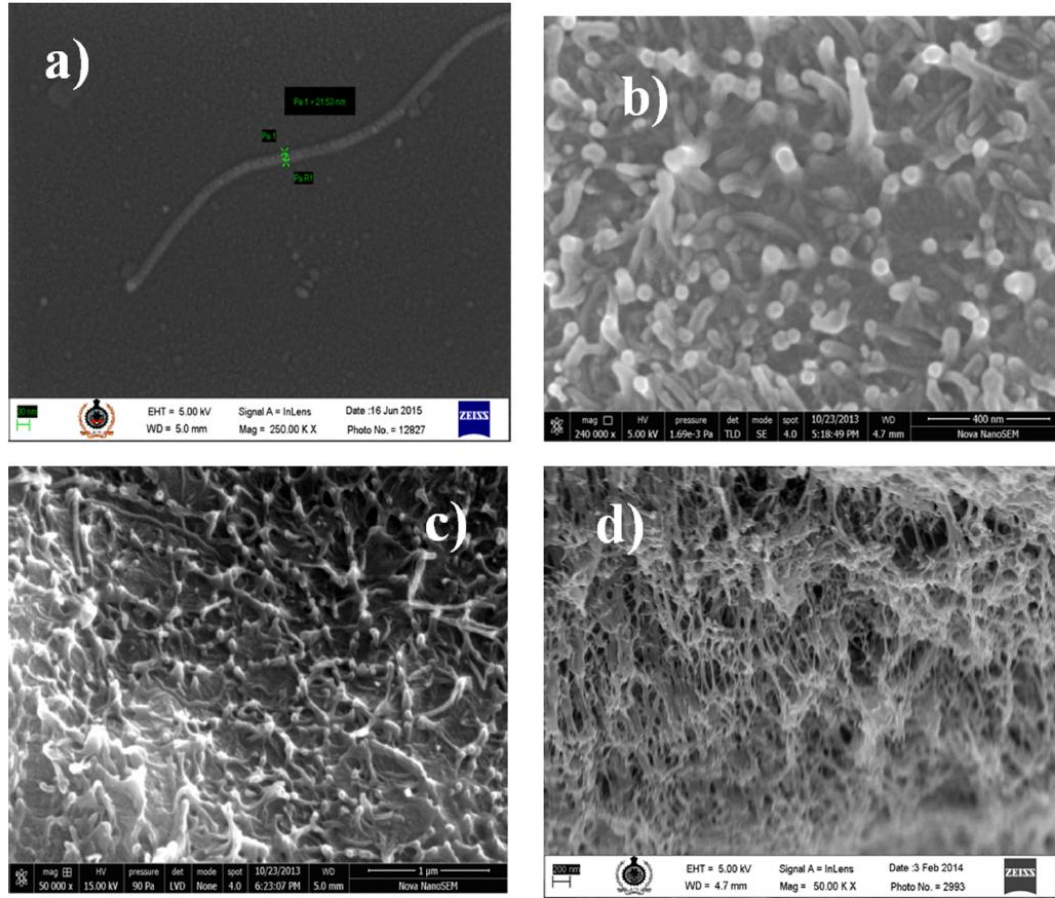


FIG. 1. FE-SEM images of MWCNT in the PVDF matrix. (a) shows a single MWCNT, and images of well dispersed MWCNTs for 3wt%, 5wt% and 9wt% samples in the PVDF matrix are shown in b),c) and d) respectively.

MRD-2011, 3.

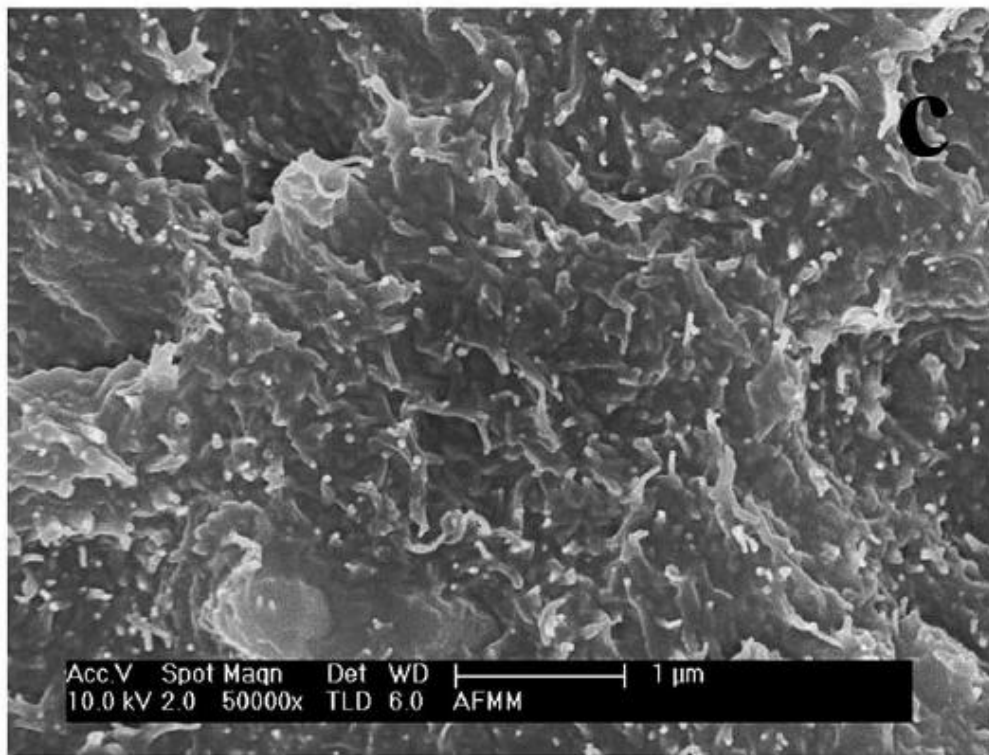
111. As shown in FIGs. 1(b)-(d), at all three weight percentages the CNTs are heavily embedded within the PVDF matrix. In FIG. 1(b), the CNTs are partially protruding from the PVDF matrix, such that the protruded length is typically equal to approximately about 3 times (on the average) of the CNT diameter. With the CNT diameter of around 15 nm, the protruded length is around 45 nm on the average. The length of the CNT is around 10–30 μm. Hence, the protruded length ranges from about 0.15% to above 0.45% of the CNT length. This means that the degree of CNT

protrusion is very small and that the vast majority of the CNT length (ranging from about 99.55% to 99.85% of the CNT length) is embedded in the PVDF matrix. The protrusion is likely an artifact resulting from how the SEM specimen is prepared. An example of the SEM specimen preparation method involves slight chemical etching of the SEM specimen surface in order to remove the PVDF matrix at the top surface of the specimen for the purpose of revealing the CNTs. A POSITA would understand that the real structure would have no protrusion, with all the CNTs fully embedded.

112. FIGs. 1(b), 1(c) and 1(d) visibly shows that the CNTs coated in PVDF. MRD-2011, 3 (“Figure 1 shows the field-emission SEM micrographs of the MWCNTs *in PVDF matrix*.”). In FIG. 1(b) at 400 nm scale, the CNTs with a diameter ~15 nm appear as thick “fingers” having diameter about 50 nm (larger in diameter than the CNTs themselves), suggesting that they are heavily coated by PVDF. *Id.*, 3. In FIG. 1(c) at a 1 μ m scale, the nanotubes also appear thick (about 100 nm in diameter), again suggesting the presence of PVDF covering the CNTs. *Id.* In FIG. 1(d) at a 200 nm scale, there are visible CNTs that appear as if they are trapped in a “web,” which is the PVDF matrix.³ *Id.*

113. In another example, an SEM image in FIG. 3(c) depicts 3% by weight of multiwalled CNTs mixed with PVDF:

³ The bottom right of Figure 1(d) is blurred, as it is out of focus. MRD-2011, 3.



MRD-2012, 6. The CNTs appear as if they are embedded within a viscous substance, which is the PVDF matrix. *Id.* Indeed, the reference specifically describes them as “CNTs *in PVDF matrix*.” MRD-2012, 3 (emphasis added); *see also* MRD-2013, 3, Figure 2 (showing how PVDF presents as domains of the matrix, even after the flow associated with heating).

114. The foregoing references demonstrate that the masterbatch of Ohata-Kavan would result in oxidized CNTs heavily coated with binder resin to form a viscous “glue” like material, similar to the “glue” depicted in Figure 6 of Liu-009. In fact, Liu-009 explains that when carbon black is mixed with PVDF prior to adding the active material, the PVDF will be “bonded to” the carbon black. MRD-2008,

7:55-62 (explaining that “the binder has previously and preferentially ***bonded to the CB [i.e., carbon black]***”).

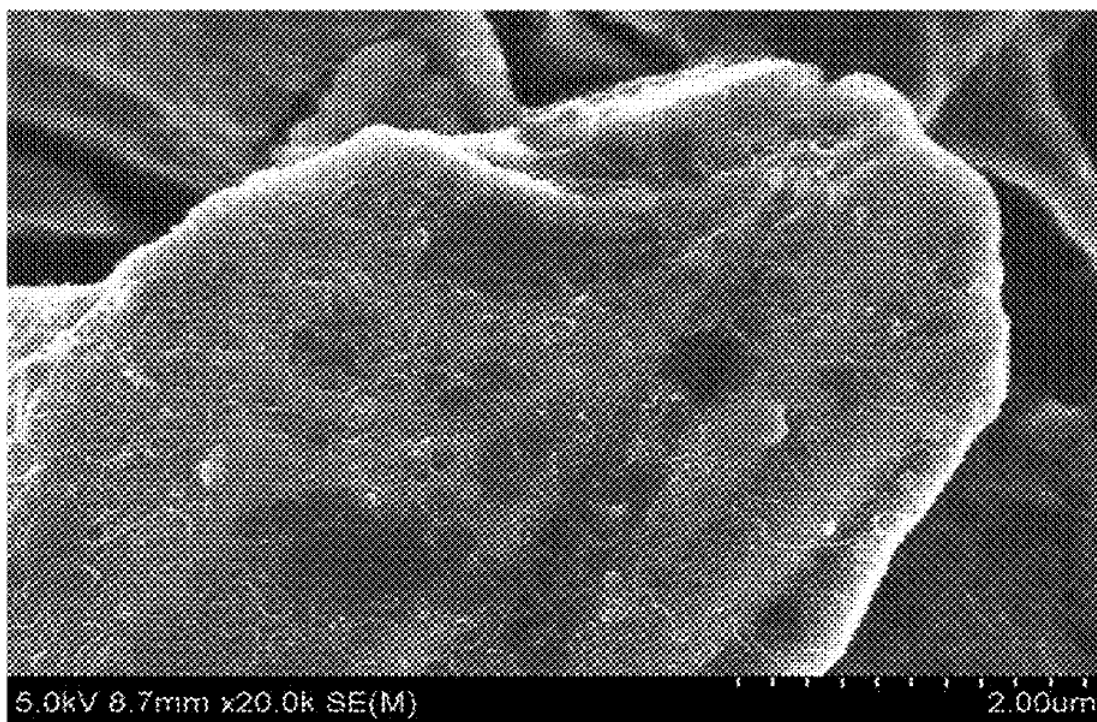
115. A POSITA would understand that PVDF molecules likewise bond to CNTs. Specifically, PVDF and oxidized CNTs attract one another due to the dipole-dipole interaction between the highly polar fluorine-carbon covalent bonds of the PVDF molecules and the presence of functional groups (including functional groups with polar covalent bonds) on the surface of the oxidized CNTs. This interaction allows for significant interfacial adhesion between PVDF and oxidized CNTs. In other words, the oxidized CNTs would not only be embedded and coated with the PVDF matrix, but the PVDF coating would be more strongly bound to the oxidized CNTs due to the interaction. MRD-2009, 2 (“In a CNT–PVDF–NMP suspension, PVDF molecular chains would *coat onto CNT surface due to the strong interaction between PVDF and CNTs.*”). I note that Dr. Zhu testified that he was unaware of this interaction between PVDF and the surface of oxidized CNTs. MRD-2024, 45:16-46:14.

116. Therefore, a POSITA would understand that the proposed combination of Ohata-Kavan would result in a masterbatch comprising oxidized CNTs that are coated with, and embedded within, the fluorocarbon resin matrix. This is the intentional design of Ohata, because the masterbatch acts as the binder (“glue”), but with embedded CNTs to improve binder conductivity. Thus, the goal of Ohata is to

achieve CNTs embedded within and coated by the resin particles, while the exterior of the binder remains exposed to the active material to glue the active material particles together, thereby enhancing the mechanical behavior of the electrode as a whole.

117. As a comparison point, Figure 4 of U.S. Patent Publication No. 2024/0274804 provides an example of CNTs in contact with the surface of an active material particle:

FIG. 4



MRD-2028 ¶¶[0114]-[0115]. However, this example follows a process more similar to Kavan's, where the naked CNTs were mixed simultaneously with the active material—not a “masterbatch” process that immerses the CNTs in resin before

mixing the CNTs with the active material. MRD-2028 ¶[0108]. The result shown above—where the CNTs are in contact with the active material—is simply not possible in Ohata-Kavan due to its unique masterbatch process. Ohata-Kavan thus cannot attach as claimed.

118. A POSITA would understand that the subsequent steps of Ohata-Kavan do not remove or eliminate the resin coating on the CNTs. After the Ohata-Kavan masterbatch is prepared, it is used to prepare the electrode material mixture paste. LGES-1004 ¶[0005]. The step involves using the masterbatch as the binder by mixing the masterbatch with a dispersion medium (such as NMP) and active material particles to form the electrode material mixture paste. LGES-1004 ¶¶[0023]-[0024], [0046]. For instance, in Example 1 for the positive electrode, Ohata discloses mixing 3.3 parts by weight of the masterbatch with 100 parts by weight of active material and 45 parts by weight of NMP. LGES-1004 ¶[0032]. NMP is a solvent that disperses the PVDF by dissolving it to break the matrix up into PVDF domains⁴ so that they can be dispersed throughout the electrode material mixture, providing localized glue-like bonds between adjacent active material particles. LGES-1004 ¶[0046] (referring to NMP “as a dispersion medium”).

⁴ PVDF domains can be thought of as islands of PVDF matrix with entrained CNTs, which can be spread throughout a composition to disperse the binder throughout.

119. This dispersion results in smaller binder particles throughout the electrode mixture, but the CNTs are still embedded within and coated by the PVDF (which is bonded to the CNTs). A POSITA would understand that the Ohata-Kavan masterbatch process does not teach or suggest filtering PVDF after creation of the material mixture, which would be required to eliminate the PVDF domains from the electrode material mixture paste. MRD-2024, 41:5-25 (Dr. Zhu testifying that the resin is not eliminated). A POSITA would understand that using an organic solvent (e.g., NMP) to disperse PVDF embedded with CNTs would still leave the conductive agent “coat[ed]” with the PVDF. MRD-2015, 1:31-34 (“PVDF dissolved in the organic solvent *tends to coat particles* of the active material and *the conductive agent*, so that PVDF is not distributed effectively between these particles.”) (emphasis added).

120. I cite to additional references that further demonstrate this. FESEM images Figures 2 and 3 (reproduced below) show that even after PVDF and CNTs have been mixed with NMP, the CNTs are still embedded within, and coated by, the PVDF:

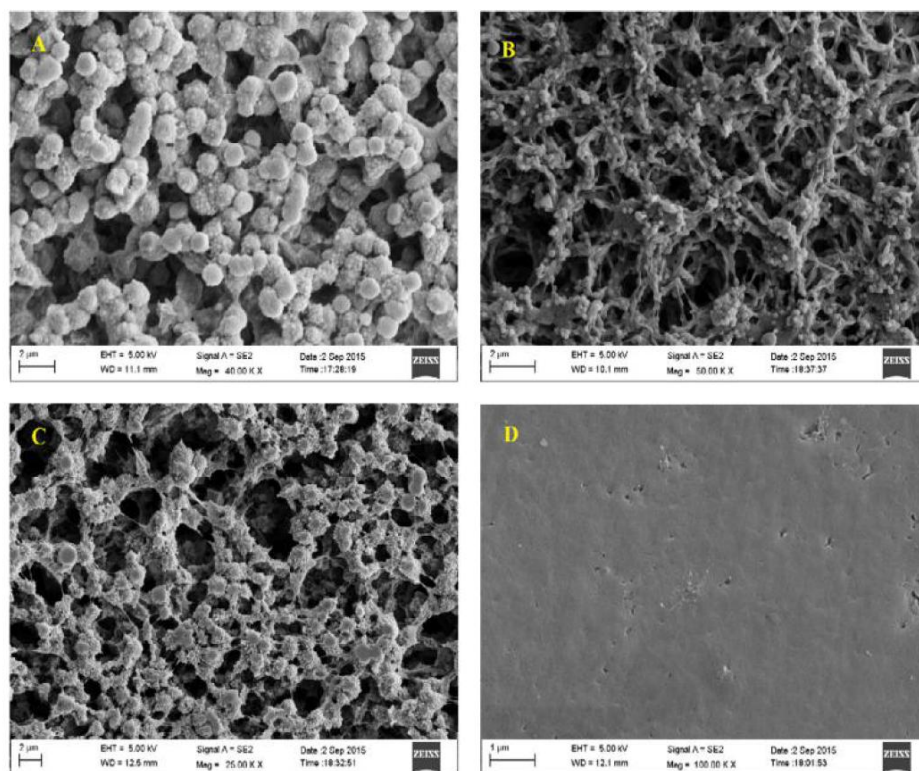


Fig. 2. (A–D): FESEM image of (A) PVDF, (B) PVDF with CNT, (C) PVDF with carbonic acid functionalised CNT and (D) PVDF with sulphonic acid functionalised CNT.

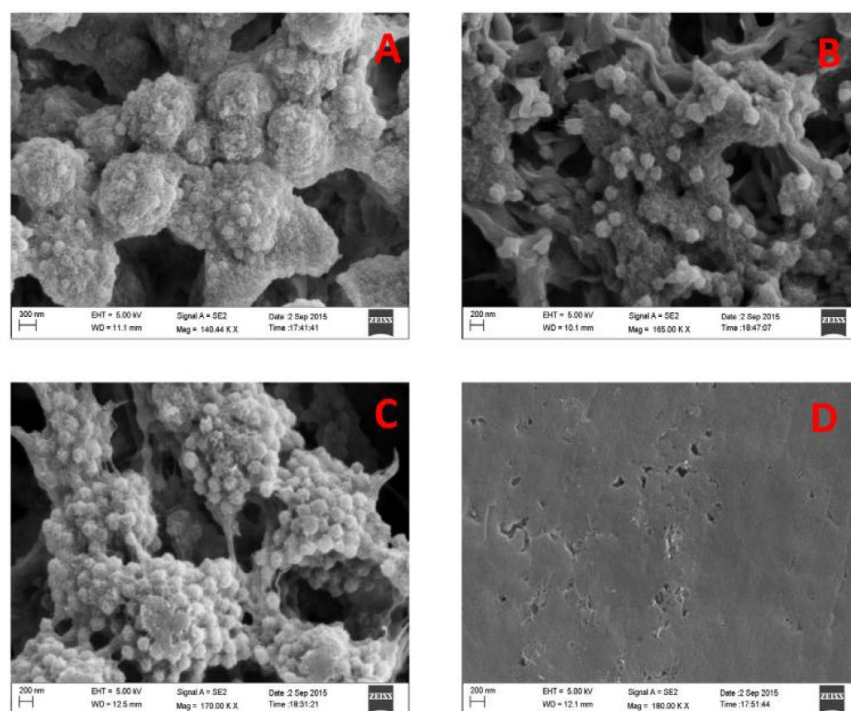


Fig. 3. (A–D) High Magnification FESEM image of (A) PVDF, (B) PVDF with CNT, (C) PVDF with carbonic acid functionalised CNT and (D) PVDF with sulphonic acid functionalised CNT.

MRD-2014, 8. The “grainy” features in Figs. 2(B), 2(C), 3(B) and 3(C) are the CNT-containing PVDF domains. Additional, higher magnification FESEM images shown in Fig. 3 depict the PVDF matrix coating the CNTs more clearly.⁵

121. Similarly, once the CNTs of the Ohata-Kavan masterbatch are blended with the resin, the entire surface of the CNTs becomes covered with resin (e.g., PVDF), which is not removed by the solvent (e.g., NMP) used during the electrode material mixture process. Rather, the solvent simply disperses the PVDF as domains, which still have the CNTs embedded within them.

122. An SEM image of CNTs is shown in Figure 2(f) below and an electrode comprising CNTs (2% by weight), PVDF (3% by weight), and lithium iron phosphate (95% by weight):

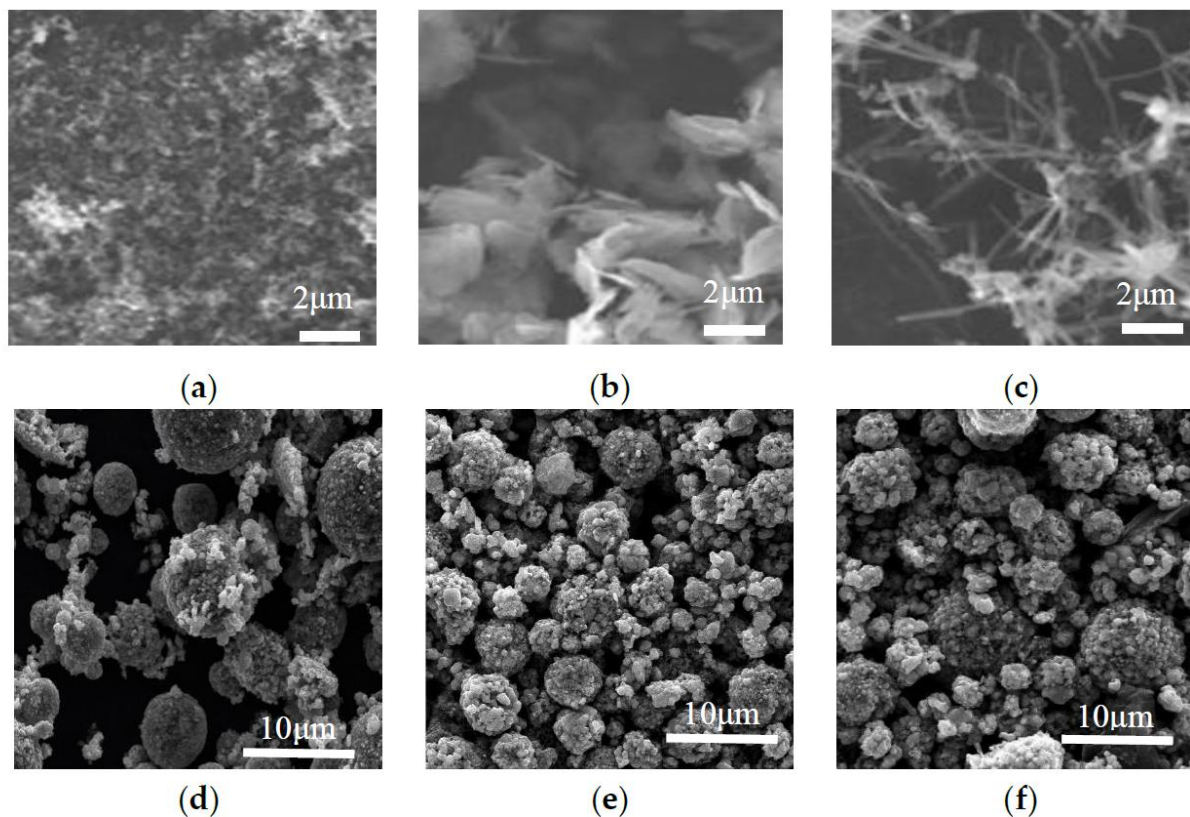


Figure 2. SEM of conductive agents and electrodes with different conductive materials: the surface morphologies of Super-P and KS-15 (a); the surface morphologies of graphene (b); the surface morphologies of carbon nanotube (c); the electrodes image of Super-P and KS-15 (d); the electrodes image of graphene (e); the electrodes image of carbon nanotubes (f).

MRD-2016, 2, 4. A POSITA would understand that the CNTs are not visible in Figure 2(f), because they are entrained in the PVDF domains interspersed between (among) the active material particles. Although this process does not follow the “masterbatch” process of Ohata, the results here demonstrate that mixing NMP solvent with PVDF resin does not eliminate the PVDF domains (or coating) that exists. Indeed, in Ohata-Kava, the CNTs are fully coated with resin before mixing with the active material and solvent, meaning a POSITA would expect the CNTs of Ohata-Kavan to be fully covered in the resin matrix.

123. Another example, U.S. Patent Application Publication No. 2014/0319429 (“Nicolas-429”) specifically identifies drawbacks of the masterbatch process of Ohata. MRD-2017 ¶¶[0009]-[0010]. Nicolas-429 proposed its own “masterbatch” process. *Id.* In Example 3, the process uses “5% by weight of CNTs, 1% by weight of PVP, 0.8% by weight of PVDF and 93.2% by weight of NMP” to form a paste, which is then mixed with LiFePO₄. *Id.* ¶¶[0111]-[0118]. As shown in Figure 2 below, domains of PVDF exist despite the use of a solvent (NMP) to disperse the PVDF:

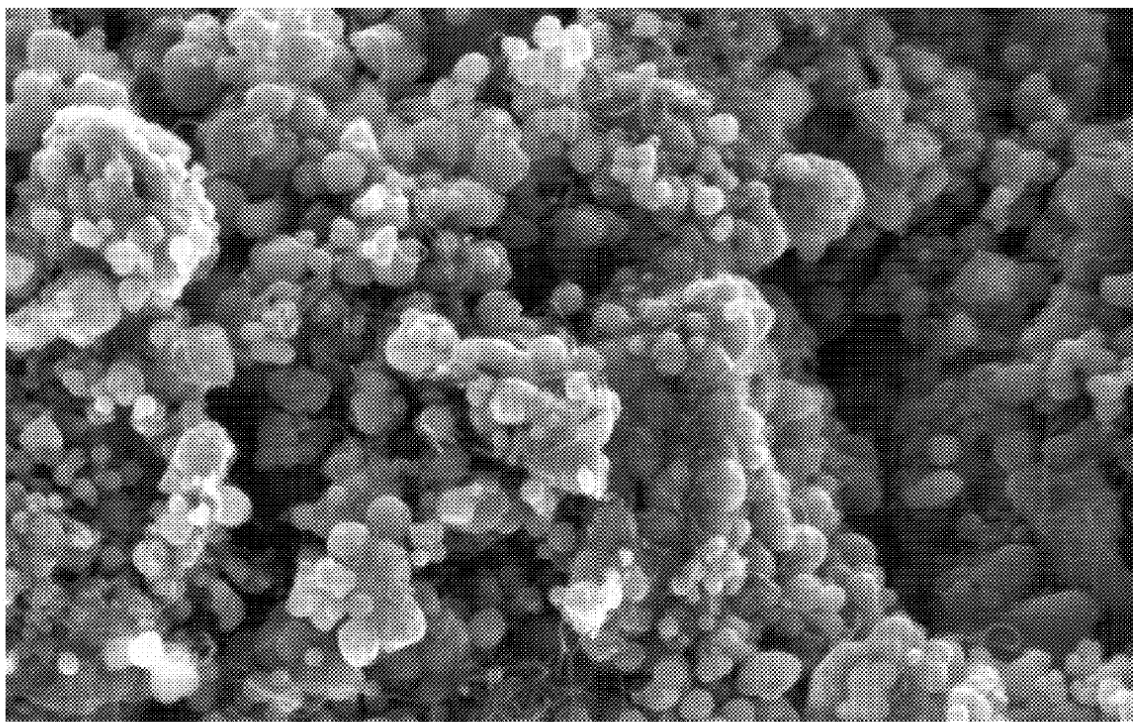


FIGURE 2

Id. ¶[0123]. Nicolas-429 explains that FIG. 2 “showed that CNTs are well dispersed **around** the micrometric LiFePO₄/C particles.” *Id.* A POSITA would understand that

they are “around” the particles but not attached to the particles, because they are embedded within the PVDF domains that prevent the active material from attaching to the surface of the CNTs. A POSITA would likewise expect Ohata-Kavan to also result in CNTs embedded within PVDF domains such that the PVDF coating would prevent the attachment of the active material particles to the surface of the CNTs from occurring.

124. Another reference, U.S. Patent Publication No. 2011/0256454 (“Nicolas-454”), also references Ohata’s masterbatch process. MRD-2018, ¶¶[0010]-[0011]. In FIG. 2A and 2B, Nicolas-454 provide SEM images of its own masterbatch (comprising CNTs and PVDF) that is mixed with NMP and an active material (LiFePO_4):

FIG. 2A

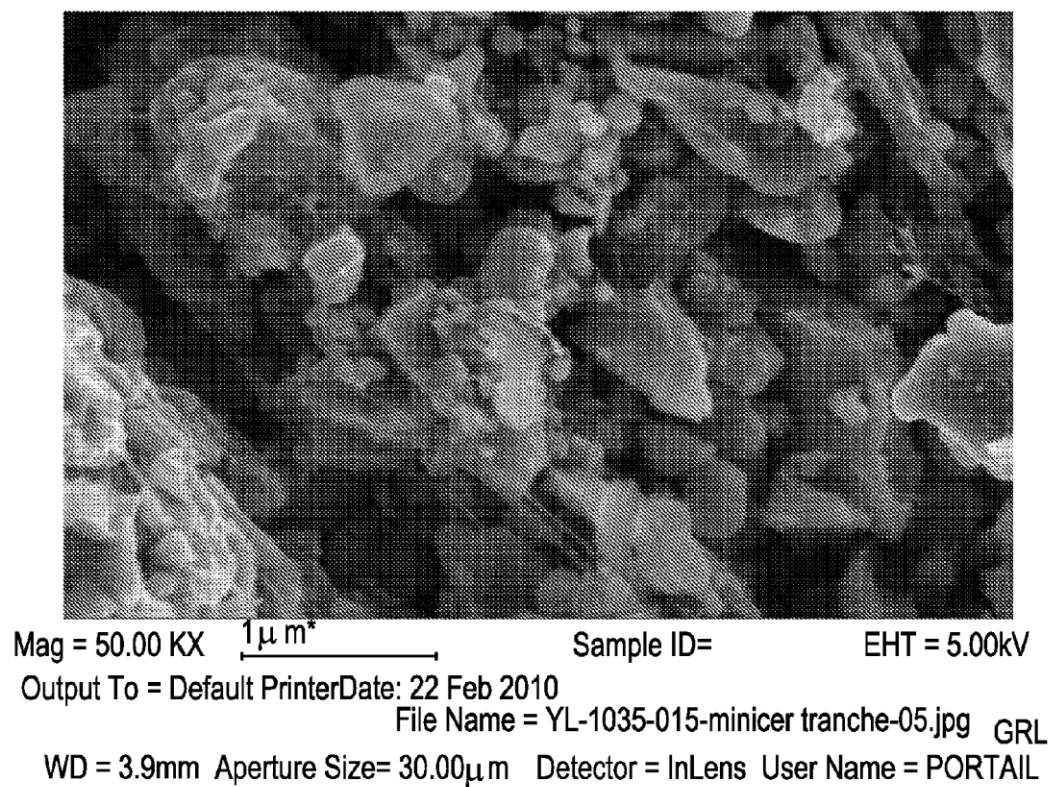
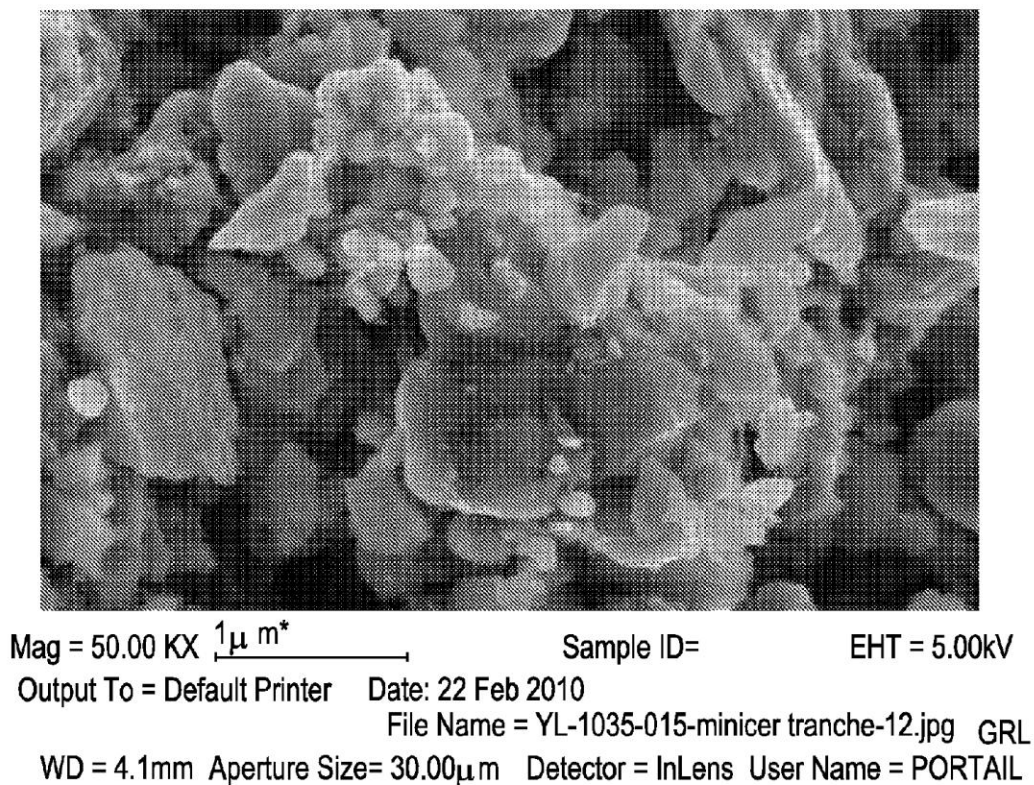


FIG. 2B



MRD-2018, $\llbracket 0121 \rrbracket$ - $\llbracket 0131 \rrbracket$. The CNTs are fully embedded within the PVDF domains, which is why they are not visible. *Id.*

125. As one final example, Figure 13 of MRD-2020 provides an SEM image of “cathode particles with adhering PVDF/carbon black clusters” after NMP mixing:

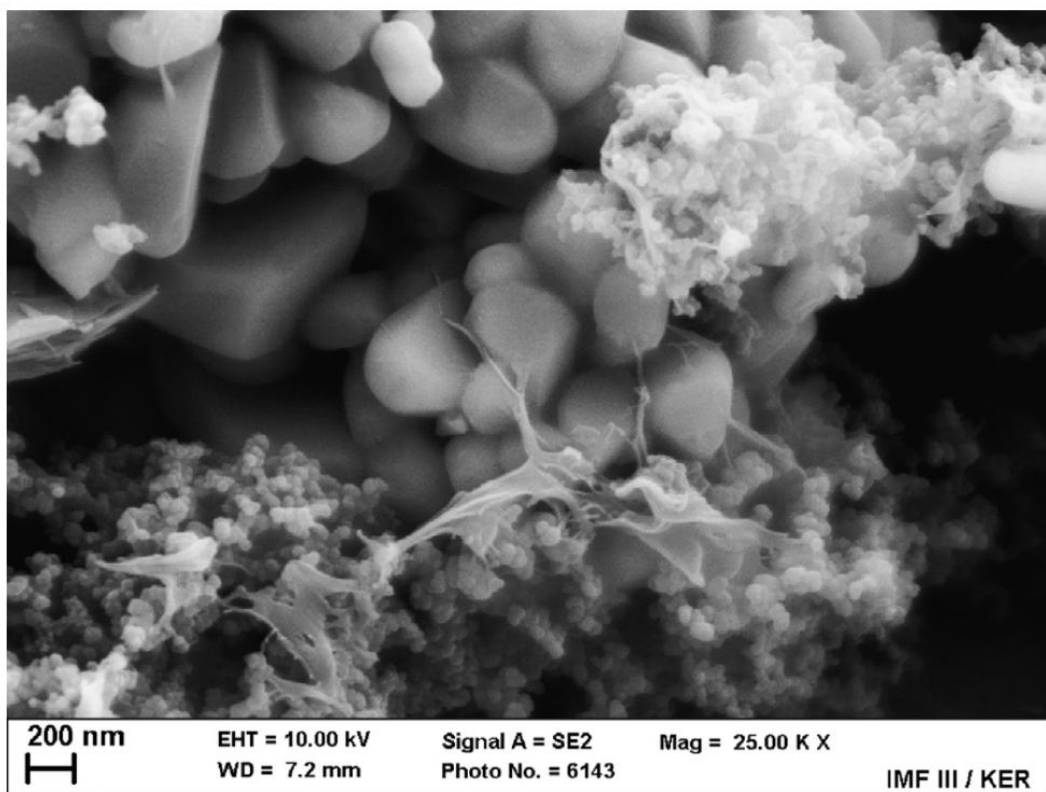


Fig. 13. SEM micrograph of a NMC cathode particles with adhering PVDF/carbon black clusters.

MRD-2020, 7. The carbon black clusters are clearly depicted as being entrained in the PVDF domains, which present as web-like or cloudy structures that the carbon black particles are embedded in. *Id.* The article teaches that mixing the carbon black with the binder first results in “gel formation” and “**PVDF polymer layer**” that “**prevents direct contact** of particle surfaces.” MRD-2020, 6-7. This is also consistent with the results of Zheng et al. [27], where **the PDVF consuming effect**

of carbon nanoparticles was depicted.” *Id.* at 6-7.⁶ Indeed, the article states that mixing CB with the binder first results in “gel formation.” *Id.* at 5. The article teaches that there is a “PVDF polymer layer” that “prevents direct contact of particle surfaces,” consistent with a POSITA’s understanding that the masterbatch process of Ohata-Kavan would result in CNTs coated in resin, thereby preventing the active material particles from attaching to the surface of the CNTs. *Id.*, 6.

126. All of the foregoing publications demonstrate that oxidized CNTs made based on the masterbatch process of Ohata-Kavan would be fully embedded within, and coated by, the resin matrix, which would prevent the active material from attaching to the surface of the CNTs. Instead, the active material would essentially be “glued” to the surface of the resin layer separating the active material from the surface of the CNTs. The resin layer can be as thin as a single layer of molecules, and it suffices to make it scientifically impossible for the active material to attach to the surface of the CNTs. In other words, the resin layer, however thin, scientifically precludes the attachment from occurring.

⁶ Figure 14 of MRD-2020 is an SEM image of “a sample of NMC and carbon black were blended in a high speed dry mixer (Hosokawa Micron NobiltaNOB-130, Japan) at 2800 RPM for 10 min before being dispersed in the binder solution.” MRD-2020, 3. Thus, there is no binder in that figure.

127. It is my opinion that Petitioner’s obviousness analysis overlooks this critical fact and incorrectly assumes that the sole reason for the “masterbatch” process of Ohata-Kavan is to create discrete CNTs.⁷ A POSITA would understand that the primary purpose of the masterbatch of Ohata-Kavan is to act as a binder, and that the claimed attachment of the active material to the surface of the CNTs would not be able to occur because the resin fully coats the surface of the CNTs during the masterbatch process. Unlike the ‘924 patent and Kavan, which expose naked oxidized CNTs to the active material during mixing to allow for attachment, Ohata-Kavan covers the CNTs with resin, preventing the claimed attachment from occurring. It is thus my opinion that even if a POSITA would have found it obvious to combine Ohata-Kavan as proposed by Petitioner, the combination would not meet this claim limitation.

⁷ Dr. Zhu essentially testified that the order of mixing components for an electrode is irrelevant, as the result will be the same. MRD-2024, 50:7-51:4. He is mistaken, because the order of mixing steps when making a chemically complex lithium battery composition is very important to the structure of the final composition. Cooking is an apt analogy, as anyone that has ever baked understands that the order of mixing ingredients can fundamentally alter the meal being made.

3. Whether a POSITA would be motivated to combine to obtain “oxidation levels from 1% to 15%” based on Kavan.

128. I understand that Petitioner provides several reasons it believes that a POSITA would have found it obvious to oxidize Ohata’s CNTs at the oxidation levels taught by Kavan. Pet., 13-15.

129. It is my opinion that a POSITA would not have had a motivation to oxidize the CNTs of Ohata pursuant to Kavan, because he or she would have readily understood that the masterbatch process of Ohata-Kavan would mitigate the benefits described by Kavan. Specifically, the functional groups associated with the oxidization would be completely covered in resin, preventing the lithium-ion active material (TiO_2 , LiMnPO_4 , or LiFePO_4) from “anchoring” to the surface of the CNTs as described by Kavan. *Supra* IX.A.2. A POSITA would have found it illogical to oxidize Ohata’s CNTs based on Kavan, given that the masterbatch process would destroy all of the oxidation benefits described by Kavan.

130. A POSITA would have also understood that oxidizing CNTs adversely affects their desirable intrinsic properties, which would further discourage a POSITA from oxidizing as taught by Kavan. It was known that “while a greater degree of functionalization may improve the dispersibility of the CNTs, such improvement may come at a decrease in intrinsic properties of the pristine CNTs.” LGES-1021, ¶[0024]. It was not only known that oxidation of CNTs shortens them, but also that it damages the structure of the pristine CNTs and reduces their electrical

conductivity. LGES-1009, 1-2 (describing shortening of tubes and damage to tube sidewalls); *see also* MRD-2024, 19:13-17, 22:1-24:3 (Dr. Zhu acknowledging negative effects of oxidizing CNTs). For example, oxidation creates defects in the CNTs sidewalls, degrading their electrical conductivity properties. These defects can also cause “unzipping,” which occurs when the CNTs are opened up to form a roughly flat, ribbon-like structure rather than a tube structure. Although a POSITA may have determined, as Kavan did, that the benefits of “anchoring” provided by oxidation offset these drawbacks, those benefits simply do not exist in Ohata-Kavan due to the masterbatch process covering the CNTs in resin.

131. I understand that Petitioner offers several reasons that a POSITA would have found it obvious to oxidize the CNTs of Ohata at the levels described by Kavan. It is my opinion that these reasons erroneously ignore the effects of the masterbatch process of Ohata-Kavan, as explained further below.

132. Petitioner’s “first” reason is that when a phosphate olive is used as the active material, “electrochemical performance of an electrode is improved by oxidized nanotubes.” Pet., 13. This reason is premised on the active material being able to “anchor” to the functional groups of the oxidized CNTs, thereby providing the benefits described by Kavan.

133. In Kavan, this anchoring occurs because the naked oxidized CNTs are *mixed directly* with the active material in water. LGES-1005, 2. Likewise, the ’924

patent teaches mixing naked oxidized CNTs with the active material to facilitate attachment. LGES-1001, 2:9-21; 5:15-20. However, in contrast to both Kavan and the '924 Patent, in Ohata-Kavan, the CNTs are *first* covered in resin during the masterbatch process as taught by Ohata, which prevents this anchoring effect from occurring. LGES-1004, ¶¶[0005], [0012], [0015]-[0016], [0030]. Consequently, in my opinion, Petitioner's above-stated first reason does not support a motivation to oxidize as taught by Kavan. Instead, a POSITA would have readily appreciated that the oxidation benefits described by Kavan would be inapplicable to Ohata-Kavan because of the unique masterbatch process, which fully covers the CNTs in resin to prevent any such anchoring from occurring.

134. Petitioner's second reason is that "a POSITA would have been motivated to use oxidized nanotubes in furtherance of Ohata's goal to have well-dispersed nanotubes in the composite." Pet., 13. As with the first reason, this reason also overlooks the critical fact that Ohata-Kavan would cover the CNTs (and their associated functional groups) in resin. A POSITA would understand that the improved dispersion described in Kavan is due to the functional groups interacting with water. Specifically, the functional groups added via oxidation are polar, hydrophilic functional groups (e.g., —COOH or —OH) on the surface of the CNTs, which enhances the CNTs' interaction with water, helping to reduce aggregation and promote better dispersion. MRD-2024, 27:17-28:5 (Dr. Zhu discussing how

functional groups are hydrophilic). In Ohata-Kavan, the naked oxidized CNTs are not exposed to water, but instead are first covered in resin. Because Kavan only teaches that naked oxidized CNTs mixed with water can help improve dispersion, Kavan does not support the assertion that oxidizing the resin-covered CNTs of Ohata-Kavan would improve dispersibility.

135. Additionally, even if oxidation generally would have been understood to help disperse CNTs in the resin of Ohata-Kavan, I understand that Petitioner's only basis for obviousness of the claimed oxidation level is based on the teachings of Kavan. In other words, Petitioner relies solely on Kavan to teach or suggest oxidation levels within the claimed range of 1% to 15%. As I explained above, however, Kavan relies on a fundamentally different interaction between water and the functional groups—not a resin and the functional groups—and so a POSITA would have had no motivation to oxidize at the levels taught by Kavan.

136. Additionally, I understand that Petitioner asserts that Ohata alone already achieves uniformly dispersed CNTs. Pet., 22 (arguing in Ohata “a conductive material is uniformly predispersed in a binder”) (quoting LGES-1004 ¶[0002])). Based on Petitioner's allegation that Ohata already achieves uniform dispersal without oxidizing its CNTs, a POSITA would have had no motivation to oxidize them to improve dispersion. This is particularly true given that it was well-known that oxidation would adversely affect the intrinsic properties of CNTs,

including by shortening them and introducing defects along the sidewalls of the CNTs. LGES-1009, 1, 5; MRD-2024, 19:13-17, 22:1-24:3 (Dr. Zhu acknowledging detrimental effects of oxidation).

137. I understand that Petitioner’s third reason is that oxidation can help purify the CNTs. Pet., 14. I first note that nothing in Ohata or Kavan teaches or suggests that the CNTs have impurities. Kavan actually teaches to the contrary. It expressly states that it uses “purified” CNTs, which a POSITA would understand to refer to CNTs lacking impurities. LGES-1005, 2 (“For oxidative functionalization, 1g of *purified* nanotubes was mixed....”). As such, there would have been no motivation to oxidize for purposes of removing impurities.

138. I understand that Petitioner also asserts that “a POSITA would have been motivated to use oxidized nanotubes in the Ohata-Kavan paste.” Pet., 15. However, it is my understanding that the obviousness issue here is not whether a POSITA would have simply been motivated “to use oxidized nanotubes,” but whether a POSITA would have been motivated to use oxidized CNTs *at the claimed level of 1% to 15% by weight of the CNT*. The only basis Petitioner provides for the assertion that the claimed range was obvious is based on Kavan’s oxidation level. As discussed above, however, the oxidation level of Kavan is premised on the goal of “anchoring” to provide the benefits taught by Kavan. Ohata-Kavan’s masterbatch process precludes these benefits from materializing because the CNTs are fully

covered in resin. A POSITA would have thus had no motivation to oxidize at the levels taught by Kavan. Additionally, a POSITA would have had an additional motivation to *not* oxidize at the levels taught by Kavan, because of the well-known disadvantages of oxidizing CNTs, and the fact that a POSITA understood that the “anchoring” benefits of Kavan would not be achieved in Ohata-Kavan

139. Petitioner’s “fourth” reason is based on applying a known technique to a known structure ready for improvement to yield predictable results. Pet., 14-15. But the alleged “predictable results based on functionalization of the carbon nanotubes” ignores the effects of the Ohata-Kavan masterbatch process, which undermines any motivation to combine, as explained in detail above. Moreover, a POSITA would have understood that the “predictable result” would have been CNTs covered in resin, which would preclude the attachment and benefits described by Kavan from occurring.

140. It is also my opinion that a POSITA would be strongly discouraged from following Kavan for at least two reasons.

141. First, Ohata teaches that “[a]lthough it is possible to add a resin during the step of preparing an electrode material mixture paste, the addition of the carbon nanotubes is difficult, taking the dispersibility of the carbon nanotubes in the resin into consideration.” LGES, 1004 ¶[0021]. In other words, Ohata teaches away from exposing the naked CNTs to the active material at the same time, which is how

Kavan “anchors” the active material to the oxidized CNTs. LGES-1005, 2. A POSITA would be discouraged from following the path set forth in Kavan—which relies on oxidizing naked CNTs and then mixing them with active material to take advantage of the functionalization of the CNTs—because it is exactly the process that Ohata teaches makes CNT dispersion difficult.

142. Second, a POSITA would have been discouraged from oxidizing Ohata’s CNTs pursuant to Kavan, because it would have been understood that the benefits of “anchoring” taught by Kavan would not be achieved because the masterbatch process covers the CNTs in resin. This discouragement would have been even more considerable, given that it was well-known that oxidizing the CNTs per Kavan would come at the cost of damaging the intrinsic properties while providing none of the benefits taught by Kavan.

4. Whether a POSITA would have had a reasonable expectation of success with the combination.

143. I understand that one consideration in the obviousness analysis is whether a POSITA would have had a reasonable expectation of success in achieving the claimed invention. It is my opinion that a POSITA would not have had a reasonable expectation of success in combining Ohata-Kavan such that the lithium-ion active material is “attached to th[e] surface” of the oxidized CNTs as claimed.

144. The basis for my opinion is that the Ohata-Kavan combination embeds the oxidized CNTs in resin before mixing with the active material. Each of the Petitioner’s reasons for a reasonable expectation of success appears to assume that Ohata-Kavan exposes the CNTs to the active material in a manner similar to the process of Kavan (by itself). But the Ohata-Kavan combination follows the masterbatch process that is fundamentally different from the process of Kavan. A POSITA would understand that the oxidized CNTs in Ohata-Kavan would be covered in resin, preventing the lithium-ion active material from accessing the functional groups to attach to the surface of the oxidized CNTs. *Id.* As such, a POSITA would not have a reasonable expectation of success in combining Ohata-Kavan to achieve active material “attached to the[] surface” of the oxidized, discrete nanotubes as claimed.

5. Whether the Ohata-Kavan combination teaches or renders obvious “discrete carbon nanotubes.”

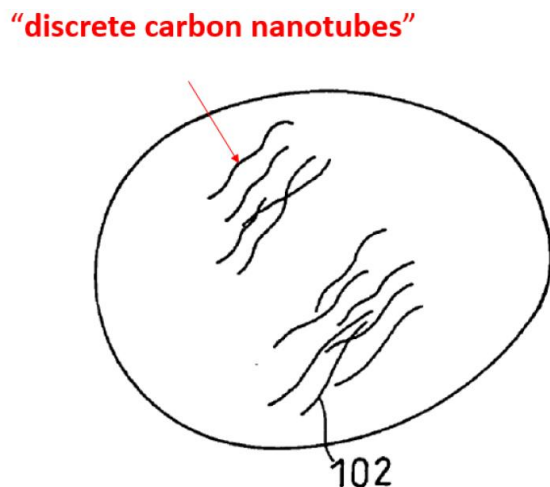
145. Petitioner characterizes “discrete” CNTs as “generally individually distinct nanotubes” (Pet., 21-22) and that are “fully isolated” or “separate” from one another. MRD-2023 ¶[0083] (“[L]ooking again to Ohata’s illustrative example, provided below, it can be seen that most of the nanotubes are depicted as being discrete, non-agglomerated, and exfoliated. Indeed, a POSITA would have understood a CNT shown below, is *fully isolated* from each other to be discrete, non-

agglomerated, and exfoliated.”); MRD-2024, 11:4-8 (testifying that “discrete” CNTs are “fully isolated” from one another), 12:17-13:22 (testifying that “discrete” CNTs are “separated from each other”).

146. It is my opinion that this interpretation is consistent with the plain and ordinary meaning of “discrete” as understood by a POSITA at the time of the invention. This is consistent with various teachings from the specification. LGES-1001, 1:45-49 (“discrete, i.e., individual, uniformly dispersed tubes”), 3:52-54 (“discrete” CNTs are “separated to give individual tubes”). This is also consistent with the ordinary meaning of “discrete.” See MRD-2007, 8 (defining “discrete” as “separate and distinct; not attached to others; unrelated”).

147. I understand Petitioner alleges that Ohata-Kavan results in “discrete” CNTs. Pet., 21. Petitioner relies on Ohata’s statement that its CNTs “are tangled and twisted with one another” but then are “**unraveled and straightened**” by blending them with a resin as part of the masterbatch process. *Id.*, 22 (emphasis in original) (citing LGES-1004 ¶[0015], FIG. 1(b)). I also understand that Petitioner argues “that a POSITA would have found it obvious that at least some of these ‘unraveled and straightened carbon nanotubes’ are discrete because they are generally ‘dispersed’ as individual nanotubes in the resin.” *Id.* Petitioner annotates Figure 1(b) of Ohata (reproduced below) to identify CNTs that it contends are “discrete.”

148. Petitioner’s annotation of FIG. 1(b) from Ohata is reproduced below, which Petitioner uses to identify CNTs consistent with its interpretation of discreteness.



Ohata, FIG. 1(a) (annotated by Petitioner)

A POSITA would not understand this figure to demonstrate that Ohata-Kavan results in “discrete” CNTs. Ohata itself calls FIG. 1 a “schematic” diagram, which conceptually illustrates the concept of disentangling CNTs by shearing. LGES-1004, ¶¶[0012]-[0013]. A POSITA would not rely on such a schematic as a real-world representation of actual masterbatch results. It would instead be understood for what it is—an illustration intended to conceptually depict the well-known concept of CNT disentanglement via shear forces.

149. A POSITA would understand that Ohata’s masterbatch process results would actually be reflected by SEM or TEM images, similar to how both the ’924 Patent and Kavan evidence their findings. For example, an actual SEM image

depicted in FIG. 5 of U.S. Patent Publication No. 2012/0058255 (“Gan”) shows CNTs mixed in a resin to form a conductive polymer composite:

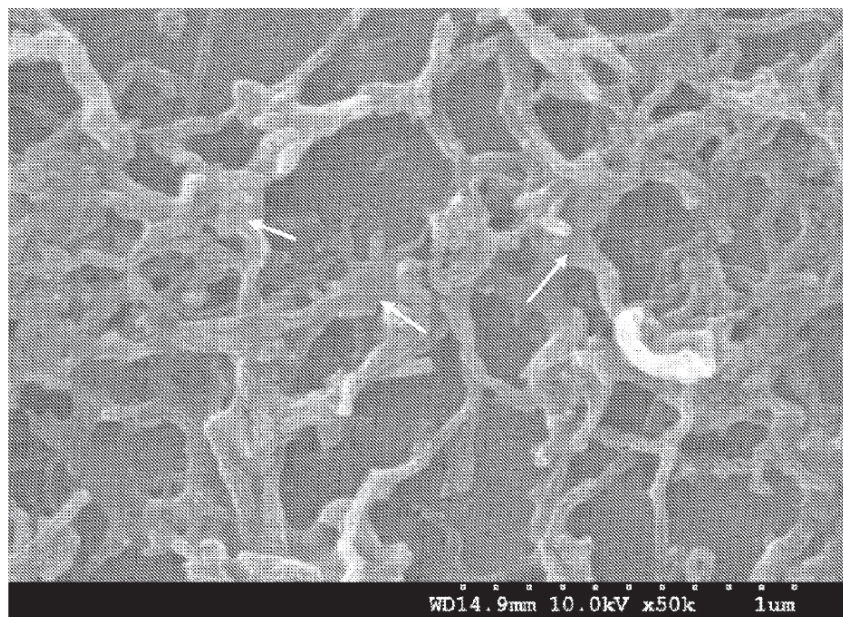


FIG.5

LGES-1021, 4, ¶¶[0014], [0041]. Gan does not purport to achieve discrete CNTs, but this image shows how the CNTs of Ohata’s masterbatch process would be randomly oriented (at least not aligned), which facilitates the formation of a continuous network of CNTs embedded within the binder that glues the active material particles together.

150. A POSITA would understand that Ohata’s masterbatch would result in a similar interconnected network of CNTs. Despite this, FIG. 1(b) depicts the CNTs as somehow being oriented in nearly the exact same direction and generally parallel to one another, rather than at random orientations throughout the resin, which is

implausible. A POSITA would thus recognize that FIG. 1 is an unrealistic, conceptual drawing intended to demonstrate the concept of CNT disentanglement.

151. Additionally, a POSITA would understand that the goal of Ohata is to create a continuous network of CNTs embedded in the binder, providing improved electrical conductivity among the active material particles. LGES-1004 ¶[0004] (explaining that “it is an object of the present invention to provide an electrode superior in **conductivity** with a small amount of conductive material”); LGES-1004, ¶¶[0018]-[0020] (explaining that when the CNT’s diameter is too large, the CNT’s length is too short, or the aspect ratio is too small, “excellent **conductive paths** may not be formed in some electrodes.”)). This was a well-known and common goal at the time of the invention. LGES-1007 ¶[0005] (“Carbon nanotubes have good electrical conductivity, and the fibrous structure thereof can better connect electrode active materials into a **continuous ‘network’** that is **electrically conductive**....”); LGES-1021 ¶[0041] (explaining that the “presence of such **continuous** conductive path through the composite is believed to be a reason why the electrical conductivity of the conductive polymer material increases when CNTs are present.”).

152. A POSITA would understand that Ohata is attempting to achieve this goal of a continuous network of CNTs in the binder to improve electrical conductivity of the binder that is positioned among the active material particles. Consistent with this goal, Ohata teaches a prior method of pre-dispersing carbon

black (i.e., a “conducting material”) in resin binder as part of a “masterbatch” process. LGES-1004, ¶[0002]. The naturally linked “chain” of carbon black particles forms a “conductive path” in the binder, which increases the electrical conductivity. *Id.* ¶[0003]. However, Ohata teaches that the shearing force associated with mixing the masterbatch breaks the conductive path, and therefore, “does not yield an electrode superior in conductivity.” *Id.* Ohata’s proposed solution is to use CNTs to form the continuous network rather than carbon black, because CNTs have strong internal bonds that make them much more resistant to shear force damage. *Id.* ¶[0015]. Indeed, Ohata did not seek to achieve discrete CNTs as part of its electrode material mixture paste, because this would decrease the likelihood of forming a conductive network, contrary to Ohata’s goal of achieving an “electrode superior in conductivity.” *Id.* ¶¶[0004], [0015]. A POSITA would not understand Ohata to teach or suggest achieving discrete CNTs, as they would have been expected to run contrary to the goal of creating a continuous, electrically conductive network.

153. A POSITA would understand that the only reason Ohata seeks to “unravel” and “straighten” the CNTs is so they can be better dispersed to form a continuous network better distributed throughout the binder. This is because it was well-known that heavier entanglement of CNTs “is undesirable because it results in formation of voids and aggregates in the composition which adversely effects the electrical conductivity properties of the composite. . .” LGES-1021 ¶[0027]; LGES-

1007 ¶[0073] (explaining that agglomeration of CNTs makes it “difficult to form an effective conductive network”). Just as a heavily wound spiderweb is more difficult to spread apart, heavily entangled CNTs are more difficult to disperse. Ohata seeks better dispersion of its CNTs so that it can provide a continuous network of CNTs throughout the entire binder. Ohata is thus seeking to achieve an interconnected network of CNTs, not discrete CNTs attached to the surface of the active material. *Id.*

154. Even if it is assumed that the *masterbatch* of Ohata-Kavan could comprise discrete CNTs, a POSITA would not expect those CNTs to remain discrete when mixed with the active material and dispersion medium as a part of the process for forming the *electrode material mixture paste*. LGES-1004 ¶[0023]. As shown by FIG. 5 of Gan (reproduced below), the random orientation of CNTs in a fluid facilitates the CNTs connecting to one another to forming a continuous conductive network. LGES-1021, 4, ¶¶[0014], [0041].

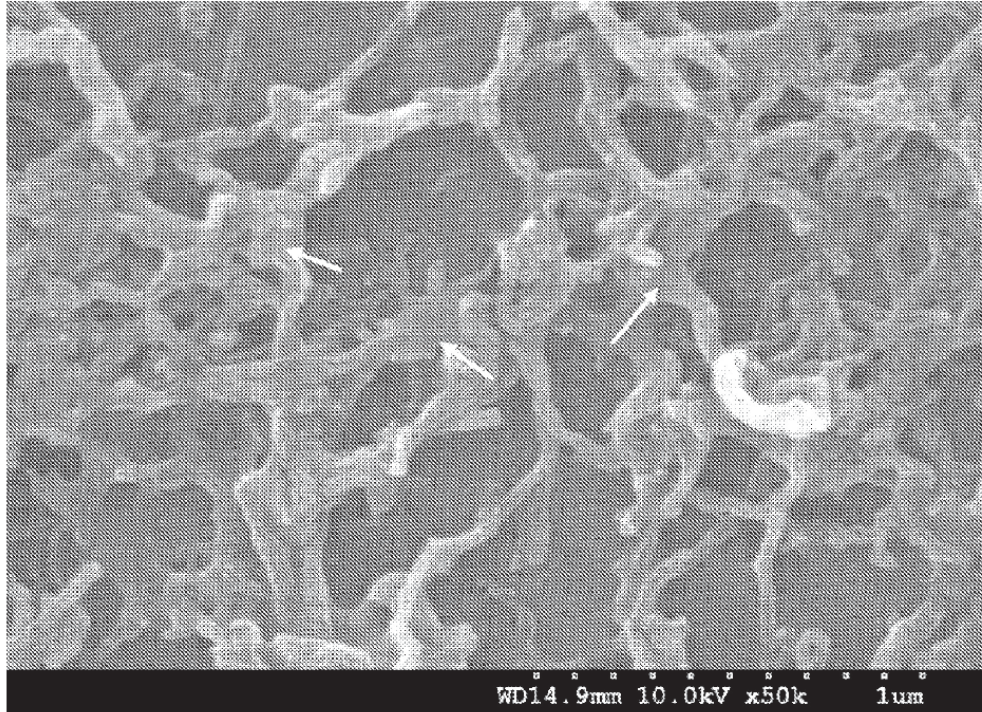


FIG.5

155. The formation of a continuous conductive network is only further facilitated when *oxidized* CNTs are mixed in a polymer (e.g., the resin of Ohata-Kavan). *Id.* This is because the functionalization of the CNTs “[r]educes contact resistance between CNTs incorporated into the conductive polymer material by drawing the CNTs close together” and “[p]rovides a conductive bridge between CNTs.” LGES-1021, ¶¶[0018]-[0021]; MRD-2026, 50:17-53:6 (Dr. Zhu agreeing with Gan’s described effects). A POSITA would understand that the formation of a continuous network of CNTs is a primary goal of Ohata—it seeks to achieve a continuous network of CNTs. *Id.* A POSITA would also understand that the only

reason Ohata teaches “unraveling” and “straightening” the CNTs is to make it easier to disperse them throughout the binder so that a continuous network is obtained throughout the entire binder—avoiding the network “voids” described by Gan. In view of the above, a POSITA would not expect the *electrode material mixture paste* of Ohata-Kavan to comprise discrete CNTs, even if there were discrete CNTs within the earlier formed *masterbatch*.

156. I understand that Petitioner also “alternatively/additionally” argues that “a POSITA would have understood or found obvious that the nanotubes in the combination composition are discrete because, at least in some instances, oxidation of nanotubes can help promote non-agglomeration of nanotubes.” Pet., 23 (emphasis in original). It appears that Petitioner and Dr. Zhu are contending that oxidizing CNTs—in and of itself—necessarily results in “discrete” CNTs. *Id.*, 23-24 (making the generalized statement that “oxidized nanotubes in the combination can be present as generally individually distinct nanotubes,”). They are mistaken.

157. While oxidation of CNTs can improve their dispersibility, CNTs that are dispersed (even uniformly dispersed) are not necessarily “discrete.” For example, CNTs forming a continuous network (i.e., the clear goal of Ohata) throughout an entire composition are “dispersed” throughout the composition even though the CNTs are interconnected (i.e., not “discrete”). Gan expressly teaches that functionalized CNTs within a “conductive polymer material” will be drawn closer

together and “[p]rovides a conductive bridge between CNTs,” facilitating the formation of a continuous network. LGES-1021, ¶¶[0018]-[0021]. Dr. Zhu testified that he agrees with Gan, and he acknowledges that both of these effects result in CNTs *in contact with one another* to form a *continuous* conductive network. MRD-2026, 50:17-53:6. This is what a POSITA would expect to occur when the masterbatch is formed and then further mixed with the dispersion medium and active material to form the electrode material mixture paste. Consequently, a POSITA would not understand CNTs to become “discrete” simply because they have been oxidized.

X. OPINIONS ON GROUND 2A: CHENG-GAN

A. Overview of Prior Art

1. Cheng

158. Cheng discloses a method of preparing composite cathode material for lithium ion batteries. LGES-1007, Abstract. Cheng attempts to “solv[e] the problem in the prior art in which carbon nanotubes are distributed only on the surface of the electrode [active] material,” which prevents “a *continuously connected three-dimensional electrically conductive network structure* both in the interior and on the surface of the [active] material” from forming. *Id.* ¶[0010]. Specifically, Cheng explains that:

[C]arbon nanotubes are used as an electrically conductive additive

instead of carbon black. The carbon nanotubes are all directly added to the active material, and are distributed only on surfaces of the electrode material, but ***cannot form a continuously connected three-dimensional electrically conductive network*** or ore (*sic*) structure both in the bulk phase and on surfaces of the electrode material, and in addition, ***the dispersion problem of the carbon nanotubes cannot be completely solved***, thereby hindering full utilization of properties of the carbon nanotubes.

Id. ¶[0009].

159. Cheng further explains that:

In view of the problems in the prior art, provided in the present invention is a high performance carbon nanotube/lithium iron phosphate composite cathode material and an ***in situ preparation*** method thereof, which can improve the high-power discharge capacity, cycle life, and compressibility of existing lithium iron phosphate cathode materials by fully utilizing properties of carbon nanotubes. Uniform dispersion of carbon nanotubes in the bulk phase and on surfaces of lithium iron phosphate is achieved by means of an ***in situ solid phase reaction process***, thereby solving the problem in the prior art in which carbon nanotubes are distributed only on the surface of the electrode material and cannot form a ***continuously connected three-dimensional electrically conductive network*** structure both in the interior and on the surface of the material, and also solving the problem in which the properties of the carbon nanotubes cannot be fully utilized because the carbon nanotubes cannot be fully dispersed.

Id. ¶[0010].

160. Thus, Cheng expressly teaches that its invention involves an “in situ solid phase reaction process” and that it is attempting to form a “continuously connected three-dimensional electrically conductive network.” *Id.*, Abstract, ¶¶[0009]-[0010].

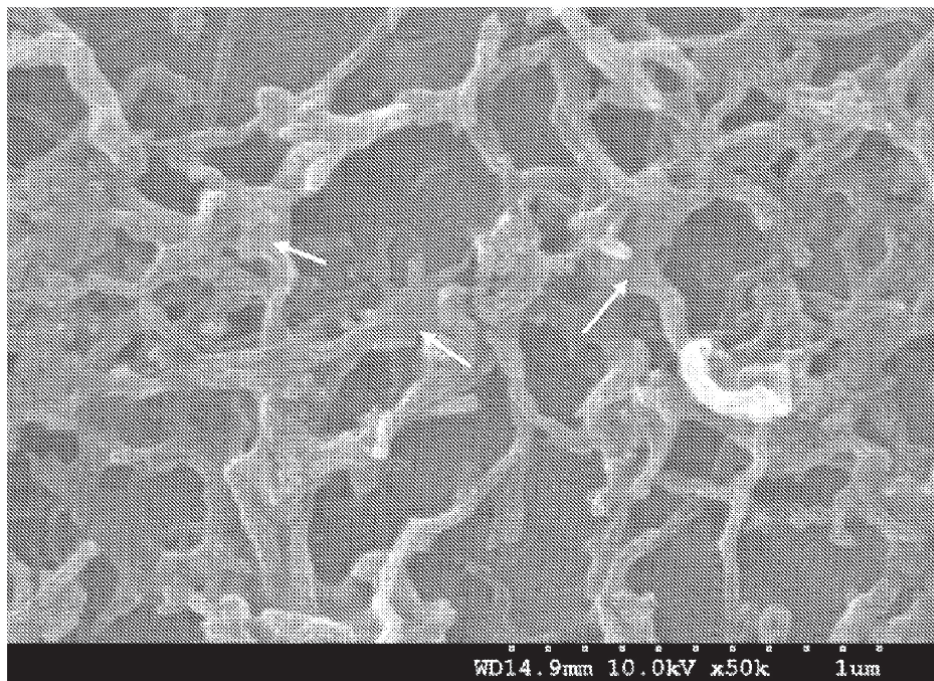
161. Cheng’s method generally involves three (3) steps. *Id.*, Abstract. First, making a CNT dispersion by taking unoxidized CNTs, acetylene black, and a dispersing agent and ultrasonically dispersing them in water or an organic solvent to obtain a mixture. *Id.* ¶[0013]. Second, making a precursor powder dispersion by mixing a lithium source, an iron source, a phosphate salt, and an organic carbon source into the mixture from the first step, followed by adding a mixing and milling medium and perform mixing ball-milling and drying. *Id.* ¶¶[0014]-[0015]. Third, performing an in situ solid phase reaction, specifically, a carbon thermal reduction, by taking the precursor powder dispersion from the second step and ***calcining it to temperatures of “600°C to 850°C in an inert protective atmosphere for 4 to 48 hours***, pulverizing the burned materials, and then sieving,” which obtains the “carbon nanotube lithium iron phosphate composite cathode material.” *Id.* ¶[0019]. A POSITA would understand that the high temperature calcining is required to: (1) convert the carbon source into carbon to act as a conductive binder; and (2) form the lithium iron phosphate (i.e., active material) from the lithium, iron, and phosphate

sources. MRD-2026, 38:18-39:14 (Dr. Zhu agreeing that calcining is required to convert carbon source into carbon, but disagreeing that the carbon acts as binder).

2. Gan

162. Gan is directed toward “composites of carbon nanotubes and conductive polymer materials.” LGES-1021 ¶[0002]. In reference to Figure 5 (reproduced below), Gan seeks to achieve a “percolated network” of CNTs and conductive polymer that “form a continuous conductive path extending through the composite.” *Id.* ¶[0041]. Gan states that the presence of such a continuous conductive path is believed to be the reason the polymer has increased electrical conductivity.

Id.



163. Gan teaches that “it is preferred that the CNTs [carbon nanotubes] are functionalized.” *Id.* ¶[0018]. “Functionalization refers to a process wherein functional groups are physically or chemically attached to the surfaces of the CNTs.” *Id.* “Functionalization of CNTs can be achieved using known processes. . .” *Id.* “In addition, functionalized SWNTs [single wall nanotubes] and MWNTs [multi-wall nanotubes] can be obtained from commercial sources. . .” *Id.* “Examples of suitable functional groups include carboxyl (—COOH), hydroxyl (—OH) and silver carboxylate (—COOHAg) groups.” *Id.*

164. Gan teaches that “the functionalization of the CNTs achieves at least one or more of the following objectives:

1. Improves the solubility and ***dispersibility*** of the CNTs in water and conductive polymer materials into which the CNTs are to be mixed.
2. Reduces contact resistance between CNTs incorporated into the conductive polymer materials ***by drawing the CNTs closer together***; and
3. Provides ***a conductive bridge*** between CNTs to reduce the electrical contact resistance therebetween.

Id. ¶¶[0018]-[0021].

165. Gan cautions that the “degree to which the CNTs are functionalized is a balance between introducing the desired functional groups into the CNTs to achieve one or more of the three objectives described above, while minimizing the effect on the desirable intrinsic properties of the CNTs.” LGES-1021 ¶[0024]. “For

example, while a greater degree of functionalization may improve the dispersibility of the CNTs, such improvement may come at a decrease in intrinsic properties of the pristine CNTs.” *Id.* “The amount of functionalized CNTs utilized will be limited to those amounts below which agglomeration of the CNTs within the polymer material matrix is avoided.” *Id.* ¶[0027]. “Agglomeration of the CNTs within the polymer material matrix is undesirable because it results in the formation of discontinuities, voids and aggregates in the composite which adversely affects the electrical conductivity properties of the composite as well as the physical properties of the composite.” *Id.* ¶[0027]. A POSITA would understand that these “voids” are gaps in the continuous conductive network of CNTs that lead to reduced electrical conductivity.

B. Independent Claim 1

166. In Cheng-Gan, Petitioner asserts, “the carbon nanotubes in Cheng’s carbon nanotube/lithium iron phosphate composite would have carbon nanotubes that are functionalized or oxidized with carboxyl or hydroxy groups at ‘about 2.5 to 10 wt%’ based on Gan’s disclosure.” Pet., 41 (citing LGES-1021, ¶[0024]). “[T]he composition of the Challenged Claims is rendered obvious by [1] functionalizing the carbon nanotubes of Cheng using well-known methods, as described in Gan, or [2] obtaining the functionalized carbon nanotubes from commercial sources, as described in Gan, and applying such functionalized nanotubes in preparing the

composite described in Cheng.” *Id.*, 42. According to Petitioner, “[a] POSITA would have been motivated to use oxidized nanotubes (or oxidized nanotubes having oxidation levels such as those described in Gan) in the Cheng’s nanotube composite...” *Id.*

1. Whether Cheng-Gan satisfies the oxidation levels from 1% to 15%.

167. It is my opinion that the Cheng-Gan combination would not result in CNTs with oxidation levels from 1 wt% and 15 wt% of the CNTs.

168. A POSITA would understand that Cheng-Gan performs a carbon thermal reduction process by taking the precursor powder dispersion (containing the oxidized carbon nanotubes) and calcining it at 600°C to 850°C in an inert protective atmosphere for 4 to 48 hours. LGES-1007 ¶[0019]. A POSITA would understand that Cheng requires this calcination step for several reasons.

169. First, calcining is required because it converts the organic carbon source (e.g. sucrose) into carbon, allowing the carbon to act as a conductive binder to bind the ion active material (e.g. lithium iron phosphate). MRD-2026, 38:18-39:5 (Dr. Zhu agreeing that the calcining converts the carbon source to carbon, but disagreeing that the carbon acts as a binder); MRD-2038, 1 (explaining that carbon formed by the pyrolysis of carbonaceous molecules such as pitch can act as a binder, even the sole binder in a porous carbon nanofiber assembly); MRD-2034, 1 (explaining that

“[t]he carbon obtained by pyrolysis of sucrose is a reactive constituent as well as the binder in the composite powder.”). The effectiveness of elemental carbon (formed by the pyrolysis of carbonaceous molecules, such as resin) as a binder has long been well established. In fact, such carbon serves as the matrix of carbon-carbon composites, which refer to carbon-matrix composites with carbon fiber as the reinforcement. The matrix is a binder. Carbon-carbon composites are dominant among lightweight structural materials, as used in the Space Shuttle.

170. Second, calcining is required to form the lithium iron phosphate by reducing the iron source (e.g., ferric oxide) in the presence of acetylene black. *Id.* (Dr. Zhu agreeing that the calcining creates the lithium iron phosphate). Without this critical calcination, there would be no lithium iron phosphate formed as the active material of the composition. Consequently, calcining is required for the electrode of Cheng-Gan to be functional.

171. A POSITA would understand that calcination would remove essentially all of the oxidized groups (i.e., functional groups) from the CNT surfaces, bringing the oxidation level below 1 wt%. It was well-known that functional groups begin to be removed at much lower temperatures. For example, it was known that at temperatures from 150 °C to 350 °C, “decarboxylation of the carboxylic groups present on the MWCNT walls” occurs. LGES-1009, 7. It was also known that “[t]hermal degradation in the range between the 350 °C and 500 °C may be explained

by the elimination of hydroxyl functionalities, attached to the MWCNT walls.” *Id.* A POSITA would therefore expect that at Cheng-Gan’s minimum calcination temperature of 600 °C—100 °C higher than the upper limit of this thermal degradation range—essentially all of the functional groups of Chen-Gang would be removed. LGES-1009, 7. This is particularly true not only because Cheng-Gan calcinates at extremely high temperatures (i.e., above 600 °C), but also because Cheng-Gan calcinates for a long period of time (at least 4 hours).

172. As another example, a journal article discussing amino-functionalized multiwall CNTs, explains that “[t]he weight loss [of oxidized multiwall carbon nanotubes] in the 150–350 °C range, with a maximum in the rate of decomposition around 275 °C, can be assigned to the decarboxylation of the carboxylic groups” and further that “[t]he removal of the hydroxyl functionalities attached to the walls of carbon nanotubes is known to occur in the 350–550°C interval,” which has an upper limit 50 °C lower than the lowest limit of 600 °C disclosed in Cheng-Gan. MRD-2029, 4. Because Cheng-Gan calcinates at a minimum temperature of 600 °C for a minimum of 4 hours, a POSITA would understand essentially all of the functional groups to be removed.

173. Another journal article, relating to thermal stability of oxygen-containing functional groups on MWCNTs, similarly supports that functional groups are removed from the surfaces of the CNTs at elevated temperatures. MRD-2030, 3

(Figure 1). A POSITA would know that CO₂ and CO are byproduct gases that are released when functional groups, such as carboxyl groups, are removed from oxidized CNTs. *Id.* In this article, Figure 1 shows that as the temperature of CNTs increased from about 100 °C to about 325 °C, the effective mole fraction (%) of CO₂ (green line) peaked, indicating the removal of carboxyl functional groups from the CNTs' surfaces. *Id.* In addition, as the temperature of the CNTs increased from about 100 °C to about 700 °C, the effective mole fraction (%) of CO (red line) peaked, indicating the removal of additional carboxyl functional groups from the CNTs' surfaces. *Id.*

174. Yet another journal article discussing the mechanism of thermal defunctionalization of oxidized carbon nanotubes, also evidences that essentially all functional groups are removed from the surfaces of oxidized CNTs at the extremely high temperatures disclosed in Cheng. MRD-2031, 3. In Figure 2(a), the “TG 1st heat” line graph shows that weight loss of CNTs begins around 200 °C. As the temperature increases beyond 200 °C, the weight loss of the CNTs increases continuously, mainly due to the continuous removal of the functional groups from the CNTs' surfaces. As temperature increases from 600 °C to 800 °C, the CNTs experience significant weight loss due to the continued removal of the functional groups on the surface of the CNTs. *Id.* Above 800 °C, the weight loss occurs more gradually as the temperature increases (more gradual than the weight loss at

temperatures below 800 °C), due to the oxidative removal of some of the carbon atoms from the CNTs' surfaces at these high temperatures. *Id.* The difference in slope between the part of the curve below 800 °C and the part above 800 °C supports the difference in mass loss mechanism between these two temperature regimes. *Id.*

175. Furthermore, in Figure 2(a), the “TG 2nd heat” line graph shows that weight loss of the carbon nanotubes starts to occur around 700 °C, such that the weight loss is gradual, akin to the gradualness of the weight loss above 800 °C in the “TG 1st heat” line graph. *Id.* In other words, the slope of the mass loss curve of TG 1st heat above 800 °C is comparable to that of the curve of TG 2nd heat above 700°C. *Id.* This can be explained because the TG 2nd heat line graph represents the same CNTs that had already experienced significant removal of functional groups, as shown in the TG 1st heat line graph. Accordingly, TG 2nd heat shows weight loss of the CNTs, mainly due to the oxidative removal of the carbon atoms from the CNTs. In other words, the first heat causes the removal of most of the functional groups, so that little additional removal of the functional groups occurs during the second heat.

176. Turning to Figure 2(b), the removal of functional groups occurs at temperatures from about 200 °C to about 800 °C. MRD-2031, Figure 2(b). The subtraction of the mass loss in the first heat by the mass loss in the second heat serves to remove the effect of the oxidative removal of the carbon atoms from the CNTs,

thereby showing the mass loss that is mainly due to the removal of the functional groups. *Id.*

177. Furthermore, in Table 2 CNTs were annealed at temperatures of 160, 370, 530, and 840 °C, for 2 hours in argon gas (an inert gas) for each of these four temperatures. MRD-2031, 3. After experiencing an annealing temperature of 840 °C, which is slightly lower than Cheng’s maximum calcination temperature of 850 °C, the CNTs (labeled “CNT4”) had only 1.3 at. % oxygen (corresponding to 1.7 wt.%)⁸ in the surface region of the CNTs, as measured by XPS (X-ray Photoelectron Spectroscopy). *Id.* XPS probes the surface region, such that the topmost atomic layers (particularly the very top atomic layer) within the thickness of this region are preferentially probed. The more interior (deeper) is the atomic layer, the lower is the chance of the atoms in the layer to emit photoelectrons, such that these electrons can get out of the material being probed. Without getting out, the electrons cannot be detected. *Id.* In Figure 1(c), the CNTs have about 10 carbon layers in the wall of the CNTs. MRD-2031, 2. The oxygen atoms are on the surface (i.e., the outermost atomic layer of the wall) of the CNTs and are not in the interior of the wall of the CNTs. *Id.* In contrast the carbon atoms are on the surface of the wall and also in the interior, i.e., not just in the outermost atomic layer. *Id.* Therefore, the oxygen

⁸ The atomic weight of oxygen is 16; that of carbon is 12. Consequently, 1.3 at.% oxygen corresponds to $(16/12)(1.3)$ wt.% oxygen = 1.7 wt.% oxygen.

concentration detected by XPS reflects mainly the oxygen concentration in the outermost layer, rather than the oxygen concentration with the entire wall of the nanotube taken into consideration to the same degree. As a result, a surface oxygen content of 1.3 at. % oxygen (corresponding to 1.7 wt.%) corresponds to a lower oxygen content when the entire wall thickness of the CNTs is considered. *Id.* Therefore, a POSITA would fully expect that after calcining the CNTs in Cheng-Gan at Cheng's maximum disclosed temperature of 850 °C for 4 to 48 hours, the oxidation level would be less than 0.75 at. % oxygen (corresponding to 1 wt.%) of the CNTs. *Id.*⁹

178. A final journal article relating to the thermal stability of plasma generated oxygenated functionalities on CNTs, also supports the concept that heat treatment of oxidized CNTs at temperatures taught by Cheng will result in essentially all the functional groups on the surfaces of the CNTs being removed in the Cheng-Gan combination. MRD-2032, 7. In Figure 6 of this article, the graph shown as squares ("Ar F-CNTs" in the legend), shows functionalized CNTs that were heated at various temperatures ranging from 20 °C to 600 °C in argon (Ar) for **only 30 minutes** at each temperature. *Id.* The data in this graph was obtained by using XPS. *Id.* As temperature increased from about 20 °C and up to about 600 °C,

⁹ The calculation for the oxidation level is to weight is $0.75 \times 16/12$, which equals 1.

the atomic percent of oxygen of the functionalized CNTs decreased, indicating that functional groups of the CNTs were being removed from the surfaces of the CNTs as temperature increased. *Id.* At 600 °C, which is the lowest temperature Cheng calcines, there was less than 2 at.% oxygen (corresponding to 2.7 wt.%) remaining in the surface region of the functionalized CNT. *Id.* This corresponds to considerably less than 2 at. % oxygen (2.7 wt. %),¹⁰ i.e., approximately 1.3 at. % oxygen (1.7 wt.%) when the entire wall thickness is considered. *Id.* However, the heating process here was only 30 minutes—i.e. about 12% of the 240-minute minimum calcining time of Cheng. *Id.* A POSITA would understand that Cheng’s minimum calcination temperature of 600 °C at the longer 4-hour period would result in an oxidation level of less than 0.75 at.% (1 wt.%) of the CNTs. *Id.*

179. I note that Dr. Zhu agrees that functional groups would be removed due to the high calcination temperatures of Cheng-Gan. MRD-2026, 42:15-20, 43:3-6. Dr. Zhu also agrees that the level of removal is affected by temperature and time. *Id.*, 44:1-14. I understand, however, that he contends the amount of functional groups removed would be limited because the CNTs are mixed “with other things” that react. *Id.*, 41:5-42:14. Dr. Zhu is mistaken for several reasons.

¹⁰ The calculation for the weight % is $2 \times 16/12$, which equals 2.7 wt. %.

180. First, the reason Cheng-Gan requires calcination at high temperatures for four hours is because those reactions *take a long period of time*. Specifically, Cheng requires at least 4 hours of calcination so that the reaction necessary to form the lithium iron phosphate and carbon can occur. However, the conversion of the lithium salt precursors to lithium salt takes time, and the precursors of the lithium salt are present at the high temperatures prior to the conversion of the precursors to lithium salt. The lithium salt precursors are chosen for their ability to form the lithium salt through reactions that involve one or more precursors that are present together in the calcination chamber. This means that the lithium salt precursors are prone to reactions. They are not inert at all. This reactive environment is conducive to the degradation or removal of the functional groups from the CNT surfaces. This also means that the reactive environment cannot help reduce the chance of the degradation or removal of the functional groups. Increasing the temperature would make it even more likely for the functional groups to degrade or be removed. An extended time period at the elevated temperature would further increase the chance of degradation or removal of the functional groups. Given the high temperature and long period of calcination, a POSITA would expect essentially the vast majority (if not all) of the functional groups to have degraded or to be removed before the calcination reactions even begin.

181. Second, a POSITA would understand that at an elevated temperature and for an extended time (such as the minimum elevated temperature and duration of Cheng), the chance of the degradation or removal of the functional groups would be even higher. Both a reactive environment and heat contribute to promoting the chance of the degradation or removal of the functional groups. A POSITA would thus accept the degradation or removal of the functional groups to be significant (or even complete) if the functional groups are in the environment of the high-temperature reactions of the composition of Cheng-Gan.

182. Third, if the functional groups were part of the reaction as Dr. Zhu contends, it would fundamentally alter the resulting composition in undesired ways. Specifically, if the functional groups on the CNTs indeed react with the lithium salt precursors during the heating process (as Dr. Zhu alleges), the lithium salt precursors would be chemically modified through this reaction. The modification of the lithium salt precursors would negatively reduce the effectiveness of the precursors to form the desired lithium salt with the desired composition. The functional groups on the surface of a material tend to hinder a reaction that is intended to occur using reactants that coexist with the material with the functional groups (Gensch paper, i.e., MRD-2042). This phenomenon is known as functional group tolerance, i.e., the ability of a reaction to tolerate the presence of functional groups.

183. Furthermore, the reaction of the functional groups with the lithium salt precursors would greatly reduce the ability of the functional groups to perform their desired function (which is to enable attachment of the CNTs to the surface of the active particles), due to the functional groups being chemically “hooked” to something else, i.e., the functional groups being engaged and hence being not available to perform their intended function. After the lithium salt precursors have been converted to the lithium salt, the reaction of the functional groups with the lithium salt, if any, would be relatively limited (compared to the reaction of the functional groups with the lithium salt precursors), due to the fact that the lithium salts are relatively stable solid compounds.

184. Consequently, Dr. Zhu is mistaken that the functional groups on the CNTs would take part in a meaningful way in a reaction during calcination. He is further mistaken that this participation would protect the functional groups from being degraded or removed during the calcination process. And, if the functional groups on the CNTs did participate, the composition would be adversely affected in such a way that a POSITA would be discouraged from functionalizing the CNTs in the first place.

185. I note that none of Petitioner’s individual prior art references involve oxidized CNTs that are heated to anywhere near the temperature or times required by Cheng. For example, Gan teaches that its oxidized CNT mixtures are only heated

to 100 °C, which is 500 °C less than the minimum temperature of Cheng. LGES-1021 ¶¶[0037]-[0038]. Likewise, Kavan teaches drying its electrode material mixture—comprising oxidized CNTs and active material (TiO₂, LiMnPO₄, or LiFEPO₄)—in a vacuum at 100 °C, which is 500 °C less than the minimum temperature of Cheng. LGES-1005, 2. In fact, the highest temperature disclosed in the '924 patent for heating its oxidized CNT-active material compositions is 185 °C for 3 hours. LGES-1001, 5:44-45. A POSITA would understand that this temperature is well below the known temperatures for significant thermal removal of functional groups associated with oxidation—whereas the minimum temperature of 600 °C taught by Cheng far exceeds them.

186. In view of the above, a POSITA would understand that calcining at the minimum temperatures and times of Cheng-Gan would result in essentially all of the functional groups being removed such that the electrode would have an oxidation level of less than 1% by weight. Thus, the Cheng-Gan combination does not satisfy the oxidation levels from 1 wt% and 15 wt% of the CNT.

187. I understand that Dr. Zhu testified that he believes the calcining step of Cheng-Gan is “optional” and that Cheng-Gan *could have* used a lower temperature. MRD-2026, 40:11-41:4, 28:28-29:4, 31:1-12, 39:6-9. He is mistaken. Cheng requires calcination to form the lithium iron phosphate (active material) and to convert the carbon source in carbon. *Id.*, 31:1-6, 38:18-39:13. Without calcining at

the minimum temperature and minimum time period taught by Cheng, Cheng-Gan would not produce a functional composition. Indeed, neither the carbon nor lithium iron phosphate would form.

2. Whether there would have been a motivation to combine to obtain oxidation levels from 1% to 15% by weight of the CNTs in light of the calcining step.

188. I understand that one part of the obviousness analysis is whether a POSITA would be motivated to combine the prior art references. In my opinion, there is no motivation to combine to obtain the oxidation levels from 1% to 15% by weight of the CNTs. I understand that Petitioner has provided several reasons that a POSITA would have allegedly found it obvious to oxidize Cheng's CNTs to the oxidation levels of 2.5 wt% to 10 wt% taught in Gan. Pet., 42-48. However, when the calcining step of Cheng-Gan is properly considered, these motivations would not have existed.

189. A POSITA would have had no motivation to oxidize the CNTs of Cheng because he or she would have readily understood that calcining at 600°C for 4 hours would remove functional groups associated with the oxidized CNTs, resulting in oxidation levels below the minimums of both Gan (2.5 wt.%) and the claims (1 wt.%). I explain the basis for this understanding in detail in Section X.B.1 above. A POSITA would find it illogical to oxidize CNTs to the level taught in Gan, given that the required calcining step of Cheng-Gan would destroy essentially all of

those functional groups, resulting in oxidation levels beneath the required minimum of Gan (2.5%) and the claims (1%). Because the oxidation level would be below Gan's required 2.5 wt% after Cheng's required calcination step, there would have been no motivation to use oxidized CNTs as taught by Gan.

190. Additionally, Gan teaches:

The degree to which the CNTs are functionalized is a balance between introducing the desired functional groups into the CNTs to achieve one or more of the three objectives described above, while minimizing the effect on the desirable intrinsic properties of the CNTs. For example, while a greater degree of functionalization may improve the dispersibility of the CNTs, ***such improvement may come at a decrease in intrinsic properties of the pristine CNTs.*** In accordance with the embodiments described herein, suitable functionalization with carboxyl or hydroxyl groups ranged from about 2.5 to about 10 wt %.

LGES-1021, ¶[0024]. In light of this teaching, a POSITA would understand Gan expressly teaches *not* applying higher oxidation levels (e.g., 25 wt.%) that might, hypothetically, result in oxidation levels from 1 wt.% to 15 wt.% by weight of the CNTs after the calcining step has removed essentially all functional groups. A POSITA would understand that as oxidation levels increase, the desirable intrinsic properties of pristine CNTs decrease. Additionally, oxidation results in the shortening of the CNTs, which is more pronounced as oxidation levels increase. Consequently, a POSITA would have been discouraged from using oxidation levels

higher than those disclosed in Gan.

191. I also understand that there may not be a motivation to combine references if one or both references contains disclosures that “teach away” from the combination. I understand that a reference “teaches away” if it discourages from following the path set out in the reference, or a POSITA would be led in a direction divergent from the path that was taken by the applicant. In my opinion, Cheng also expressly teaches away from using CNTs oxidized to the levels of Gan.

192. A POSITA would be strongly discouraged from relying on CNTs oxidized per Gan, because a POSITA would readily understand that Cheng’s calcining step would destroy the key benefits provided by the added functional groups. This is particularly true given that oxidizing CNTs comes at the cost of damaging the intrinsic properties of the CNTs. LGES-1021 ¶[0024]. While Gan teaches that oxidation levels from about 2.5 wt.% to 10 wt.% reach a “suitable” balance, there is always a cost to oxidizing the CNTs. *Id.* This is yet another reason a POSITA would be discouraged from oxidizing in Cheng-Gan—it would negatively affect the intrinsic properties of the CNTs and provide no benefits because essentially all of the functional groups resulting from the oxidation are removed via calcination. *Id.*

193. I understand Petitioner offers several motivations to combine these references. Petitioner’s first offered motivation is “to achieve a better constructed

electrically conductive network of nanotubes within Cheng's nanotube / lithium iron phosphate composite, which is a design objective in Cheng." Pet., 42. Petitioner's second offered motivation is "to enhance dispersion of carbon nanotubes in water and/or conducting agent in Cheng." *Id.*, 43-44. However, Petitioner acknowledges that both motivations are premised on the benefits provided by the functional groups associated with oxidation. *Id.*, 42-44. As I explain in great detail above, essentially all of those functional groups would be removed during the calcination step. Consequently, these motivations would not have existed.

194. Petitioner's third offered motivation is that Gan's oxidation levels "remains within a safe threshold that preserves 'the desirable intrinsic properties of the CNTs.'" Pet., 44. However, the fact that oxidizing CNTs would allegedly not be detrimental to the CNTs is not a motivation to oxidize in the first place. The teaching cited by Petitioner is merely that Gan believes that its oxidation levels would not have a significant detrimental effect on the intrinsic properties of the CNTs. Pet., 44. Even accepting this as true, the mere fact that modifying a composition would not be detrimental to the composition is not indicative of whether there would be a motivation to make that modification in the first place.

195. Petitioner's fourth motivation is that extensive application of oxidized CNTs were well-known in various fields including lithium ion battery industry, and further that oxidized CNTs were commercially available. Pet., 45. Like the third

alleged motivation, this is also not a motivation to combine. Rather, this is simply a generalized statement that oxidized CNTs were used in the lithium ion battery industry and could be commercially purchased. *Id.* The fact that oxidized CNTs were used in the industry and available for purchase does not provide a reason to use them in the hypothetical Cheng-Gan combination. Indeed, a POSITA would understand that there are many materials used in the lithium ion battery industry that could be commercially purchased, but that does not in and of itself motivate a POSITA to use those materials in a specific composition, such as the composition of Cheng.

196. Petitioner’s fifth “motivation” is that it was well-known that [1] “the role of oxidation is to create ‘foothold’ functional groups, such as carboxyl groups, which then serve as attachment points to anchor . . . nanoparticles [e.g., LiFePO_4],” and [2] oxidized carbon nanotubes improve the “colloidal stability of CNTs,” ensuring their uniform dispersion.” Pet., 46 (quoting LGES-1010, 2; LGES-1003, ¶[115]). Here, the alleged benefits are again tied to the functional groups associated with oxidation. Pet., 46. A POSITA would understand that the calcining step of Cheng-Gan would remove the “footholds” or “attachment points to anchor” referenced above, thereby eliminating the benefit of “facilitating the bonding between carbon nanotubes and nanoparticles (such as lithium iron phosphate). LGES-1010, 2.

197. Petitioner's sixth "motivation" is based on applying a known technique to a known structure ready for improvement to yield predictable results. Pet., 47. But the reliance on "predictable results based on functionalization of the carbon nanotubes" ignores the required calcination step of Cheng-Gan, which undermines any motivation to combine. Pet. 47. A POSITA would not have predicted the functionalization of CNTs in Cheng-Gan to work for their intended purpose when accounting for the calcination step. Instead, a POSITA would have expected essentially all of the oxidation to be removed, undermining the asserted motivation to combine in the first place.

198. I understand Petitioner also asserts that "a POSITA would have been motivated to use [1] oxidized carbon nanotubes." Pet., 42. However, a POSITA's motivation "to use oxidized carbon nanotubes" does not demonstrate a motivation to use carbon nanotubes oxidized at the oxidation levels claimed. I understand that Petitioner's only basis for the position that the claimed oxidation range (i.e., 1-15%) was obvious is Gan's disclosure of oxidation levels of about 2.5 to about 10 wt%. Pet., 42 ("[A] POSITA would have been motivated to use ... [2] oxidized carbon nanotubes having the oxidation levels taught in Gan . . ."). Because a POSITA would have recognized that the calcining step would result in CNTs oxidized below the 2.5 wt% minimum required by Gan, there a POSITA would not have had a motivation to rely on the oxidation levels of Gan. Pet., 42.

3. Whether there is a reasonable expectation of success in light of the calcining step.

199. I understand that part of the obviousness analysis requires considering whether a POSITA would have had a reasonable expectation of success in combining prior art references.

200. In my opinion, a POSITA would not have a reasonable expectation of success in combining Cheng and Gan such that the CNTs maintain (1) Gan's required minimum oxidation level of 2.5 wt% or (2) the minimum oxidation level of 1 wt% required by the claims. Petitioner asserts that there would have been a reasonable expectation of success that the oxidation levels would "fall within the range disclosed in Gan (2.5–10 wt%)" in the Cheng-Gan combination. Pet., 48-50. However, Petitioner mistakenly overlooks the required calcining step of Cheng-Gan, which would remove essentially all of those functional groups. A POSITA would have had no reasonable expectation of success in achieving oxidation above either level when the calcining step is properly accounted for.

4. Whether Cheng-Gan achieves "discrete" CNTs.

201. It is my opinion that the Cheng-Gan combination does not achieve "discrete" CNTs, and I disagree with Petitioner's contrary assertion. Cheng and Gan both teach that they are trying to form a "continuous" or "percolated conductive" network of fibrous CNTs. LGES-1007 ¶[0005] ("Carbon nanotubes have good

electrical conductivity, and the fibrous structure thereof can better connect electrode active materials into a continuous ‘network.’”); LGES-1021 ¶[0041] (“A percolated network refers to the network of CNTs and conductive polymer that form a continuous conductive path extending through the composite.”)). While Cheng and Gan both do seek uniform distribution of CNTs, both references’ objective is for the CNTs to be interconnected (i.e., not “discrete”) to provide an electrically conductive network. LGES-1007 ¶[0005]; LGES-1021 ¶¶[0027], [0041]). Dr. Zhu agrees. MRD-2026, 12:23-13:1, 18:12-19:4, 54:16-55:23. Petitioner’s position that Cheng-Gan results in discrete CNTs as claimed is erroneously premised on (1) incorrectly equating the terms “uniformly dispersed” with “discrete,” and (2) incorrectly equating the steps of Cheng-Gan to the fundamentally different steps of the ’924 patent. Pet., 51-55.

202. Cheng’s design goal is to form a “***continuously connected*** three-dimensional electrically conductive network” of CNTs and active material. *Supra* Section X.A.1. Cheng teaches that the “fibrous structure” of CNTs “can better connect electrode active materials into a continuous ‘network’ that is electrically conductive.” LGES-1007 ¶[0005]. Cheng further explains that certain prior art used carbon nanotubes (rather than carbon black) directly mixed with the active material, but that the CNTs “cannot form a continuously connected three-dimensional electrically conductive network or ore (sic) structure both in the bulk phase and on

surfaces to the electrode material.” LGES-1007 ¶[0009]. Cheng also notes that “the dispersion problem of the carbon nanotubes cannot be completely solved, thereby hindering full utilization of properties of the carbon nanotubes.” LGES-1007 ¶[0009]. A POSITA would thus understand that the problems Cheng is attempting to address are the aggregation of CNTs that prevents formation of a “continuously connected three-dimensional electrically conductive network structure both in the interior and on the surface of the material, and also ... the problem in which the properties of carbon nanotubes cannot be fully utilized because the carbon nanotubes cannot be fully dispersed.” LGES-1007 ¶¶[0010], [0005], [0009].

203. In other words, one of Cheng’s key design objectives is to form a conductive network of CNTs to not only electrically connect adjacent active material particles, but also the CNTs residing on the surface of the active material particles. The presence of the CNTs on the surface of the active material particles (not just between the particles) serves to enhance the electrical continuity of the overall composite. *Id.* A POSITA would understand that the aggregation of CNTs can severely hinder this objective, because it can cause discontinuities in a network of CNTs and make it more difficult for the CNTs to provide electrical connectivity to the overall composite.

204. To address the adverse effects of CNT agglomeration, Cheng seeks a “[u]niform dispersion of carbon nanotubes” that can “significantly improve filtration

of the electrolyte in the electrode material.” LGES-1007 ¶[0007]. Specifically, Cheng explains that by using CNTs with a larger diameter and smaller length, the “CNTs are less entangled with each other and more dispersible.” LGES-1007 ¶[0021]. It is important to note that Cheng is not seeking to eliminate the interconnectivity of the CNTs. Rather, Cheng wants to make the CNTs easier to disperse throughout the composition to provide a comprehensive conductive network throughout the composite. *Id.* By better dispersing the CNTs throughout the composition, a broader continuous network can be formed through the entire composition, rather than agglomerates of CNTs that result in network voids or otherwise inhibit uniform distribution of the network throughout the composition.

205. Gan likewise attempted to form a “continuous” network of CNTs and recognized that generally “the amount of functionalized CNTs utilized will be limited to those amounts below which agglomeration of the CNTs within the polymer material matrix is avoided.” LGES-1021 ¶[0027]. “Agglomeration of the CNTs within the polymer material matrix is undesirable because it results in the formation of voids and aggregates in the composite which adversely affects the electrical conductivity properties of the composite as well as the physical properties of the composite.” *Id.*, ¶[0027]. In other words, Gan teaches that it wants to avoid aggregates of CNTs. The aggregation results in voids, which result in inadequate interconnected CNTs to form the conductive network. *Id.* ¶ [0027].

206. In reference to FIG. 5 of Gan below, which is an SEM image of non-functionalized CNTs, a conductive polymer (poly(3,4-ethylenedioxythiophene) (“PEDOT”)), and a non-conductive binder (polystyrene sulfonate (“PSS”)), the CNTs form a “continuous conductive path through the composite” and “[t]he presence of such a continuous conductive path through the composite is believed to be a reason why the electrical conductivity of the conductive polymer material increases when CNTs are present.” LGES-1021 ¶[0041]. The white arrows “identify locations where the PEDOT:PSS effectively wraps around and binds with the MWNTs to form a percolated network.” *Id.* ¶[0041]. “A percolated network refers to the network of CNTs and conductive polymer that form a continuous conductive path extending through the composite.” *Id.*

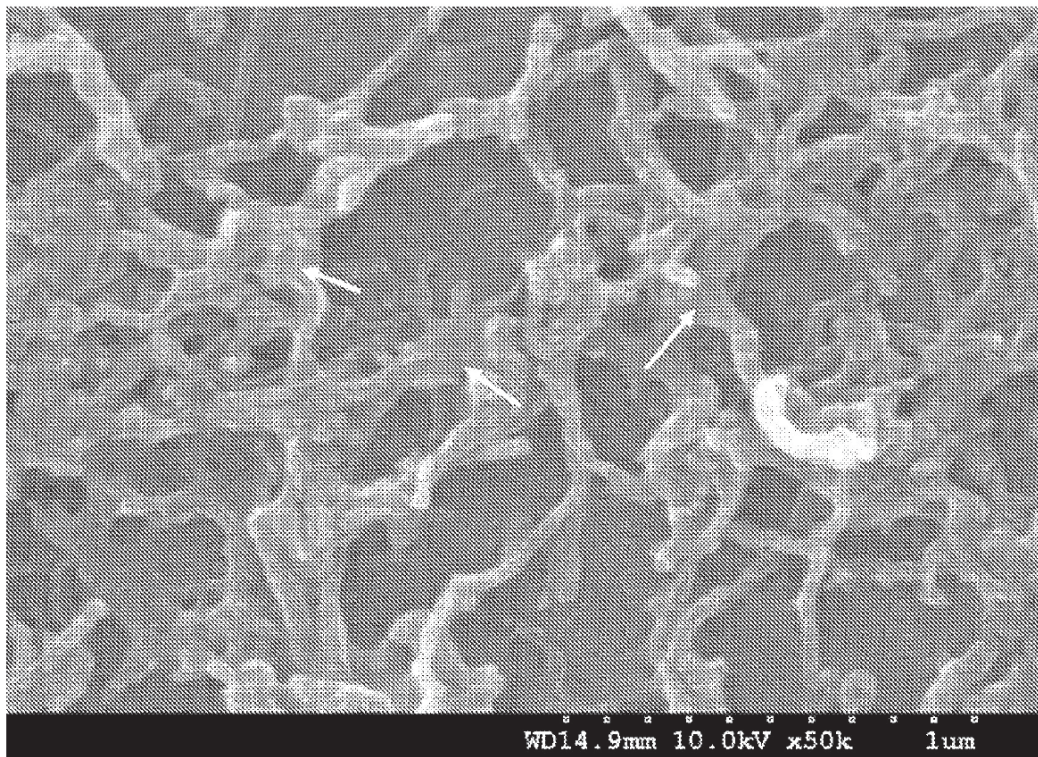


FIG.5

207. Thus, like Cheng, Gan also seeks to form a “continuous” or “percolated” network of CNTs (as depicted in FIG. 5) to increase electrical conductivity throughout the composition. *Id.* ¶[0041]. In other words, Cheng seeks to achieve a uniform **network** of CNTs throughout its composition, and well dispersed CNTs help achieve that goal.

208. Gan teaches that functionalization of CNTs achieves at least three objectives: (1) “[i]mproves the solubility and dispersibility of the CNTs in water and conductive polymer;” (2) “[r]educes contact resistance between CNTs incorporated into the conductive polymer material by drawing the CNTs closer together”; and (3)

“[p]rovides a conductive bridge between CNTs to reduce the electrical contact resistance therebetween.” LGES-1021 ¶¶[0019]-[0021]. A POSITA would understand that each of these objectives is directed toward maintaining an interconnected network of CNTs, while avoiding aggregation that results in network voids (i.e., network discontinuities) discussed above. LGES-1021 ¶¶[0019]-[0021].

209. Specifically, objective (1) is to avoid aggregates that cause network voids by better dispersing the CNTs throughout the composite. LGES-1021 ¶[0019]. An apt visual analogy would be a spiderweb that is stretched to cover a larger area—the network of webbing remains but it is being stretched to expand in size. Next, objective (2) is to ensure that the CNTs remain networked together “by drawing the CNTs closer together.” LGES-1021 ¶[0020]. As Gan explains with respect to Figure 5, interconnected CNTs can provide better electrical conductivity so long as the interconnections are not wrapped in non-conductive polymer. LGES-1021 ¶[0041]. Likewise, objective (3) is directed toward ensuring the CNTs remain electrically interconnected by “providing a conductive bridge between CNTs.” LGES-1021 ¶[0021]. In other words, the “contact resistance” of the interface between CNTs is reduced by ensuring that the CNTs are intricately connected (e.g. as shown in Figure 5).

210. In view of the above, a POSITA would understand that Cheng and Gan seek to have a “continuous” or “percolated” network of CNTs, whereby the CNTs

are non-agglomerated and better dispersed throughout a composition. Neither reference teaches or suggests that the CNTs are discrete, and neither reference teaches or suggests that its goal is to obtain discrete CNTs. Having discrete CNTs in Cheng and Gan would run contrary to the purpose of both references, which is to maintain a continuous or percolated network of CNTs throughout their respective compositions. There is no indication that either Cheng or Gan recognized that having discrete CNTs attached to the surface of the active material provides any benefit, such as retardation of active material cracking.

211. Despite Cheng and Gan both seeking a continuous network of CNTs, I understand that Petitioner argues that Cheng-Gan results in “discrete” CNTs. Pet., 51-55. However, Petitioner erroneously equates “discrete” CNTs with “uniformly dispersed” or “non-agglomerated” CNTs. Pet., 51-55. CNTs can be “non-agglomerated” and “uniformly dispersed,” without being “discrete.” For example, in a continuous network of dispersed CNTs, the CNTs may be “non-agglomerated” and “uniformly dispersed,” but by definition are not “discrete” because they are continuously connected (i.e., each CNT is attached to one or more other CNTs to form the continuous network). This is precisely the type of CNT network that Cheng and Gan seek to achieve. I have fully reviewed Cheng and Gan and neither teaches or suggests that they are seeking to achieve “discrete” CNTs. Petitioner’s “discrete” arguments in Cheng-Gan combination are premised on the inaccurate proposition

that “uniformly dispersed” and “non-agglomerated” CNTs are the equivalent of “discrete” CNTs.

212. I understand Petitioner’s first argument relies on Cheng’s teachings, arguing that Cheng achieves “fully dispersed” and “uniformly dispersed” CNTs to “form a continuously connected three-dimensional electrically conductive network structure both in the interior and on the surface of the material.” Pet. 51-52. However, “uniformly dispersed” and “fully dispersed” CNTs do not mean “discrete,” as explained above.¹¹ See e.g., LGES-1001, 2:29 (using “uniform dispersion” and “discrete” separately).

213. Additionally, Cheng does not teach or suggest discrete carbon nanotubes anywhere in its disclosure. None of the words “discrete,” “individual,” or “distinct” appear in Cheng. Cheng’s design objective is to achieve “better dispersion of both the carbon nanotubes themselves and throughout the lithium iron phosphate.” Pet., 46. Cheng does not teach discrete carbon nanotubes, because one of its major design objectives is to obtain uniform and **continuous network** of dispersed CNTs both on the surface of the active material particles and outside the active material particles. LGES-1007 ¶¶[0021], [0023].

¹¹ Independent claim 1 requires a composition comprising “discrete carbon nanotubes.” LGES-1001, claim 1. Claim 5, which depends on claim 1, requires that the composition comprises “uniformly dispersible ... carbon nanotubes.” Because a dependent claim is presumed to be narrower, this further demonstrates that “discrete” and “uniformly dispersible” have different meanings.

214. Notably, the portion of Cheng quoted by Petitioner—“form a continuously connected three-dimensional electrically conductive network structure both in the interior and on the surface of the material,”—is inconsistent with Petitioner’s position that Cheng-Gan would achieve discrete CNTs. Pet., 37 (quoting LGES-1021 ¶[0010])). A POSITA would understand that Cheng is explicitly teaching that it does not want its CNTs to be discrete, but rather it wants a “continuously connected ... network structure” formed with the active material. In other words, Cheng wants its CNTs to be interconnected throughout its composition (including the surface of the active material particles), while avoiding aggregation to reduce voids and improve the likelihood that the CNTs are networked throughout the composition. Having “discrete” CNTs would result in undesirable voids in the “continuous network” that Cheng expressly seeks to achieve.

215. Petitioner’s second argument also relies on the teachings of Cheng alone, alleging that Cheng teaches that its composite material results in a “non-aggregated and uniform dispersion of nanotubes.” Pet., 52. I first note that Cheng does not use any form of the word “aggregate.” However, even assuming that Cheng did use that word, as I explained above, neither “non-aggregated” nor “uniform dispersion” mean “discrete.” Petitioner is relying on quoted terms from Cheng—“effective conductive **network**” and “uniformly distributed **network structure**”—that undermine its position of showing discrete CNTs. (Pet., 53 (quoting LGES-1007

¶¶[0021], [0023])). Each quoted term supports that Cheng desires a network of connected CNTs. A POSITA would understand that the quoted language refers to a “uniformly distributed **network structure**” rather than “uniformly distributed” CNTs, because the goal of Cheng is to have a uniformly distributed, continuous network of CNTs dispersed throughout its composite, both on the surface of the active material particles and outside the active material particles. LGES-1007 ¶¶[0021], [0023].

216. Petitioner third argument is that Cheng teaches that the diameter and length of the CNTs “contribute to lesser aggregation and **better dispersion** of carbon nanotubes, thereby contributing to the **uniform dispersion** and **non-aggregated state of nanotubes.**” Pet., 53 (emphasis in original). To support this, Petitioner cites Cheng’s teaching that “the carbon nanotubes are **less entangled** with each other and are **more easily dispersed.**” *Id.* (quoting LGES-1007 ¶[0021]) (emphasis in original)). However, a POSITA would not understand any of the terms bolded by Petitioner to mean “discrete.”

217. A POSITA would understand that the cited portions of Cheng merely teach that it was known that the diameter and length of CNTs can affect dispersibility. However, these teachings do not demonstrate that Cheng achieved “discrete” CNTs, which would undermine his expressly stated goal of having a “continuously connected” network of CNTs. *Id.* In fact, a POSITA would recognize

that Cheng does not teach that the CNTs are “not entangled,” but merely that the CNTs are “less entangled with each other and are more easily dispersed,” which is what allows Cheng to form its “continuous” network of CNTs throughout the composition. LGES-1007 ¶[0021]. A POSITA would understand that “less entangled” means that there is still a degree of entanglement, but by being “less entangled” the CNTs can be more easily dispersed to help ensure that the continuous network of CNTs covers more volume of the composite material.

218. Petitioner’s fourth argument is its assertion that because Example 2 of the ’924 patent (hereafter, “Example 2”) describes three sequential steps, and Cheng-Gan allegedly performs “similar steps” in the same order, a POSITA would have understood Cheng-Gan to “likely yield similar dispersion results” as Example 2. Pet., 53-54. Specifically, Petitioner alleges that “Example 2 of the ’924 patent describes sequential steps of [1] forming oxidized carbon nanotube / solvent mixture based on ultrasonic dispersion, [2] mixing the mixture with lithium source, iron source and phosphate source with mixing medium (e.g., deionized water), and [3] heat treatment.” (hereinafter, “Steps [1], [2], and [3]”). Pet., 53-54. According to Petitioner, “Cheng, modified to use oxidized nanotubes as in Gan, disclose each and all of the above-noted steps of Example 2 in sequential order” and that “this suggests that similar steps in forming the composite would have likely yielded similar dispersion results.” Pet., 54.

219. Although Example 2 and Cheng-Gan may appear generally similar in the abstract, the specific materials used and steps performed are materially and meaningfully different. As explained below, a POSITA would fully expect the results from each respective process to be likewise materially and meaningfully different, particularly with respect to the dispersion results.

Step [0] cutting and selection steps

220. The specification teaches “the process of making discrete carbon nanotubes,” involves cutting CNTs into segments, dissolving the residual catalyst, and properly selecting the CNT feedstock, including selecting evenly spaced catalyst sites. LGES-1001, 4:4-21. Neither Cheng nor Gan discloses a similar pre-processing step to “help with exfoliation” and achieve discrete CNTs. *Id.* This distinction alone renders Petitioner’s comparison deficient.

Step [1] forming oxidized carbon nanotube / solvent mixture based on ultrasonic dispersion

221. In Step [1] of Example 2, 0.2 g of multi-wall carbon nanotubes, with aspect ratio of about 60, are oxidized to about 8 wt.% and added to 23.5 g of diethylene glycol (a solvent) and sonicated for 15 minutes. LGES-1001, 4:36-39. The result of this step is a dispersion of oxidized carbon nanotubes in a solvent.

222. In Step [1] of Cheng-Gan, 10 g of [oxidized] carbon nanotubes that have a length of 10-15 μm and a tube diameter of 50-150 nm and 6 g of polyvinylpyrrolidone (PVP) as a dispersing agent are added to 500 ml of deionized

water. LGES-1007 ¶[0040]. “After ultrasonic dispersion, 20 g of acetylene black were further added followed by ultrasonic or high-speed stirring and mixing to obtain a homogenous mixture of the [oxidized] carbon nanotubes and the acetylene black.” LGES-1007 ¶[0040].

223. Example 2 and Cheng-Gan use different materials and have different processing steps occurring in their respective Step [1]. LGES-1001,4:36-39; LGES-1007 ¶[0040].

224. First, Example 2 starts with carbon nanotubes that have an aspect ratio of about 60. LGES-1001, 5:36-38. In contrast, in Cheng-Gan, the carbon nanotubes have a preferred aspect ratio of about 67-300. Pet., 60.

225. Second, Cheng-Gan uses **polyvinylpyrrolidone (PVP)** as a dispersing agent for the carbon nanotubes. LGES-1007 ¶[0040]. PVP is a water-soluble, nonionic polymer. *Id.* In contrast, Example 2 does not use any dispersing agent or any water-soluble nonionic polymer—it uses diethylene glycol solvent. LGES-1001, 5:38.

226. Third, the PVP in Example 1 of Cheng-Gan is calculated to have a ratio of the number of Li^+ ions (in 1000 g LiH_2PO_4) to the number of H_2O molecules (2 kg of water) of 8.67%. LGES-1007 ¶[0041]. In contrast, Example 2 is calculated to have a ratio of the number of Li^+ ions (in 0.65 g of lithium acetate) to the number of H_2O molecules (4.2 ml of water) of 4.23%, which is significantly lower than the

above value of 8.67% of Cheng-Gan. LGES-1001, 5:42-44. A higher Li⁺ ion content, as used in Cheng-Gan, is expected to increase the viscosity, thereby making it more difficult to disperse the CNTs.

227. Fourth, Cheng-Gan uses acetylene black (a type of carbon black) in creating its carbon nanotube dispersion. LGES-1007 ¶[0013]. In contrast, in Example 2, neither acetylene black nor a similar substance is used. LGES-1001, 5:36-53. Notably, Cheng explicitly teaches (in a comparative example) that the acetylene black and CNTs can “agglomerate,” making it “difficult to form an effective conductive network.” LGES-1007 ¶[0073]). Dr. Zhu agreed. MRD-2026, 23:5-9. A POSITA would understand that, even beyond the other difference discussed above, the presence of PVP and acetylene black in the Cheng-Gan composition by itself fundamentally distinguishes its method and composition from that of Example 2 and would result in increased agglomeration. This distinction alone would have been enough for a POSITA to conclude that the dispersion results would not be “similar” as Petitioner asserts.

Step [2] mixing the mixture with lithium source, iron source and phosphate source with mixing medium (e.g. deionized water)

228. In Step [2] of Example 2, 1.16 g of iron acetate (iron source) dissolved in 4 ml of deionized water is added to the mixture of Step [1], and then the mixture is heated under nitrogen, stirring and sonication. LGES-1001, 5:39-41. Next, after heating the mixture for 1 hour at 140°C, a solution of 0.65 g of lithium acetate

(lithium source) and 0.74 g of ammonium phosphate (phosphate source) in 4.2 ml of deionized water is added. LGES-1001, 5:42-44.

229. By contrast, in Step [2] of Cheng-Gan, a precursor dispersion is made by taking the mixture from Cheng-Gan's Step [1] and "[m]ixing a lithium source, iron source, and phosphate salt at an atom ratio of Li : Fe : P = 1: 1: 1 **at one time, and simultaneously adding an organic carbon source.**" LGES-1007 ¶[0015]. A mixing and milling medium is then added to the mixture to perform mixing and ball-milling for 6 to 24 hours. *Id.* The mixture is then dried at 60°C to 110°C to obtain precursor powder. *Id.* The organic carbon source mainly comprises sucrose, glucose, a phenolic resin, or the like. LGES-1007 ¶[0018]. The lithium source comprises lithium carbonate, lithium hydroxide, lithium acetate, lithium dihydrogen phosphate, lithium citrate, or the like. The iron source comprises iron oxalate, iron acetate, ferric citrate, ferric oxide, ferroferric oxide, ferrous phosphate, or the like. A phosphate salt comprises ammonium dihydrogen phosphate, diammonium hydrogen phosphate, ferrous phosphate, lithium dihydrogen phosphate, or the like.

230. Just as in Step [1], Example 2 and Cheng-Gan use different materials and have different processing steps occurring in their respective Step [2].

231. First, in Example 2 it is critical that the iron acetate (iron source), which is water-soluble, is added independently in the mixture of Step [1], and not simultaneously with the lithium acetate (lithium source) and ammonium phosphate

(phosphate source). LGES-1001, 5:39-41. This order of addition is critical because the iron from the iron acetate bonds to the surface of the oxidized carbon nanotubes to create iron sites, which allows the lithium iron phosphate crystals to grow at the iron sites. In contrast, in Cheng-Gan, the “lithium source, an iron source, and a phosphate salt” are mixed “at one time, and simultaneously adding an organic carbon source” to the mixture from Cheng-Gan-Step [1]. LGES-1007 ¶¶[015].

232. Second, as set forth in Examples 1 and 5 of Cheng, Cheng teaches using Fe_2O_3 (ferric oxide), which is insoluble in water. LGES-1007 ¶¶[0041], [0057]. Since ferric oxide is insoluble in water, it will remain as insoluble particles in the Cheng-Gan dispersion, creating a non-uniform growth of lithium iron phosphate crystals on the carbon nanotubes, which will adversely affect the ability of the carbon nanotubes to uniformly disperse. Further, the ferric oxide has a higher density (5.24 g/cm^3) than water (1.0 g/cm^3), and therefore, it will sink in the dispersion, which would also hinder the carbon nanotubes’ ability to uniformly disperse. MRD-2033.

233. Third, Example 2 does not use an organic carbon source (e.g. sucrose). LGES-1001, 5:36-53. In contrast, Cheng-Gan requires an organic carbon source (e.g. sucrose), because when the organic carbon source is calcined in Step [3], it is converted to carbon, whereby the carbon acts as a binder, which would also affect dispersibility of the carbon nanotubes. LGES-1007 ¶¶[0014], [0018], [0041]. Thus,

Step [2] of Cheng-Gan involves a binder material, whereas Step [2] of Example 2 does not.

Step [3] heat treatment

234. In Step [3] of Example 2, the mixture from Step [2] is raised to 185°C over 30 minutes, then held at 185°C for 4 hours, which is a relatively low temperature and a relatively short time period, to prevent loss of oxidative species (i.e., functional groups) from the carbon nanotube's surface. LGES-1001, 5:44. Next, the mixture is cooled to 110°C and sonicated for 5 minutes followed by further cooling to ambient temperature while stirring. LGES-1001, 5:46-48. "The solids are separated from the mixture by centrifugation followed by ethanol washing." *Id.*, 5:48-49. The resultant powder is dried, which yields discrete carbon nanotubes with lithium iron phosphate attached to the surface of the carbon nanotubes. *Id.*, 5:32-34, 49-50.

235. Petitioner describes Step [3] of Cheng-Gan as merely a "heat treatment" step, but in reality, this step is an in situ solid phase reaction / carbon thermal reduction reaction involving calcination at extremely high temperatures for long periods of time. LGES-1007 ¶¶[0019], [0039]. This refers to a chemical reaction whereby the reactants are solid materials that react in an inert atmosphere at a very high temperature. In the in situ solid phase reaction, after the mixed precursor powder is dried from Cheng-Gan Step [2], the precursor powder is calcined at 600°C

to 850°C in an inert protective atmosphere for 4 to 48 hours,¹² pulverizing the burned material, and then sieving the same through a sieve of 140 to 400 meshes. LGES-1007, ¶[0019]. The result of completing the in situ solid phase reaction will yield the Cheng-Gan carbon nanotube/lithium iron phosphate composite cathode material. LGES-1007 ¶[0019].

236. Example 2 and Cheng-Gan use fundamentally different “heat treatment” processes in their respective Step [3]. The heat treatment of Example 2 does not involve an in situ solid phase reaction, does not involve carbon thermal reduction, does not involve a carbon source, and does not require calcining—each of these are required in Cheng-Gan. LGES-1001, 5:36-53; LGES-1007 ¶¶[0019], [0039]. Example 2’s heat treatment is initially at 140°C, then ramped up to 185°C over 30 minutes, and then held at 185°C for 4 hours, followed by cooling, centrifugation, and a washing step to obtain a composition comprising discrete carbon nanotubes with lithium iron phosphate attached to the surface of the carbon nanotubes. LGES-1001, 5:42-50. In Example 2, the heating step is performed in

¹² In Examples 1 and 5, Cheng calcines its precursor powder at 700 °C for 15 hours. LGES-1007, ¶¶[0041], [0077]. In Examples 2 and 4, Cheng calcines its precursor powder at 700 °C for 24 hours. LGES-1007 ¶¶[0045], [0077]. In Example 3, Cheng calcines its precursor powder at 800 °C for 6 hours. LGES-1007 ¶¶[0045], [0049].

order to react iron acetate, ammonium phosphate, and lithium acetate to form lithium iron phosphate. *Id.*

237. By contrast, Cheng-Gan relies on an in situ solid phase reaction / carbon thermal reduction, requiring a calcination step at very high temperatures (i.e., 600°C to 850°C) and for a long period of time (i.e., 4 to 48 hours) in an inert atmosphere, followed by pulverizing the burned material, and sieving to obtain its carbon nanotube/lithium iron phosphate composite. LGES-1007 ¶¶[0010], [0012], [0019]. Cheng's calcination step converts its organic carbon source (e.g. sucrose) into carbon via a pyrolysis reaction and is necessary so the resulting carbon serves as a conductive binder in the composite. The calcination step is also required to form the lithium iron phosphate. Thus, the reason for the heating step in Example 2 is completely different from that for Cheng's calcination.

238. Additionally, Petitioner does not recognize that after the calcination step in Cheng-Gan, the resultant carbon nanotube/lithium iron phosphate composite would cool to room temperature. During cooling, thermal contraction occurs. Due to the difference in the thermal expansion coefficient of carbon (created as a byproduct from the decomposition of the organic carbon source) compared to the CNTs, the CNTs are pulled closer and tighter together, so they are less dispersed, which helps form the "continuous" network of CNTs sought by Cheng. *Id.*

239. Petitioner fails to consider the differences in the thermal expansion coefficient (“TEC”) between **elemental carbon**, formed as a product of the decomposition of the organic carbon source, and the **CNTs**, in connection with Cheng’s calcination step and subsequent cooling. Thermal expansion occurs when the material of an object expands as it is heated and thermal contraction occurs when the material of an object contracts as it is cooled. The TEC is a measure of how the size of a material changes when it is heated or cooled. More specifically, the TEC relates to the amount that a material expands, corresponding to the fractional expansion of the material per degree change in temperature. The greater the TEC is for the material, the more it will expand per degree of temperature increase and the more it will contract per degree of temperature decrease.

240. A POSITA would understand that after Cheng’s calcination step at a minimum temperature of 600°C, which is a mandatory step to form its carbon nanotube/lithium iron phosphate composite cathode material, the composite cathode material will eventually cool from the calcination temperature to room temperature (e.g., about 18°C to about 24°C) for handling purposes. The composite cathode material comprises **elemental carbon** (created as a result of the decomposition of the organic carbon source during the calcination step) and **CNTs**. As mentioned before, the elemental carbon serves as a conductive binder and binds to the CNTs and the lithium iron phosphate to accomplish Cheng’s goal of achieving a

“continuously connected three-dimensional electrically conductive network” for its composite cathode material. LGES-1007, ¶[0010].

241. The elemental carbon (carbon binder) resulting from the calcination of the organic carbon source is noncrystalline, with a disordered structure (turbostratic carbon). In contrast, CNT has an ordered structure. As a result, the TEC of the elemental carbon is greater than (more positive than) the TEC of the CNTs. The TEC is (i) $-1.2 \times 10^{-5} \text{ K}^{-1}$ for MWCNT along its axis (Piat paper, i.e., MRD-2040, negative, as for graphite in the in-plane direction) and (ii) $+8 \times 10^{-5} \text{ K}^{-1}$ for pyrolytic carbon (Shirasu paper, i.e., MRD-2041, positive, the average of the values of $+7.5 \times 10^{-5} \text{ K}^{-1}$ and $+9.0 \times 10^{-5} \text{ K}^{-1}$, Fig. 4). The difference between these two values is large, with CNT contracting upon heating, i.e., expanding upon cooling, while the carbon binder (pyrolytic carbon) expands upon heating, i.e., contracting upon cooling. The axial elongation of the CNT upon cooling contributes to causing the contraction of the carbon binder (bonded to the CNT) in the direction transverse to the CNT axis (Poisson’s effect). This contribution is in addition to that due to the thermal contraction of the carbon binder during cooling.

242. The carbon binder binds the CNTs together at certain locations. As both carbon binder and CNTs cool down from the calcination temperature, this difference in the TEC of these two materials causes the CNTs (with the carbon binder bonded between them) to be pulled closer together, thereby making it more difficult for the

CNTs to become individualized, separate or distinct. This is a mechanism that contributes to the CNTs being drawn together, when Cheng-Gan's composite cathode material is cooled to room temperature. The drawing together would promote the interconnection of the CNTs so as to form the "continuous" conductive network sought by Cheng.

243. Since each of the Steps [1], [2], and [3] of Example 2 and Cheng-Gan are materially different, a POSITA would expect that the two final compositions would exhibit fundamentally different dispersion results of the carbon nanotubes. A POSITA would expect Cheng-Gan to result in a continuous network of CNTs, which is the result expressly sought by Cheng-Gan. Petitioner's assertion that Cheng-Gan and Example 2 would achieve the same "dispersion results"—simply because the respective steps are generally similar—is inconsistent with the understanding of a POSITA. To the contrary, both Cheng and Gan teach that they are trying to achieve the opposite of discrete CNTs—i.e., they desire to have a continuous network of CNTs. The claims, on the other hand, requires discrete CNTs.

244. Petitioner offers an "alternative" argument that "a POSITA would have understood or found obvious that the nanotubes in the combination composition are discrete because, at least in some instances, oxidation of nanotubes can help promote non-agglomeration of nanotubes." Pet., 54 (emphasis in original). In other words, Petitioner appears to be arguing that oxidation alone necessarily results in the CNTs

of Cheng-Gan being “discrete.” The only support offered by Petitioner for this assertion is the argument that oxidation can help “inhibit[] aggregation of nanotubes into clumps” via the functional groups added by the oxidation. Pet., 54. However, the cited evidence merely supports that oxidation can help disperse CNTs—not that it results in discrete CNTs. A POSITA would understand that CNTs can be uniformly dispersed throughout a composition to form a continuous network, without the CNTs necessarily being “discrete.” As such, Petitioner’s logic—that merely oxidizing CNTs means they are “generally present as individually distinct nanotubes”—is inconsistent with the understanding of a POSITA. Pet., 54. A POSITA would not understand the known “behavior of oxidized nanotubes” to necessarily results in discrete nanotubes. Pet., 54. Although oxidation can help improve dispersion, that does not automatically achieve “discrete” CNTs.

5. Whether Cheng and Gan teach away from the claimed invention

245. A POSITA would have understood that conventional wisdom at the time of the invention was that it was desirable to have a continuous or percolated network of CNTs, as demonstrated by Cheng and Gan. *Infra*, Section VIII.B. Specifically, Cheng sought a “continuously connected three-dimensional electrically conductive network” of CNTs both on and around the active material, whereas Gan explains that “the presence of such a continuous conductive path [as shown in Figure 5] through the composite is believed to be a reason why the electrical conductivity

of the conductive polymer material increases when CNTs are present.” LGES-1007 ¶[0005]; LGES-1021 ¶[0041].

246. I understand that a reference “teaches away” if it discourages from following the path set out in the reference, or a POSITA would be led in a direction divergent from the path that was taken by the applicant. Given that both Cheng and Gan seek a continuous or percolated network of CNTs to improve conductivity, a POSITA would understand that both references teach away from the claimed invention. This is because the claimed invention is directed toward “discrete carbon nanotubes,” which cannot form part of the “continuous” network of CNTs sought by Cheng and Gan. Indeed, Cheng and Gan want the CNTs to interconnect with one another (i.e., not be discrete), whereas the claimed invention explicitly wants CNTs to not interconnect (i.e., be discrete).

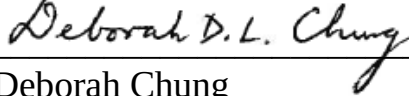
247. I also note that Gan teaches that while functionalization of the CNTs may achieve improved dispersibility, it also “draw[s] the CNTs closer together” and “provides a conductive bridge between CNTs to reduce the electrical contact resistance therebetween” LGES-1021 ¶¶[0020], [0022]. A POSITA would understand that drawing the CNTs “closer together” and forming a “conductive bridge” between CNTs is inconsistent with the ’924 patent’s goal of achieving “discrete” CNTs. LGES-1021 ¶¶[0020], [0022]. Therefore, a POSITA would be further discouraged from functionalizing CNTs as taught by Gan, because Gan

teaches that the functionalization would achieve results that would not yield discrete CNTs, but rather would result in a continuous network of interconnected CNTs.

XI. CONCLUSION

248. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code. I further declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Dated: March 31, 2025



Deborah Chung

APPENDIX A

CURRICULUM VITA

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http://en.wikipedia.org/wiki/Deborah_Chung

<https://www.amacad.org/person/deborah-chung>

<https://www.buffalo.edu/news/releases/2023/04/025.html>

<https://heritageproject.caltech.edu/interviews-updates/deborah-chung>

<http://engineering.buffalo.edu/mechanical-aerospace/people/faculty/d-chung.html>

<http://alum.mit.edu/www/ddlchung>

<https://scholar.google.com/citations?user=I1m7ZW8AAAAJ>

<https://www.youtube.com/watch?v=INZrNhDK9c>

https://www.youtube.com/watch?v=u_GGEbotQAM

<https://www.webofscience.com/wos/author/record/675681>

PROFESSIONAL INTEREST

Multidisciplinary research and teaching that are focused on materials science and engineering, particularly multifunctional structural materials (with functions including self-sensing, self-powering and vibration damping), electromagnetic shielding materials, and thermal interface materials (for microelectronic cooling). Other topics include three-dimensional printing, dielectric conductors and interface-derived viscoelasticity.

SCIENTIFIC IMPACT

- A. Pioneer and the foremost international leader in the field of multifunctional structural materials (without device incorporation), with the following specific contributions.
 1. Invention of smart (self-sensing) concrete and associated development of piezoresistivity-based strain sensing in cement-based and carbon fiber composites.
 2. Discovery of the function of the interlaminar interface in carbon fiber polymer-matrix composites as a sensor, thus enabling unprecedentedly high sensitivity to changes at this damage-prone interface.
 3. Development of the self-sensing in carbon fiber polymer-matrix composite beams under flexure by surface resistance measurement, with the strain at the tensile and compressive surfaces separately and sensitively determined, and with the piezoresistivity mechanism elucidated.
 4. Development of capacitance-based self-sensing, with applications including 3D-printing monitoring (with unprecedented ability of sensing interlayer defects in the build).
 5. Development of inductance-based self-sensing, with applications including fiber-tow twist-level sensing, strain sensing, damage sensing, and surface roughness sensing.
 6. First report of structural capacitors (i.e., capacitors in the form of structural materials).
 7. Pioneering the emerging field of high-permittivity electronic conductors, first determination of the electric permittivity of electronic conductors (carbons and metals), discovery of ferroelectricity in a metal, and discovery of the application in electret-based self-powering (with unprecedented self-charging capability), with the latter discovery allowing structures to be energy sources (a new untapped source of energy), and with elucidation of the dielectric behavior in terms of the carrier-atom interaction (carrier meaning the mobile charges) and polarization connectivity.
 8. Discovery of interface-derived viscoelasticity and the consequent unprecedented development of structural materials that are effective for vibration damping.
- B. Pioneer and the foremost international leader in the field of thermal interface materials for microelectronic cooling, with the following specific contributions.
 1. Changing the paradigm of the design of thermal interface materials from thermal-conductivity-based design to conformability-based design, thereby resulting in the development of superior but low-cost thermal interface materials that excel due to conformability.
 2. Development of unprecedentedly effective thermal pastes with conformable solid components.
- C. Pioneer and the foremost international leader in the field of materials for electromagnetic interference (EMI) shielding, with the following specific contributions.
 1. Changing the paradigm of the design of EMI shielding materials from electrical-conductivity-based design to interface-area-based design, thereby resulting in the development of an unprecedentedly effective EMI shielding material in the form of nickel-coated carbon nanofiber (originally known as nickel filament).
 2. Discovery of absorption-dominated EMI shielding in metals, the shielding of which has long been assumed to be dominated by reflection.

3. Discovery of unusually high EMI shielding effectiveness in exfoliated-graphite-based flexible graphite sheets, which are valuable for EMI gasketing.
4. Development of radio-wave reflective concrete and its application in automobile lateral guidance.

EXPERIENCE

UNIVERSITY AT BUFFALO, THE STATE UNIVERSITY OF NEW YORK, Buffalo, NY

*SUNY Distinguished Professor of Mechanical and Aerospace Engineering (2024-present)

*Professor of Mechanical and Aerospace Engineering (1986-2024)

*Founding Director, Composite Materials Research Laboratory, 1989-present

*Niagara Mohawk Power Corp. Endowed Chair Professor, 1991-2008

CARNEGIE-MELLON UNIVERSITY, Pittsburgh, PA

*Associate Professor of Metallurgical Engineering and Materials Science (1982-1986)

*Assistant Professor of Metallurgical Engineering and Materials Science and Electrical Engineering (1977-1982)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, MA (1974-77)

*Visiting Scientist at the Francis Bitter National Magnet Laboratory - Research on graphite intercalation compounds under the supervision of Professor M.S. Dresselhaus

CALIFORNIA INSTITUTE OF TECHNOLOGY, Pasadena, CA (1971-73)

Research on superconducting alloys and amorphous materials under the supervision of Professor Pol E. Duwez

EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, MA

Ph.D. Degree in Materials Science, 1977

Thesis on "The Electronic, Lattice and Structural Properties of Graphite Intercalation Compounds" under the supervision of Professor M.S. Dresselhaus

S.M. Degree in Materials Science, 1975

Thesis on "Optical Studies of Graphite Intercalated with Bromine" under the supervision of Professor M.S. Dresselhaus

CALIFORNIA INSTITUTE OF TECHNOLOGY, Pasadena, CA

M.S. Degree in Engineering Science, 1973

B.S. Degree in Engineering and Applied Science, 1973

HONORS

PAIR Distinguished Lecturer, Hong Kong Polytechnic University, Hong Kong, Dec. 17, 2024.

Certificate of Special Congressional Recognition, in recognition of receiving the University at Buffalo President's Medal, U.S. Congress, May 2024.

President's Medal, University at Buffalo, The State University of New York, 2024.

Member, American Academy of Arts and Sciences, elected in 2023.

Ranked 1st (among 49,100 researchers) in the world in the field of carbon fibers (scholargps.com, 2022)

Ranked 1st (among 12,770 researchers) in the world in the field of electromagnetic interference (scholargps.com, 2022)

Ranked 16th (among 570,007 researchers) in the world in the field of mechanical engineering (scholargps.com, 2022)

Ranked 110th (among 4,146,930 researchers) in the world in the field of engineering and computer science (scholargps.com, 2022)

https://scholargps.com/search.php?q=d.d.l.+chung&type=profile&specialty%5B0%5D=Carbon+Fibers&scholar=D.D.L.+Chung&scholar_ranks=true&scholar=D.D.L.%20Chung&first_name=D.D.L.&middle_name=&last_name=Chung

Feature article "Materials for electromagnetic interference shielding" by Chung and published in Materials Chemistry and Physics is the third most cited Materials Chemistry and Physics article in the last two years (2020-2022).

Inaugural speaker, Professor Millie Dresselhaus Memorial Lecture, MIT, 2022.

Ranked 1st in the world in the field of Building and Construction (Stanford University study, 2021)

Ranked 1st among all researchers in University at Buffalo (living/deceased, all fields combined) (Stanford University study, every year since its inception in 2018)

Ranked 13th among 315,721 materials researchers in the world (living and deceased), 10th among those that are living, and 1st among those who are female (Stanford University study, 2022).

Lan Wong and Deborah Chung Center for Science and Arts, Christian Central Academy, Williamsville, NY, building dedication in 2021.

Drs. Lan Wong and Deborah Chung Analytical Chemistry Laboratory, California State University, Northridge, laboratory dedication in 2021.

Drs. Lan Wong and Deborah Chung Distinguished Lecture Series on the Path to Professional Success, California State University, Northridge, initiated in 2021.

Drs. Lan Wong and Deborah Chung Lecture Series honoring the late Prof. M.S. Dresselhaus and the late Prof. K. Biemann, School of Science, MIT, initiated in 2021.

Drs. Lan Wong and Deborah Chung Graduate Student Scholarship Fund, School of Science, MIT, initiated in 2021.
 Honoree, 4th UKIERI Concrete Congress, India, March 5-8, 2019.
 Top Peer Reviewer 2019. For placing in the top 1% of reviewers in Materials Science on Publons global reviewer database. Also for placing in the top 1% of reviewers in Cross-Field on Publons global reviewer database.
 Albert Nelson Marquis Lifetime Achievement Award, Marquis Who's Who, 2018.
 The 2018 Publons's Global Peer Review Awards for being placed in the top 1% of peer reviewers in Materials Science (ranked 5th in the world) and for being placed in the top 1% of peer reviewers in Chemistry. These awards are based on the number of reviews of manuscripts submitted to various journals for consideration of publication.
 Honoree, one of the three first alumnae of Caltech, 2018 (45th anniversary of graduation)
 Pu-Woei Chen and D.D.L. Chung, "Carbon Fiber Reinforced Concrete as a Smart Material Capable of Non-Destructive Flaw Detection", *Smart Mater. Struct.* 2(1), 22-30 (1993). This paper is one of the 25 most cited papers in the 25-year history of the journal *Smart Materials and Structures*, 2017.
 Paper with M. Sharma honored as Editors' Choice in *Journal of Electronic Materials*, 2015.
 U.S. Faculty Scholar, Vietnam Education Foundation, 2013-14.
 Visiting Professor, Hefei University of Technology, Hefei, P.R. China, appointed in 2013.
 One of the top ten best cited papers in *Composites B* in all times past, honored in 2012.
 Honorary Doctorate Degree, University of Alicante, Alicante, Spain, 2011.
 Guest Professor, Tongji University, Shanghai, P.R. China, appointed in 2010.
 Top Reviewer in 2008, an international award in relation to the journal *Carbon*, Elsevier Pub., 2009.
 Special Recognition Award, The American Carbon Society, 2007.
 Hsun Lee Award, jointly awarded by Institute of Metal Research (Chinese Academy of Sciences) and Shenyang National Laboratory for Materials Science, to recognize research accomplishment in materials science and technology, 2005.
 Invited Professor, Tianjin University, Tianjin, P.R. China, appointed in 2005.
 Visiting Professor, Jinan University, Jinan, P.R. China, appointed in 2005.
 Charles E. Pettinos Award, a triennial international award to recognize one person or one group for outstanding research accomplishments in carbon science and technology, The American Carbon Society, 2004.
 Chancellor's Award for Excellence in Scholarship and Creative Activities, Academic Year 2002-2003, The State University of New York.
 Outstanding Inventor, State University of New York, 2002.
 Visiting Professor, Wuhan University of Technology, Wuhan, P.R. China, appointed in 2002.
 Visiting Professor, Southeast University, Nanjing, P.R. China, appointed in 2002.
 Visiting Professor, Beijing Technology and Business University, Beijing, P.R. China, appointed in 2002.
 Fellow, American Carbon Society, conferred in 2001.
 Honorary Professor, Shantou University, Shantou, Guangdong, P.R. China, appointed in 2000.
 Fellow, ASM International, conferred in 1998.
 Advisory Professor, Harbin Institute of Technology, Harbin, P.R. China, appointed in 1995.
 "Teacher of the Year", 1992-93, awarded by Tau Beta Pi (New York Nu).
 Ralph R. Teetor Educational Award, Society of Automotive Engineers, 1987, for being one of the top engineering educators in the U.S.
 Robert Lansing Hardy Gold Medal for the most promising metallurgist in the U.S. in 1980, American Institute of Mining, Metallurgical, and Petroleum Engineers
 One of the four first woman graduates of California Institute of Technology, 1973
 First woman engineering graduate of California Institute of Technology, 1973
 Josephine de Karman Fellowship (1972-73) for graduate and senior undergraduate students of exceptional ability

MEMBERSHIPS

Fellow, American Academy of Arts and Sciences, elected in 2023.
 Fellow, American Carbon Society, 2001-present; Member, 1979-present; Advisory Board member, 1999-2005;
 Member, American Ceramic Society, 1989-1990, 1994, 2018-.
 Member, American Concrete Institute, 1989-1990, 1994-1996.
 Member, American Society of Mechanical Engineers, 2014-18.
 Fellow, ASM International (formerly known as the American Society for Metals, a professional organization for materials scientists and engineers), 1998-present; Member, 1986-present; Director of Buffalo Chapter, 1987-1994; Member of Superconductor Materials Committee, 1989-1993.
 Member, Materials Research Society, 1981-2017.
 Member, Society for the Advancement of Material and Process Engineering, 2007-2014.
 Member, Society of Automotive Engineers, 1987-1989
 Member, The Minerals, Metals & Materials Society (TMS), 1977-present. Executive Committee Member of the Three-Rivers Section of TMS-AIME, 1986. Member of the Membership Development Committee (national) of TMS-AIME, 1986-1988.

OTHER PROFESSIONAL ACTIVITIES

- * Invited Specialist of United Nations Development Program to assist the technical development of the People's Republic of China, July 16 - August 5, 1986.
- * Member, Committee on Materials for High Density Electronic Packaging, National Materials Advisory Board, Commission on Engineering and Technical Systems, National Research Council, 1987-1990.
- * Member, Panel for selection of Presidential Young Investigators, Division of Materials Research, National Science Foundation, November 23, 24, 1987.
- * Chairman, Symposium on Carbon Fibers and Composites, sponsored by American Carbon Society, Buffalo, NY, July 18-21, 1988.
- * Symposium Organizer, Symposium on Mechanical Behavior of Electronic Materials and Structures in Microelectronics, Material Research Society Meeting, Anaheim, April 1991.
- * Conference Chairman, Conference on Materials for Electronic Packaging, SUNY/ Buffalo, August 20-22, 1991.
- * Conference Chairman, 21st Biennial Conference on Carbon, sponsored by American Carbon Society, SUNY/ Buffalo, June 13-18, 1993.
- * Consultant to National Power PLC, UK, 1995-96.
- * Member, Proposal Review Panels, National Science Foundation, November 1997-present.
- * Topical Area Chairman, 23rd Biennial Conference on Carbon, sponsored by American Carbon Society, Pennsylvania State University, July 13-18, 1997.
- * Technical Co-Chair and Member of International Advisory Board, 5th International Conference on Composites Engineering, Las Vegas, NV, July 5-11, 1998.
- * Member, Advisory Board, American Carbon Society, 1999-2006.
- * Topical Area Chairman, 24th Biennial Conference on Carbon, sponsored by American Carbon Society, Charleston, SC, July 11-16, 1999
- * Member, International Editorial Board, New Carbon Materials, 1999- present
- * Member, Honorary Editorial Advisory Board, Carbon, 2001-present.
- * Member, Advisory Board, Carbon Letters (formerly Carbon Science) (Korea), 2007-present.
- * Member, International Editorial Board, Polymers & Polymer Composites, 2001-present.
- * External Reviewer for Research Grants Council, Hong Kong, 2001-present.
- * Member, International Advisory Committee, 2002 International Conference on Carbon, Beijing, China, Sept. 15-20, 2002.
- * Member, Local Scientific Committee, 14th International Conference on Composite Materials, San Diego, July 14-18, 2003.
- * Topical Area Chairman, Carbon 2004 International Conference, Providence, RI, July 11-16, 2004.
- * Editor, Book Series on *The Road to Scientific Success: Life Experience of Prominent Researchers*, World Sci. Pub., 2004-.
- * Editor, Book Series on *Engineering Materials for Technological Needs*, World Sci. Pub., 2005-.
- * External Reviewer for State Natural Science Award, China, 2006.
- * Nominator, Kyoto Prize, Inamori Foundation, Kyoto, Japan, 2007, 2011 and 2015.
- * Associate Editor, Journal of Electronic Materials, 2008-.
- * Associate Editor, Polymers and Polymer Composites, 2008-2019
- * Reviewer for National Priorities Research Program, Qatar National Research Fund, 2009-.
- * Member, International Advisory Committee, World Conference on Carbon, Biarritz, France, June 14-19, 2009, organized by the French Carbon Group (GFEC).
- * Reviewer for King Abdulaziz City for Science and Technology, Saudi Arabia, 2009-.
- * Member, International Advisory Committee, World Conference on Carbon, Shanghai, China, July 24-29, 2011.
- * Member, International Experts Committee, new Doctorate Program on "Engineering of Materials, Structures and Terrain: Sustainable Construction", Department of Civil Engineering, University of Alicante, Alicante, Spain, 2012-13.
- * Member, Advisory Committee, School of Engineering, Hong Kong University of Science and Technology, Hong Kong, 2013.
- * Reviewer for National Centre of Science and Technology, Kazakhstan, 2014-
- * Reviewer for Office of Science, DOE, 2014-
- * Reviewer of Applications for Establishment of the Hong Kong Branches of Chinese National Engineering Research Centres, 2014.
- * Editor-in-Chief, Composite Materials section of SpringerMaterials, 1/2015 - 12/2016.
- * Member, Editorial Board, Functional Composite Materials (journal), Springer Nature (2017-2025); Journal of Materials Science: Composites (rebranded, 2025-).
- * Proposal reviewer, U.S. – Israel Binational Science Foundation, 2017.
- * Member, Panel on Review of In-house Laboratory Independent Research in Materials Sciences at the Army's Research, Development, and Engineering Centers, The National Academies, 2018-19.
- * Member, Advisory Committee, Carbon 2019 International Conference, Kentucky, July 2019.
- * Member, International Advisory Committee, Carbon 2020 International Conference, Kyoto, Japan, June 28 – July 3,

2020.

* Member, Advisory Board, Materials Chemistry and Physics (journal), Elsevier (2020-).

* Member, International Advisory Board, 2022 World Conference on Carbon, July 3-8, 2022, London, UK.

* Member, Editorial Board, World Scientific Annual Review of Functional Materials (journal), World Sci. Pub. (2022-).

* Member, Scientific Committee on the topic Carbon fibers and composites, The World Conference on Carbon 2023, Cancun, Riviera Maya, Mexico, July 16-21, 2023.

* Guest Editor, Special Issue on Carbon Films in memory of Professor Millie Dresselhaus, Materials Chemistry and Physics (2022-).

*Member, International Editorial Board, Composites Science and Technology (2024-).

BOOKS

Authored books

1. Kenji Uchino, D.D.L. Chung and R.E. Newnham, *JME Materials Science: Introduction to Electrical Properties for Ceramists* (JME Zairyo Kagaku: Seramisuto no tame no Denki Bussei Nyumon), Uchida Rokakuho Publishing Co., Ltd., Tokyo, Japan, 1990, 156 pp. Book written in Japanese. Translated from English.
2. D.D.L. Chung, P.W. DeHaven, H. Arnold and D. Ghosh, *X-Ray Diffraction at Elevated Temperatures*, VCH Publishers, 1993.
3. D.D.L. Chung, *Carbon Fiber Composites*, 1st Ed., Butterworth-Heinemann, 1994; *Carbon Composites: Composites with Carbon Fibers, Nanofibers and Nanotubes*, 2nd Ed., Elsevier, 2017, 706 pages.
4. D.D.L. Chung, *Composite Materials for Electronic Functions*, Materials Science Foundations, Vol. 12, i-iii, 1-77, Trans Tech Publications Ltd., Switzerland, 2000.
5. D.D.L. Chung, *Applied Materials Science*, CRC Press, 2001.
6. D.D.L. Chung, *Composite Materials: Functional Materials for Modern Technologies*, 1st Ed., "Engineering Materials and Processes" Book Series, Brian Derby, Series Editor, Springer, 2003; *Composite Materials: Science and Applications*, 2nd Ed., Springer, 2010.
7. D.D.L. Chung, *Multifunctional Cement-Based Materials*, *Civil and Environmental Engineering* Book Series, Mike Meyer, Series Editor, Marcel Dekker, 2003.
8. D.D.L. Chung, Book series titled *Engineering Materials for Technological Needs*, Vol. 2, *Functional Materials: Electrical, Dielectric, Electromagnetic, Optical and Magnetic Applications*, World Scientific, 2010; Vol. 4, 2nd Ed., 552 pages, 2021.
9. Rebecca Chan Chung, D.D.L. Chung, Cecilia Ng Wong, *Piloted to Serve*, Deborah Chung, 2012; Enhanced Edition, 2020.
10. D.D.L. Chung, Book series titled *Engineering Materials for Technological Needs*, Vol. 3, *Carbon Materials: Science and Applications*, World Scientific, 2019, 382 pages.

Edited books

1. Ephraim Suhir, Robert C. Cammarata, D.D.L. Chung and Masahiro Jeno, *Materials Research Society Symposium Proceedings*, Vol. 226 (Mechanical Behavior of Materials and Structures in Microelectronics), Symposium held April 30 – May 3, 1991, Anaheim, CA, Materials Research Society, Pittsburgh, PA, 1991.
2. D.D.L. Chung and E.A. Heintz, *Extended Abstracts*, 21st Biennial Conference on Carbon, American Carbon Society, 1993.
2. D.D.L. Chung, *Materials for Electronic Packaging*, Butterworth-Heinemann, Boston, MA, 1995.
3. D.D.L. Chung, Book Series titled *The Road to Scientific Success: Inspiring Life Stories of Prominent Researchers*, World Scientific Pub., Singapore, Vol. 1, 2006; Vol. 2, 2014; Vol. 3, 2023.
4. D.D.L. Chung, Book Series titled *Engineering Materials for Technological Needs*, World Scientific Pub., Singapore, 2005-. Vol. 1: *High Performance Construction Materials*, Caijun Shi and Y. L. Mo (eds.), World Scientific Pub., Singapore, 2008. Chinese translation, Chongqing University Press, China, 2011.

PATENTS (issued)

1. D.D.L. Chung, "Low-Density Graphite-Polymer Electrical Conductors", U.S. Patent 4,704,231 (1987).
2. D.D.L. Chung, "Composites of In-Situ Exfoliated Graphite", U.S. Patent 4,946,892 (1990), Canadian Patent 1,330,609 (1994).
3. D.D.L. Chung, "Exfoliated Graphite Fibers and Associated Method", U.S. Patent 4,915,925 (1990).
4. D.D.L. Chung, "Carbon Fiber Reinforced Cement Concrete Composites Improved by Using Chemical Agents", U.S. Patent 5,032,181 (1991).
5. D.D.L. Chung, "Superconductor-Metal Laminates and Method of Making", U.S. Patent 5,059,582 (1991).
6. D.D.L. Chung, "Carbon Fiber Composites with Improved Fatigue Resistance", U.S. Patent 5,091,242 (1992).
7. D.D.L. Chung, "Carbon Fiber Reinforced Tin Alloy as a Low Thermal Expansion Solder Preform", U.S. Patent 5,089,356 (1992).
8. D.D.L. Chung, "Phosphate Binders for Metal-Matrix Composites", U.S. Patent 5,536,686 (1996); European patent application WO 9409169 (1994).

9. Yi-Han Kao, Liwei Song, D.D.L.Chung and Kevin T. Fredette, "Halogen Doped Superconductive Fullerenes", U.S. Patent 5,380,703 (1995).
10. Yi-Han Kao, Liwei Song, D.D.L. Chung, and Kevin T. Fredette, "Inter-Halogen-Doped Superconductive Fullerenes," U.S. Patent 5,561,102 (1996).
11. D.D.L. Chung and Xiaoping Shui, "Metal Filaments for Electromagnetic Interference Shielding", U.S. Patent 5,827,997 (1998).
12. D.D.L. Chung, "Particulate Carbon Complex," U.S. Patent 5,643,670 (1997).
13. D.D.L. Chung and Weiming Lu, "Mesoporous Activated Carbon," U.S. Patent 5,990,041 (1999).
14. D.D.L. Chung, "Methods and Sensors for Detecting Strain and Stress," U.S. Patent 6,079,277 (2000).
15. D.D.L. Chung, "Composite Material Strain/Stress Sensor," U.S. Patent 5,817,944 (1998).
16. D.D.L. Chung, "Conformable Interface Materials for Improving Thermal Contacts", U.S. Patent 7,535,715 (2009); Chinese Patent CN 101416304 B (2011).
17. D.D.L. Chung and Chuangang Lin, "High-Performance Interface Materials for Improving Thermal Contacts", U.S. Patent 8,013,024 (2011).
18. D.D.L. Chung and Sivaraja Muthusamy, "Cement-Graphite Composite Materials for Vibration Damping", U.S. Patent 8,211,227 (2012).
19. D.D.L. Chung and Xiaoqing Gao, "Microstructured high-temperature hybrid material, its composite material and method of making", U.S. Patent 9409823 (issued on Aug. 9, 2016).
20. D.D.L. Chung, "Thixotropic liquid-metal-based fluid and its use in making metal-based structures with or without a mold", U.S. Patent 9993996 B2 (June 12, 2018); China Patent CN 105458254A (April 6, 2016).
21. D.D.L. Chung, "Systems and method for monitoring three-dimensional printing", U.S. Patent 10449721 (Oct. 22, 2019).
22. D.D.L. Chung, "Cement-based material systems and method for self-sensing and weighing", U.S. Patent 10,620,062 B2 (April 14, 2020).
23. D.D.L. Chung, "Electrically conductive electret and associated electret-based power source and self-powered structure", U.S. Patent 11081285 (Aug. 3, 2021).

BOOK CHAPTERS

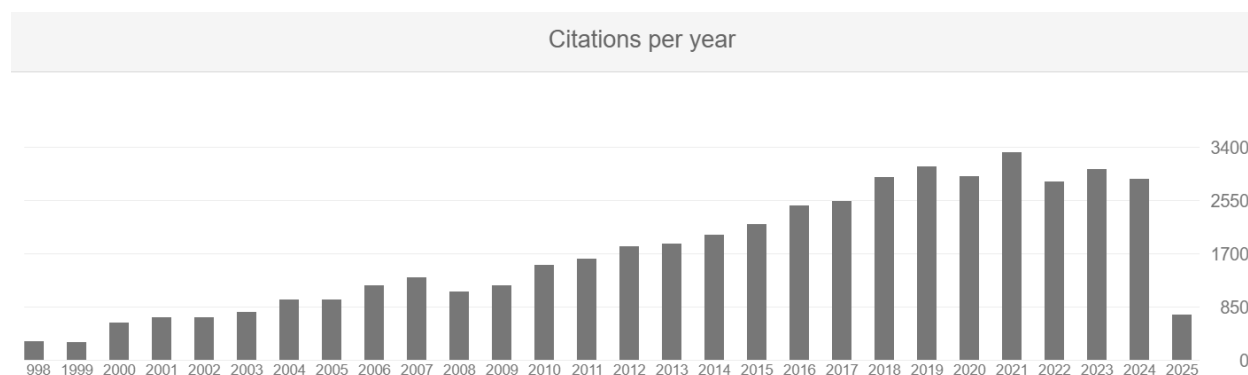
1. D.D.L. Chung, "Overview of Materials for Electronic Packaging", *Materials for Electronic Packaging*, D.D.L. Chung (Ed.), Butterworth-Heinemann, Boston, MA, 1995, p. 3-39.
2. D.D.L. Chung, "Low Thermal Expansion Composite Materials for Electronic Packaging", *Materials for Electronic Packaging*, D.D.L. Chung (Ed.), Butterworth-Heinemann, Boston, MA, 1995, p. 145-152.
3. D.D.L. Chung, "Conducting Polymer-Matrix Composites", *Materials for Electronic Packaging*, D.D.L. Chung (Ed.), Butterworth-Heinemann, Boston, MA, 1995, p. 153-171.
4. Darold C. Wobschall and D.D.L. Chung, "Ohmmeters", *The Encyclopedia of Electrical and Electronics Engineering*, Vol. 15, pp. 122-123, Wiley, 1999.
5. D.D.L. Chung, "X-Ray Diffraction for Structure Determination", *Encyclopedia of Analytical Chemistry*, R.A. Meyers (Ed.), Wiley, Chichester, UK, 2000, Vol. 15, p. 13347-13384.
6. D.D.L. Chung and C. Zweben, "Composites for Electronic Packaging and Thermal Management", *Comprehensive Composite Materials*, Vol. 6, Pergamon, 2000, p. 701-725.
7. D.D.L. Chung, "Graphite Intercalation Compounds", *Encyclopedia of Materials: Science and Technology*. K.H.J. Buschow, R.W. Cahn, M.C. Flemings, B. Ilshner, E.J. Kramer and S. Mahajan (eds.), Elsevier, Oxford, Vol. 4, p. 3641-3645 (2001).
8. D.D.L. Chung, "Applications of Submicron Diameter Carbon Filaments", *Proc. NATO Advanced Study Institute, NATO Science Series, Series E: Applied Sciences - Vol. 372 (Carbon Filaments and Nanotubes: Common Origins, Differing Applications?, Laszlo P. Biro (Ed.))*, Kluwer Academic Publishers, Dordrecht, 2001, p. 275-288; also in *Nanostructured Carbon for Advanced Applications*, G. Benedek et al. (Ed.), Kluwer, Netherlands, 2001, p. 331-345.
9. Shoukai Wang, Sihai Wen, Victor H. Guerrero and D.D.L. Chung, "Thermoelectric Structural Composites and Thermocouples Using Them" *Materials Research Society Symposium Proceedings*, Volume 691, Issue Thermoelectric Materials 2001: Research and Applications, Materials Research Society, 2002, pp. 177-182.
10. D.D.L. Chung, "Composites, Intrinsically Smart Structures", *Encyclopedia of Smart Materials*, ed. Mel Schwartz, Wiley, 2002, Vol. 1, p. 223-243.
11. D.D.L. Chung, "Carbon-Cement Composites", *World of Carbon 2 (Fibers and Composites)*, Pierre Delhaes (Ed.), Taylor & Francis, 2003, p. 219-241.
12. D.D.L. Chung, "Functional Composite Materials", *Advances in Condensed Matter and Materials Research*, Ed. Francois Gerard, Nova Science Pub., Hauppauge, NY, 2003, p. 89-147.
13. Sihai Wen and D.D.L. Chung, "Fiber Reinforced Cement for Piezoelectricity and Pyroelectricity", ACI Special Publication SP-216, *Innovations in Fiber-Reinforced Concrete for Value*, Ed. N. Banthia, M. Criswell, P. Tatnall and K. Folliard, American Concrete Institute, Farmington Hills, MI, 2003, p. 115-128.
14. D.D.L. Chung, "Multifunctional Polymer-Matrix Structural Composites", Annual Technical Conference - Society of Plastics Engineers, Volume 62nd, Issue Vol. 2, Society of Plastics Engineers, 2004, pp.1410-1414.
15. D.D.L. Chung, "Composite Materials", *Kirk-Othmer Encyclopedia of Chemical Technology*, 5th Ed., Wiley, 2004.

16. D.D.L. Chung, "Composite Materials", *Kirk-Othmer Concise Encyclopedia of Chemical Technology*, 5th Ed., Wiley, 2007.
17. D.D.L. Chung, G. Song, N. Ma and H. Gu, "Smart Materials and Structures", *High Performance Construction Materials*, Caijun Shi and Y. L. Mo (eds.), Vol. 1 of Book Series "Engineering Materials for Technological Needs", World Scientific Pub., Singapore, 2008. Chinese translation, Chongqing University Press, China, 2011.
18. D.D.L. Chung, "Sensors in Composites", *Wiley Encyclopedia of Composites*, 2nd Ed., edited by Luigi Nicolais, Assunta Borzacchiello and Stuart M. Lee. Wiley-Interscience, 2014.
19. D.D.L. Chung, "Composite Materials", *Kirk-Othmer Encyclopedia of Chemical Technology*, 6th Ed., Wiley, 2016.
20. D.D.L. Chung, "Graphite Intercalation Compounds", *The Reference Module in Materials Science and Engineering*, Saleem Hashmi, Editor, Elsevier, 2016.
21. D.D.L. Chung, "Self-Sensing Structural Composites in Aerospace Engineering", *Advanced composite materials for aerospace engineering: processing, properties and applications*, Sohel Rana and Raul Fanguero, Editors, Woodhead Pub., Elsevier, 2016, Ch. 10, p. 295-331.
22. D.D.L. Chung, "Carbon Fibers", *ASM Handbook*, Volume 21, 2016.
23. D.D.L. Chung, in, *Successful Women Ceramic and Glass Scientists and Engineers: 100 Inspirational Profiles*, L.D. Madsen, Wiley, 2016, ISBN: 978-1-118-73360-8.
24. D.D.L. Chung, "Carbon-Matrix Composites", *Encyclopedia of Materials: Technical Ceramics and Glasses*, Elsevier, 2020.
25. D.D.L. Chung, "Sensing Materials: Self-Sensing Materials", *Encyclopedia of Sensors and Biosensors*, Elsevier, 2023, p. 196-203.

ARCHIVAL PEER-REVIEWED INTERNATIONAL JOURNAL PAPERS

Google Scholar: h-index = 115, 49,718 citations, annual citations reaching 3,317 (as viewed on Mar. 30, 2025).

The number of citations for each year over the years is shown in the chart below, as obtained from Google Scholar.



633 archival peer-reviewed international journal papers categorized by material type are listed below. Only published peer-reviewed journal papers are listed.

CARBON (175 journal papers)

1. D.D.L. Chung and M.S. Dresselhaus, "Magnetoreflexion Study of Graphite Intercalated with Bromine," *Solid State Comm.* 19, 227 (1976).
2. D.A. Platts, D.D.L. Chung and M.S. Dresselhaus, "Far-Infrared Magnetoreflexion Studies of Graphite Intercalated with Bromine," *Phys. Rev.* B15, 1087 (1977).
3. D.D.L. Chung and M.S. Dresselhaus, "Magneto-Optical Studies of Graphite Intercalation Compounds," (invited paper), *Physica* 89B, 131 (1977).
4. J.J. Song, D.D.L. Chung, P.C. Eklund and M.S. Dresselhaus, "Raman Scattering in Graphite Intercalation Compounds," *Solid State Comm.* 20, 1111 (1976).
5. D.D.L. Chung, G. Dresselhaus and M.S. Dresselhaus, "Intralayer Crystal Structure and Order-Disorder Transformations of Graphite Intercalation Compounds," *Mater. Sci. Eng.* 31, 107 (1977).
6. M.S. Dresselhaus, G. Dresselhaus, P.C. Eklund and D.D.L. Chung, "Lattice Vibrations in Graphite and Intercalation Compounds of Graphite," *Mater. Sci. Eng.* 31, 141 (1977).
7. D.D.L. Chung, "Structural Studies of Graphite Intercalation Compounds," *J. Electron. Mat.* 7, 89 (1978).
8. J.S. Culik and D.D.L. Chung, "Calorimetric Study of the Order-Disorder Transformations in Graphite-Halogens," *Mater. Sci. Eng.* 37, 213 (1979).

9. D.D.L. Chung, "Nomenclature of Graphite Intercalation Compounds," Mater. Sci. Eng. 39, 283 (1979).
10. D.D.L. Chung, "Graphite-Halogens As Temperature Calibration Standards for Transmission Electron Microscopy," Rev. Sci. Instrum. 51, 932 (1980).
11. J.S. Culik and D.D.L. Chung, "Thermal Gravimetric Analysis of Graphite-Bromine," Mater. Sci. Eng. 44, 129 (1980).
12. K.K. Bardhan and D.D.L. Chung, "A Kinetic Model of the First Intercalation of Graphite," Carbon 18, 303 (1980).
13. K.K. Bardhan and D.D.L. Chung, "Surface Profilometric Study of the Kinetics of the Intercalation of Graphite," Carbon 18, 313 (1980).
14. K.K. Bardhan, J.C. Wu and D.D.L. Chung, "Phase Transitions in Graphite-Halogens," Synth. Met. 2, 109 (1980).
15. K.K. Bardhan, J.C. Wu, J.S. Culik, S.H. Anderson and D.D.L. Chung, "Kinetics of Intercalation and Desorption in Graphite," Synth. Met. 2, 57 (1980).
16. D.D.L. Chung "Exfoliation of Graphite," Therm. Expans., [Proc. Int. Therm. Expans. Symp.], 7th 1979 (Pub. 1982), 37-44. Edited by D.C. Larsen. Plenum: New York, NY.
17. D. Ghosh and D.D.L. Chung, "Electron Diffraction Evidence of Domain Twinning in Graphite-Bromine Single Crystals," Mater. Res. Bull. 18 (16), 727-33 (1983).
18. S.H. Anderson and D.D.L. Chung, "Thermodynamics of Intercalation of Bromine in Graphite," Mater. Res. Soc. Symp. Proc. 20 (Intercalated Graphite), 271-6 (1983).
19. S.H. Anderson and D.D.L. Chung, "Exfoliation of Single Crystal Graphite and Graphite Fibers Intercalated with Halogens," Synth. Met. 8, 343-9 (1983).
20. D. Ghosh and D.D.L. Chung, "Effect of Intercalate Desorption on the Two-Dimensional Structure of Graphite-Bromine," Synth. Met. 7, 283-8 (1983).
21. D. Ghosh and D.D.L. Chung, "Two-Dimensional Structure of Bromine Intercalated Graphite," Mater. Res. Bull. 18 (10), 1179-89 (1983).
22. S.H. Anderson and D.D.L. Chung, "Exfoliation of Intercalated Graphite," Carbon 22 (3), 253-63 (1984).
23. S.H. Anderson and D.D.L. Chung, "Intercalate Displacement and Exchange in Graphite," Synth. Met. 7, 107-15 (1983).
24. J.S. Culik and D.D.L. Chung, "Calorimetric Study of the Rate of the 277 K Phase Transition in Graphite-Bromine," Carbon 22 (1), 102-3 (1984).
25. D. Ghosh and D.D.L. Chung, "Synchrotron X-Ray Diffraction Study of the Room Temperature Incommensurate Phase in Graphite-Bromine Intercalation Compound," J. Phys. Lett. 44 (18), 761-9 (1983).
26. D. Ghosh, R. Gangwar and D.D.L. Chung, "Superlattice Ordering in Graphite-ICI Single Crystals and Fibers," Carbon 22 (3), 225-33 (1984).
27. S.H. Anderson and D.D.L. Chung, "Graphite Ribbons Formed From Graphite Fibers," Carbon 22 (6), 613-4 (1984).
28. Edward Beam III, D. Ghosh and D.D.L. Chung, "Calorimetric Study of the Phase Transitions in Graphite Intercalated with Iodine Monochloride," Mater. Lett. 2 (6A&B), 515-8 (1984).
29. J.S. Culik and D.D.L. Chung, "Calorimetric Evidence for Two-Step Melting in Graphite-Bromine," Carbon 23 (4), 459-60 (1985).
30. D. Ghosh and D.D.L. Chung, "Synchrotron X-ray Diffraction Study of the Incommensurate Graphite-Bromine Compound: Change in the c-axis Repeat Distance During the Incommensurate-Commensurate Transition," Mater. Lett. 3 (4), 161-4 (1985).
31. D.D.L. Chung, "Structure and Phase Transitions of Graphite Intercalated with Bromine," Phase Transitions 8, 35-57 (1986).
32. D.D.L. Chung and Lan W. Wong "Effect of Exfoliation on the Electrical Resistivity of Intercalated Graphite," Synth. Met. 12, 533-538 (1985).
33. D.D.L. Chung and C.G. Woychik, "Searching the Evidence for the Intercalation of Coal," Fuel 66, 799-802 (1987).
34. D.D.L. Chung and Lan W. Wong, "Dependence of the Electrical Resistance of Intercalated Graphite Fibers on Electric Power," Carbon 24(4), 443-445 (1986).
35. D.D.L. Chung and Lan W. Wong, "Electromechanical Behavior of Graphite Intercalated with Bromine," Carbon 24(5), 639-647 (1986).
36. J.L. Feldman, W.T. Elam, A.C. Ehrlich, E.F. Skelton, D.D. Dominguez, D.D.L. Chung and F.W. Lytle, "Polarized X-ray Absorption Studies of Graphite Intercalated Bromine Compounds," Phys. Rev. B 33(12), 7961-7982 (1986).
37. S.H. Anderson Axdal and D.D.L. Chung, "A Theory for the Kinetics of Intercalation of Graphite," Carbon 25(3), 377-389 (1987).
38. S.H. Anderson Axdal and D.D.L. Chung, "Kinetics and Thermodynamics of Intercalation of Bromine in Graphite: I. Experimental," Carbon 25(2), 191-210 (1987).
39. S.H. Anderson Axdal and D.D.L. Chung, "Kinetics and Thermodynamics of Intercalation of Bromine in Graphite: II. Theory," Carbon 25(2), 211-218 (1987).
40. D.D.L. Chung, "Intercalate Vaporization During the Exfoliation of Graphite Intercalated with Bromine," Carbon 25(3), 361-365 (1987).
41. D.D.L. Chung and Lan W. Wong, "Measurement of Thermal Stress in Graphite Intercalated with Bromine," Int. J. Thermophysics 9(2), 279-282 (1988).
42. D.D.L. Chung, "Exfoliation of Graphite," J. Mater. Sci. 22(12), 4190-98 (1987).
43. Jeng-Maw Chiou, C.T. Ho and D.D.L. Chung, "Effect of Bromination on the Oxidation Resistance of Pitch-Based

- Carbon Fibers", Carbon 27(2), 227-231 (1989).
44. C.T. Ho and D.D.L. Chung, "Structure of Brominated Thornel P-100 Carbon Fibers", Carbon 27, 603-609 (1989).
 45. M.S.A. Baksh, R.T. Yang and D.D.L. Chung, "Composite Sorbents by Chemical Vapor Deposition on Activated Carbon", Carbon 27(6), 931-934 (1989).
 46. C.T. Ho and D.D.L. Chung, "Carbon Fibers Brominated by Electrochemical Intercalation", Carbon 28, 521 (1990).
 47. C.T. Ho and D.D.L. Chung, "Inhibition of the Oxidation of Carbon-Carbon Composites by Bromination", Carbon 28(6), 815-824 (1990).
 48. C.T. Ho and D.D.L. Chung, "Bromination of Graphitic Pitch-Based Carbon Fibers", Carbon 28(6), 831-837 (1990).
 49. C.T. Ho and D.D.L. Chung, "Kinetics of Intercalate Desorption from Carbon Fibers Intercalated with Bromine", Carbon 28(6), 825-830 (1990).
 50. D.D.L. Chung, "Intercalated Graphite as a Smart Material for High-Stress, High-Strain, Low-Electric-Field Electromechanical Switching", Smart Mater. Struct. 1, 233-236 (1992).
 51. L.W. Song, K.T. Fredette, D.D.L. Chung and Y.H. Kao, "Superconductivity in Interhalogen-Doped Fullerenes", Solid State Comm. 87(5), 387-391 (1993).
 52. Xiaoping Shui, D.D.L. Chung and Christine A. Frysz, "Hairy Carbon Electrodes Studied by Cyclic Voltammetry and Battery Discharge Testing", J. Power Sources 47(3), 313-320 (1994).
 53. Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Electrochemical Behavior of Porous Carbons," Carbon 35(7), 893-916 (1997).
 54. Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Effect of Chemisorbed Oxygen on the Electrochemical Behavior of Graphite Fibers," Carbon 32(8), 1499-1505 (1994).
 55. Xiaoping Shui, Christine A. Frysz, and D.D.L. Chung, "Solvent Cleansing of the Surface of Carbon Filaments and Its Benefit to the Electrochemical Behavior," Carbon 33(12), 1681-1698 (1995).
 56. Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Carbon Filaments and Carbon Black as a Conductive Additive to the Manganese Dioxide Cathode of a Lithium Electrolytic Cell," J. Power Sources 58(1), 41-54 (1996).
 57. Christine A. Frysz, Xiaoping Shui, and D.D.L. Chung, "Use of Carbon Filaments in Place of Carbon Black as the Current Collector of a Lithium Cell with a Thionyl Chloride-Bromine Chloride Catholyte," J. Power Sources 58(1), 55-66 (1996).
 58. Xiaoping Shui and D.D.L. Chung, "High-Strength High-Surface-Area Porous Carbon Made From Submicron-Diameter Carbon Filaments," Carbon 34(6), 811-814 (1996); 34(9), 1162 (1996).
 59. Xiangcheng Luo and D.D.L. Chung, "Electromagnetic Interference Shielding Reaching 130 dB Using Flexible Graphite," Carbon 34(10), 1293-1294 (1996).
 60. Xiaojun Wang and D.D.L. Chung, "Electromechanical Behavior of Carbon Fiber," Carbon 35(5), 706-709 (1997).
 61. Weiming Lu and D.D.L. Chung, "Mesoporous Activated Carbon Filaments," Carbon 35(3), 427-430 (1997).
 62. Shoukai Wang and D.D.L. Chung, "Self-Monitoring of Strain and Damage by a Carbon-Carbon Composite," Carbon 35(5), 621-630 (1997).
 63. Xiaoping Shui, Christine A. Frysz, and D.D.L. Chung, "Electrochemical Behavior of Hairy Carbons," Carbon 35(10/11), 1439-1455 (1997).
 64. Michael S. Salib, Athos Petrou, and D.D.L. Chung, "Optomechanical Actuation Using Intercalated Graphite," Carbon 35(5), 709-711 (1997).
 65. Christine A. Frysz and D.D.L. Chung, "Electrochemical Behavior of Flexible Graphite," Carbon 35(6), 858-860 (1997).
 66. Christine A. Frysz and D.D.L. Chung, "Improving the Electrochemical Behavior of Carbon Black and Carbon Filaments by Oxidation," Carbon 35(8), 1111-1127 (1997).
 67. Xiangcheng Luo and D.D.L. Chung, "Flexible Graphite for Sensing Stress/Displacement", J. Intelligent Material Systems and Structures 8, 389-392 (1997).
 68. Xiaojun Wang and D.D.L. Chung, "Piezoresistive Behavior of Carbon Fiber in Epoxy," Carbon 35(10/11), 1649-1651 (1997).
 69. D.D.L. Chung, "Self-Monitoring Structural Materials," Mater. Sci. Eng. Rev. R22(2), 57-78 (1998).
 70. Shoukai Wang, Xiaoping Shui, Xuli Fu, and D.D.L. Chung, "Early Fatigue Damage in Carbon Fiber Composites, Observed by Electrical Resistance Measurement," J. Mater. Sci. 33(15), 3875-3884 (1998).
 71. Shoukai Wang, Xuli Fu, and D.D.L. Chung, "Nondestructive Evaluation of Brittle-Matrix Composites During Loading by Electrical Resistance Measurement," Ceramic Trans. 89 (Nondestructive Evaluation of Ceramics), 145-156 (1998).
 72. Xiaojun Wang, Xuli Fu, and D.D.L. Chung, "Strain Sensing Using Carbon Fiber," J. Mater. Res. 14(3), 790-802 (1999).
 73. Xiangcheng Luo and D.D.L. Chung, "Electromagnetic Interference Shielding Using Continuous Carbon Fiber Carbon-Matrix and Polymer-Matrix Composites," Composites: Part B, 30(3), 227-231 (1999).
 74. Sihai Wen, Shoukai Wang and D.D.L. Chung, "Carbon Fiber Structural Composites as Thermistors", Sensors & Actuators A 78, 180-188 (1999).
 75. Sihai Wen, Shoukai Wang and D.D.L. Chung, "Piezoresistivity in Continuous Carbon Fiber Polymer-Matrix and Cement-Matrix Composites", J. Mater. Sci. 35(14), 3669-3675 (2000).
 76. Weiming Lu and D.D.L. Chung, "Preparation of Conductive Carbons with High Surface Area", Carbon 39(1), 39-

- 44 (2000).
77. D.D.L. Chung, "Flexible Graphite for Gasketing, Adsorption, Electromagnetic Interference Shielding, Vibration Damping, Electrochemical Applications, and Stress Sensing", J. Mater. Eng. Perf. 9(2), 161-163 (2000).
 78. Xiangcheng Luo and D.D.L. Chung, "Vibration Damping Using Flexible Graphite", Carbon 38(10), 1510-1512 (2000).
 79. Sihai Wen and D.D.L. Chung, "Effect of Carbon Fiber Grade on the Electrical Behavior of Carbon Fiber Reinforced Cement", Carbon 39, 369-373 (2001).
 80. Xiangcheng Luo and D.D.L. Chung, "Graphite-Graphite Electrical Contact under Dynamic Mechanical Loading", Carbon 39, 615-618 (2001).
 81. D.D.L. Chung, "Electromagnetic Interference Shielding Effectiveness of Carbon Materials", Carbon 39(2), 279-285 (2001).
 82. Xiaoping Shui and D.D.L. Chung, "Electrical Resistivity of Submicron-Diameter Carbon-Filament Compacts", Carbon 39 (ER11), 1717-1722 (2001).
 83. Xiangcheng Luo and D.D.L. Chung, "Tribology of Graphite and Concrete, Studied by Contact Electrical Resistance Measurement During Cyclic Compression", J. Tribology, 123(4), 682-685 (2001).
 84. D.D.L. Chung, "Comparison of Submicron Diameter Carbon Filaments and Conventional Carbon Fibers as Fillers in Composite Materials", Carbon 39(8), 1119-1125 (2001).
 85. Weiming Lu and D.D.L. Chung, "Anodic Performance of Vapor-Deprived Carbon Filaments in Lithium-Ion Secondary Battery", Carbon 39(4), 493-496 (2001).
 86. D.D.L. Chung, "Fibrous Composite Interfaces Studied by Electrical Resistance Measurement", Adv. Eng. Mater. 2(12), 788-796 (2000).
 87. Yunsheng Xu and D.D.L. Chung, "Silane-Treated Carbon Fiber for Reinforcing Cement", Carbon 39 (ER13), 1995-2001 (2001).
 88. Junhua Wu and D.D.L. Chung, "Increasing the Electromagnetic Interference Shielding Effectiveness of Carbon Fiber Polymer-Matrix Composite by Using Activated Carbon Fibers", Carbon 40 (ER3), 445-447 (2002).
 89. D.D.L. Chung, "Structural Health Monitoring by Electrical Resistance Measurement", Smart Mater. Struct. 10(4), 624-636 (2001).
 90. Yan Chen, David T. Shaw and D.D.L. Chung, "Hydrogen Storage in Aligned Carbon Nanotubes", Appl. Phys. Lett. 78(15), 2128-2130 (2001).
 91. Xiangcheng Luo and D.D.L. Chung, "Flexible Graphite Under Repeated Compression Studied by Electrical Resistance Measurements", Carbon 39(7), 985-990 (2001).
 92. Yie Meng Hoi and D.D.L. Chung, "Flexible Graphite as a Compliant Thermoelectric Material", Carbon 40(7), 1134-1136 (2002).
 93. Weiming, Lu and D.D.L. Chung, "A Comparative Study of Carbons for Use as an Electrically Conducting Additive in the Manganese Dioxide Cathode of an Electrochemical Cell", Carbon 40 (ER3), 447-449 (2002).
 94. Weiming, Lu and D.D.L. Chung, "Oxidation Protection of Carbon Materials by Acid Phosphate Impregnation", Carbon 40(8), 1249-1254 (2002).
 95. Randy Chugh and D.D.L. Chung, "Flexible Graphite as a Heating Element", Carbon 40(13), 2285-2289 (2002).
 96. D.D.L. Chung, "Graphite", J. Mater. Sci. 37(8), 1475-1489 (2002).
 97. Weiming Lu and D.D.L. Chung, "Effect of the Pitch-Based Carbon Anode on the Capacity Loss of Lithium-Ion Secondary Battery", Carbon 41(5), 945-950 (2003).
 98. Jorge Sanchez-Coronado, D.D.L. Chung, M. Martinez-Escandell, J. Narciso and F. Rodríguez-Reinoso, "Effect of Boron Carbide Particle Addition on the Thermomechanical Behavior of Carbon-Matrix Silicon Carbide Particle Composite", Carbon 41(6), 1096-1099 (2003).
 99. Jorge Sanchez-Coronado and D.D.L. Chung, "Thermomechanical Behavior of a Graphite Foam", Carbon 41(6), 1175-1180 (2003).
 100. Junhua Wu and D.D.L. Chung, "Improving Colloidal Graphite for Electromagnetic Interference Shielding by the Use of 0.1 μm Diameter Carbon Filaments", Carbon 41(6), 1313-1315 (2003).
 101. Chia-Ken Leong and D.D.L. Chung, "Carbon Black Dispersions as Thermal Pastes that Surpass Solder in Providing High Thermal Contact Conductance", Carbon 41(13), 2459-2469 (2003).
 102. Taejin Kim and D.D.L. Chung, "Carbon Fiber Mats as Resistive Heating Elements", Carbon 41(12), 2436-2440 (2003).
 103. D.D.L. Chung, "Electrical Applications of Carbon Materials", J. Mater. Sci. 39(8), 2645-2661 (2004).
 104. Chia-Ken Leong and D.D.L. Chung, "Pressure Electrical Contact Improved by Carbon Black Paste", J. Electron. Mater. 33(3), 203-206 (2004).
 105. Chia-Ken Leong and D.D.L. Chung, "Carbon black dispersions and carbon-silver combinations as thermal pastes that surpass commercial silver and ceramic pastes in providing high thermal contact conductance", Carbon 42(11), 2323-2327 (2004).
 106. Sihai Wen and D.D.L. Chung, "Effect of Carbon Black on the Thermal, Mechanical and Electrical Properties of Pitch-Matrix Composites", Carbon 42(12-13), 2393-2397 (2004).
 107. Sihai Wen and D.D.L. Chung, "Pitch-Matrix Composites for Electrical, Electromagnetic and Strain-Sensing Applications", J. Mater. Sci. 40(15), 3897-3903 (2005).

108. Yunsheng Xu, Chia-Ken Leong and D.D.L. Chung, "Carbon Nanotube Dispersions as Thermal Pastes", J. Electron. Mater. 36(9), 1181-1187 (2007).
109. Chia-Ken Leong, Yasuhiro Aoyagi and D.D.L. Chung, "Carbon-Black Thixotropic Thermal Pastes for Improving Thermal Contacts", J. Electron. Mater. 34(10), 1336-1341 (2005).
110. Yuan-Chan Hsu and D.D.L. Chung, "Silver Particle Carbon-Matrix Composites as Thick Films for Electrical Applications", J. Electron. Mater. 36(9), 1188-1192 (2007).
111. Chia-Ken Leong, Yasuhiro Aoyagi and D.D.L. Chung, "Carbon Black Pastes as Coatings for Improving Thermal Gap-Filling Materials", Carbon 44(3), 435-440 (2006).
112. Chia-Ken Leong and D.D.L. Chung, "Improving the Electrical and Mechanical Behavior of Electrically Conductive Paint by Partial Replacement of Silver by Carbon Black", J. Electron. Mater., 35(1), 118-122 (2006).
113. Timothy A. Howe, Chia-Ken Leong and D.D.L. Chung, "Comparative Evaluation of Thermal Interface Materials for Improving the Thermal Contact Between an Operating Computer Microprocessor and Its Heat Sink", J. Electron. Mater. 35(8), 1628-1635 (2006).
114. Chuangang Lin, Timothy A. Howe and D.D.L. Chung, "Electrically Nonconductive Thermal Pastes with Carbon as the Thermally Conductive Component", J. Electron. Mater. 36(6), 659-668 (2007).
115. Chuangang Lin and D.D.L. Chung, "Effect of Carbon Black Structure on the Effectiveness of Carbon Black Thermal Interface Pastes" Carbon 45(15), 2922-2931 (2007).
116. Seungjin Han, Jan T. Lin, Yasuhiro Aoyagi and D.D.L. Chung, "Enhancing the Thermal Conductivity and Compressive Modulus of Carbon Fiber Polymer-Matrix Composites in the Through-Thickness Direction by Nanostructuring the Interlaminar Interface with Carbon Black", Carbon 46(7), 1060-1071 (2008).
117. Yasuhiro Yamada and D.D.L. Chung, "Epoxy-Based Carbon Films with High Electrical Conductivity Attached to an Alumina Substrate", Carbon 46(13), 1798-1801 (2008).
118. Yasuhiro Yamada and D.D.L. Chung, "Three-Dimensional Microstructuring of Carbon by Thermoplastic Spacer Evaporation During Pyrolysis", Carbon 46(13), 1765-1772 (2008).
119. Chuangang Lin and D.D.L. Chung, "Graphite Nanoplatelet Pastes versus Carbon Black Pastes as Thermal Interface Materials", Carbon 47(1), 295-305 (2009).
120. Kesong Hu and D.D.L. Chung, "Flexible Graphite Modified by Carbon Black Paste for Use as a Thermal Interface Material", Carbon 49, 1075-1086 (2011).
121. Po-Hsiu Chen and D.D.L. Chung, "Dynamic Mechanical Properties of Flexible Graphite Made from Exfoliated Graphite", Carbon 50, 283-289 (2012).
122. D.D.L. Chung, "Carbon Materials for Structural Self-Sensing, Electromagnetic Shielding and Thermal Interfacing", Carbon 50, 3342-3353 (2012).
123. D.D.L. Chung and Yoshihiro Takizawa, "Performance of Isotropic and Anisotropic Heat Spreaders", J. Electronic Mater., 41(9), 2580-2587 (2012). (The final publication is available at)
124. Andi Wang, Xiaoqing Gao, Rossman F. Giese, Jr. and D.D.L. Chung, "A ceramic-carbon hybrid as a high-temperature structural monolith and reinforcing filler and binder for carbon/carbon composites", Carbon 59, 76-92 (2013).
125. Shuang Lu and D.D.L. Chung, "Viscoelastic behavior of carbon black and its relationship with the aggregate size", Carbon 60, 346-355 (2013).
126. Po-Hsiu Chen and D.D.L. Chung, "Viscoelastic behavior of the cell wall of exfoliated graphite", Carbon 61, 305-312 (2013).
127. D.D.L. Chung, "Interface-derived extraordinary viscous behavior of exfoliated graphite", Carbon 68, 646-652 (2014).
128. Andi Wang and D.D.L. Chung, "Dielectric and electrical conduction behavior of carbon paste electrochemical electrodes, with decoupling of carbon, electrolyte and interface contributions", Carbon 72, 135-151 (2014).
129. Po-Hsiu Chen and D.D.L. Chung, "Thermal and electrical conduction in the compaction direction of exfoliated graphite and their relation to the structure", Carbon 77, 538-550 (2014).
130. Po-Hsiu Chen and D.D.L. Chung, "Elastomeric behavior of exfoliated graphite, as shown by instrumented indentation testing", Carbon 81, 505-513 (2015).
131. Munish Sharma and D.D.L. Chung, "Solder-graphite network composite sheets as high-performance thermal interface materials", J. Electronic Materials 44(3), 929-947 (2015). Honored as Editors' Choice (hence Open Access).
132. Xinghua Hong and D.D.L. Chung, "Exfoliated graphite with relative dielectric constant reaching 360, obtained by exfoliation of acid-intercalated graphite flakes without subsequent removal of the residual acidity", Carbon 91, 1-10 (2015).
133. Morteza Moalleminejad and D.D.L. Chung, "Dielectric constant and electrical conductivity of carbon black as an electrically conductive additive in a manganese-dioxide electrochemical electrode, and their dependence on electrolyte permeation", Carbon 91, 76-87 (2015).
134. Ailipati Delixiati and D.D.L. Chung, "Bentonite-derived materials preferably with nanocarbon incorporation exhibiting exceptionally high dielectric loss at relatively low electrical conductivity", J. Materials Sci. 51, 969-978 (2016).
135. D.D.L. Chung, "A review of exfoliated graphite" (invited paper, 50th Anniversary edition), J. Mater. Sci. 51, 554-

- 568 (2016).
136. Andi Wang and D.D.L. Chung, "First report of fumed alumina incorporation in carbon-carbon composite and the consequent improvement of the oxidation resistance and mechanical properties", Carbon 101, 281-289 (2016).
 137. Yoshihiro Takizawa, Daojun Wang and D.D.L. Chung, "Carbon black and fumed alumina exhibiting high interface-derived mechanical energy dissipation", Carbon 103, 436-448 (2016).
 138. Lifeng Xiao and D.D.L. Chung, "Mechanical energy dissipation modeling of exfoliated graphite based on interfacial friction theory", Carbon 108, 291-302 (2016).
 139. Miguel Ramirez and D.D.L. Chung, "Electromechanical, self-sensing and viscoelastic behavior of carbon fiber tows", Carbon 110, 8-16 (2016).
 140. Xinghua Hong, Weidong Yu, Andi Wang and D.D.L. Chung, "Graphite oxide paper as a polarizable electrical conductor in the through-thickness direction", Carbon 109, 874-882 (2016).
 141. Xinghua Hong, Weidong Yu and D.D.L. Chung, Electric permittivity of reduced graphite oxide. Carbon 111, 182-190 (2017).
 142. Xinghua Hong and D.D.L. Chung, "Carbon nanofiber mats for electromagnetic interference shielding", Carbon 111, 529-527 (2017).
 143. Asma A. Eddib and D.D.L. Chung, "The importance of the electrical contact between specimen and testing fixture in evaluating the electromagnetic interference shielding effectiveness of carbon materials", Carbon 117, 427-436 (2017). Corrigendum to The importance of the electrical contact between specimen and testing fixture in evaluating the electromagnetic interference shielding effectiveness of carbon materials, Carbon 120, 337 (2017).
 144. Xinghua Hong, Weidong Yu and D.D.L. Chung, "Significant effect of sorbed water on the electrical and dielectric behavior of graphite oxide", Carbon 119, 403-418 (2017).
 145. Xueping Wu, Qingxin Zhang, Cun Liu, Xianlong Zhang, D.D.L. Chung, "Carbon-coated sepiolite clay fibers with acid pre-treatment as low-cost organic adsorbents", Carbon 123, 259-272 (2017).
 146. Asma A. Eddib and D.D.L. Chung, "Radio-frequency linear absorption coefficient of carbon materials, its dependence on the thickness and its independence on the carbon structure", Carbon 124, 473-478 (2017).
 147. Asma A. Eddib and D.D.L. Chung. Electric permittivity of carbon fiber. Carbon 143, 475-480 (2019).
 148. D.D.L. Chung. Interface-derived solid-state viscoelasticity exhibited by nanostructured and microstructured materials containing carbons or ceramics. Carbon 144, 567-581 (2019).
 149. Xiang Xi and D.D.L. Chung. Effect of nickel coating on the stress-dependent electric permittivity, piezoelectricity and piezoresistivity of carbon fiber, with relevance to stress self-sensing. Carbon 145 (2019) 401-410.
 150. Xiang Xi and D.D.L. Chung. Piezoelectric and piezoresistive behavior of unmodified carbon fiber. Carbon 145 (2019) 452-461.
 151. Xiang Xi and D.D.L. Chung. Capacitance-based self-sensing of flaws and stress in carbon-carbon composite, with reports of the electric permittivity, piezoelectricity and piezoresistivity. Carbon 146, 447-461 (2019). Corrigendum to "Capacitance-based self-sensing of flaws and stress in carbon-carbon composite, with reports of the electric permittivity, piezoelectricity and piezoresistivity". Carbon 158, 545 (2020).
 152. Xiang Xi and D.D.L. Chung. Colossal electric permittivity discovered in polyacrylonitrile (PAN) based carbon fiber, with comparison of PAN-based and pitch-based carbon fibers. Carbon 145, 734-739 (2019).
 153. Xiang Xi and D.D.L. Chung. Electret, piezoelectret, dielectricity and piezoresistivity discovered in exfoliated-graphite-based flexible graphite, with applications in mechanical sensing and electric powering. Carbon 150, 513-548 (2019).
 154. Hongtao Guan and D.D.L. Chung. Effect of the planar coil and linear arrangements of continuous carbon fiber tow on the electromagnetic interference shielding effectiveness, with comparison of carbon fibers with and without nickel coating. Carbon 152, 898-908 (2019).
 155. Hongtao Guan and D.D.L. Chung. Radio-wave electrical conductivity and absorption-dominant interaction with radio wave of exfoliated-graphite-based flexible graphite, with relevance to electromagnetic shielding and antennas. Carbon 157, 549-562 (2020).
 156. Xiang Xi and D.D.L. Chung. Electret behavior of unpoled carbon fiber with and without nickel coating. Carbon 159, 122-132 (2020).
 157. Xiang Xi and D.D.L. Chung. Electret behavior of carbon fiber structural composites with carbon and polymer matrices, and its application in self-sensing and self-powering. Carbon 160, 361-389 (2020).
 158. D.D.L. Chung and Xiang Xi. Electric poling of carbon fiber with and without nickel coating. Carbon 162, 25-35 (2020).
 159. Xiang Xi and D.D.L. Chung. Dynamics of the electric polarization and depolarization of graphite. Carbon 172, 83-95 (2021).
 160. Xiang Xi and D.D.L. Chung. Role of grain boundaries in the dielectric behavior of graphite. Carbon 173, 1003-1019 (2021).
 161. Xiang Xi and D.D.L. Chung. Pyropermittivity and pyroelectret behavior of graphite. Carbon 174, 357-367 (2021).
 162. Hongtao Guan and D.D.L. Chung. Absorption-dominant radio-wave attenuation loss of metals and graphite. J. Mater. Sci. 56(13), 8037-8047 (2021). <https://doi.org/10.1007/s10853-021-05808-2>.
 163. Xiang Xi and D.D.L. Chung. Dielectric behavior of graphite, with assimilation of the AC permittivity, DC polarization and DC electret. Carbon 181, 246-259 (2021).

164. D.D.L. Chung, Jonah T. Bannon, Wenyi Yang. Dielectric behavior discovered in electrically conductive thick film. J. Mater. Sci.: Mater. Electronics 32(14), 19605-19613 (2021).
165. D.D.L. Chung and Xiang Xi. Piezopermittivity for capacitance-based strain/stress sensing. Sensor Actuators A 332, 113028 (2021).
166. D.D.L. Chung and Xiang Xi. Factors that govern the electric permittivity of carbon materials in the graphite allotrope family. Carbon 184, 245-252 (2021).
167. D.D.L. Chung and Xiang Xi. A review of the colossal permittivity of electronic conductors, specifically metals and carbons. Mater. Res. Bull. 148, 111654 (2022).
168. Xiang Xi and D.D.L. Chung. Pyropermittivity as an emerging method of thermal analysis, with application to carbon fibers. J. Thermal Analysis and Calorimetry 147, 10267-10283 (2022).
169. D.D.L. Chung and Dang Q. Duong. Observation of electric polarization continuity in graphite. Mater. Chem. Phys. 297, 127357 (2023).
170. D.D.L. Chung. A review of self-sensing in carbon fiber structural composite materials. World Sci. Ann. Rev. Funct. Mater. 1, 2230004 (2023). DOI:10.1142/S2810922822300045. Invited paper for the inaugural issue.
171. D.D.L. Chung. First review of conductive electrets for low-power electronics. J. Low Power Electron. Appl. 13(2), 25 (2023).
172. Min Kyoung Kim and D.D.L. Chung. Unprecedented sensing of the twist level in fiber tows, as shown for carbon fiber by inductance-based self-sensing, which provides fast, low-cost and large-format sensing. Carbon 214, 118349 (2023).
173. D.D.L. Chung. A critical review of carbon-based thermal interface materials. Mater. Chem Phys. 309, 128432 (2023).
174. D.D.L. Chung. A perspective on electromagnetic interference shielding materials comprising exfoliated graphite. Carbon 216, 118569 (2024).
175. Min Kyoung Kim and D.D.L. Chung. Piezoiductance in a carbon fiber tow. Carbon 223, 119013 (2024).

CEMENT-MATRIX COMPOSITES (189 journal papers)

1. Qijun Zheng and D.D.L. Chung, "Carbon Fiber Reinforced Cement Composites Improved by Using Chemical Agents", Concr. Cem. Res. 19, 25-41 (1989).
2. Jeng-Maw Chiou, Qijun Zheng and D.D.L. Chung, "Electromagnetic Interference Shielding by Carbon Fiber Reinforced Cement", Composites 20(4), 379-381 (1989).
3. D.D.L. Chung and Qijun Zheng, "Electronic Properties of Carbon Fiber Reinforced Gypsum Plaster", Compos. Sci. Technol. 36, 1-6 (1989).
4. Qijun Zheng and D.D.L. Chung, "Microporous Calcium Silicate Thermal Insulator Prepared by a Hydrothermal Reaction Accelerated by Admixtures", Mat. Sci. Tech. 6, 666-669 (1990).
5. Xiaoming Yang and D.D.L. Chung, "Latex-Modified Cement Mortar Reinforced by Short Carbon Fibers", Composites, 23(6), 453-460 (1992).
6. Pu-Woei Chen and D.D.L. Chung, "Concrete Reinforced with up to 0.2 vol.% of Short Carbon Fibers", Composites 24(1), 33-52 (1993).
7. Pu-Woei Chen and D.D.L. Chung, "Carbon Fiber Reinforced Concrete as a Smart Material Capable of Non-Destructive Flaw Detection", Smart Mater. Struct. 2(1), 22-30 (1993).
8. Pu-Woei Chen and D.D.L. Chung, "Carbon Fiber Reinforced Concrete as an Electrical Contact Material for Smart Structures", Smart Mater. Struct. 2(3), 181-188 (1993).
9. Pu-Woei Chen and D.D.L. Chung, "Concrete as a New Strain/Stress Sensor", Composites, Part B 27B, 11-23 (1996).
10. Pu-Woei Chen, Xuli Fu, and D.D.L. Chung, "Improving the Bonding Between Old and New Concrete by the Addition of Carbon Fibers to the New Concrete", Cem. Concr. Res. 25(3), 491-496 (1995).
11. Pu-Woei Chen and D.D.L. Chung, "Carbon Fiber Reinforced Concrete as an Intrinsically Smart Concrete for Damage Assessment During Dynamic Loading", J. Am. Ceram. Soc. 78(3), 816-818 (1995).
12. Pu-Woei Chen and D.D.L. Chung, "Improving the Electrical Conductivity of Composites Comprised of Short Conducting Fibers in a Non-Conducting Matrix: the Addition of a Non-Conducting Particulate Filler," J. Electron. Mater. 24(1), 47-51 (1995).
13. D.D.L. Chung, "Strain Sensors Based on the Electrical Resistance Change Accompanying the Reversible Pull-Out of Conducting Short Fibers in a Less Conducting Matrix", Smart Mater. Struct. 4, 59-61 (1995).
14. Pu-Woei Chen and D.D.L. Chung, "Effect of Polymer Addition on the Thermal Stability and Thermal Expansion of Cement", Cem. Concr. Res. 25(3), 465-469 (1995).
15. Pu-Woei Chen and D.D.L. Chung, "A Comparative Study of Concretes Reinforced with Carbon, Polyethylene and Steel Fibers and Their Improvement by Latex Addition", ACI Materials J. 93(2), 129-133 (1996).
16. Pu-Woei Chen and D.D.L. Chung, "Low-Drying-Shrinkage Concrete Containing Carbon Fibers", Composites: Part B, 27B, 269-274 (1996).
17. Pu-Woei Chen, D.D.L. Chung. Carbon fiber reinforced concrete as an intrinsically smart concrete for damage assessment during static and dynamic loading. ACI Mater. J. 93(4), 341-350 (1996).
18. Xuli Fu and D.D.L. Chung, "Carbon Fiber Reinforced Mortar as an Electrical Contact Material for Cathodic Protection,"

- Cem. Concr. Res. 25(4), 689-694 (1995).
19. Zeng-Qiang Shi and D.D.L. Chung, "Concrete for Magnetic Shielding," Cem. Concr. Res. 25(5), 939-944 (1995).
 20. Xuli Fu and D.D.L. Chung, "Contact Electrical Resistivity between Cement and Carbon Fiber: Its Decrease with Increasing Bond Strength and Its Increase During Fiber Pull-Out," Cem. Concr. Res. 25(7), 1391-1396 (1995).
 21. Xuli Fu and D.D.L. Chung, "Linear Correlation of Bond Strength and Contact Electrical Resistivity Between Steel Rebar and Concrete," Cem. Concr. Res. 25(7), 1397-1402 (1995).
 22. Xuli Fu and D.D.L. Chung, "Vibration Damping Admixtures for Cement," Cem. Concr. Res. 26(1), 69-75 (1996).
 23. Xuli Fu and D.D.L. Chung, "Self-Monitoring of Fatigue Damage in Carbon Fiber Reinforced Cement," Cem. Concr. Res. 26(1), 15-20 (1996).
 24. Xuli Fu and D.D.L. Chung, "Effect of Methylcellulose Admixture on the Mechanical Properties of Cement," Cem. Concr. Res. 26(4), 535-538 (1996).
 25. Xuli Fu and D.D.L. Chung, "Effect of Polymer Admixtures to Cement on the Bond Strength and Electrical Contact Resistivity Between Steel Fiber and Cement," Cem. Concr. Res. 26(2), 189-194 (1996).
 26. Xuli Fu, Weiming Lu, and D.D.L. Chung, "Improving the Bond Strength between Carbon Fiber and Cement by Fiber Surface Treatment and Polymer Addition to Cement Mix," Cem. Concr. Res. 26(7), 1007-1012 (1996).
 27. Xuli Fu and D.D.L. Chung, "Degree of Dispersion of Latex Particles in Cement Paste, as Assessed by Electrical Resistivity Measurement," Cem. Concr. Res. 26(7), 985-991 (1996).
 28. Xuli Fu and D.D.L. Chung, "Improving the Bond Strength Between Steel Rebar and Concrete by Oxidation Treatments of the Rebar," Cem. Concr. Res. 26(10), 1499-1503 (1996).
 29. Xuli Fu and D.D.L. Chung, "Submicron Carbon Filament Cement-Matrix Composites for Electromagnetic Interference Shielding," Cem. Concr. Res. 26(10), 1467-1472 (1996); 27(2), 314 (1997).
 30. Xuli Fu and D.D.L. Chung, "Single Fiber Electromechanical Pull-Out Testing and Its Application to Studying the Interface Between Steel Fiber and Cement," Composite Interfaces 4(4), 197-211 (1997).
 31. Xuli Fu, Weiming Lu, and D.D.L. Chung, "Improving the Tensile Properties of Carbon Fiber Reinforced Cement by Ozone Treatment of the Fiber," Cem. Concr. Res. 26(10), 1485-1488 (1996).
 32. Mingguang Zhu and D.D.L. Chung, "Improving Brick-to-Mortar Bond Strength by the Addition of Carbon Fibers to the Mortar," Cem. Concr. Res. 27(12), 1829-1839 (1997).
 33. Mingguang Zhu, Robert C. Wetherhold, and D.D.L. Chung, "Evaluation of the Interfacial Shear in a Discontinuous Carbon Fiber/Mortar Matrix Composite," Cem. Concr. Res. 27(3), 437-451 (1997).
 34. Pu-Woei Chen, Xuli Fu, and D.D.L. Chung, "Microstructural and Mechanical Effects of Latex, Methylcellulose and Silica Fume on Carbon Fiber Reinforced Cement," ACI Mater. J. 94(2), 147-155 (1997).
 35. Xuli Fu and D.D.L. Chung, "Bond Strength and Contact Electrical Resistivity Between Cement and Stainless Steel Fiber: Their Correlation and Dependence on Fiber Surface Treatment and Curing Age," ACI Mater. J. 94(3), 203-208 (1997).
 36. Xuli Fu and D.D.L. Chung, "Nondestructive Bond Strength Testing by Contact Electrical Resistivity Measurement," ACI Special Publication SP-168: Innovations in Nondestructive Testing of Concrete, edited by Stephen Pessiki and Larry Olson, 1997, p. 295-317.
 37. Jiangyuan Hou, Xuli Fu, and D.D.L. Chung, "Improving Both Bond Strength and Corrosion Resistance of Steel Rebar in Concrete by Water Immersion or Sand Blasting of Rebar," Cem. Concr. Res. 27(5), 679-684 (1997).
 38. Jiangyuan Hou and D.D.L. Chung, "Cathodic Protection of Steel Reinforced Concrete Facilitated by Using Carbon Fiber Reinforced Mortar or Concrete," Cem. Concr. Res. 27(5), 649-656 (1997).
 39. Xuli Fu and D.D.L. Chung, "Improving the Bond Strength Between Steel Rebar and Concrete by Ozone Treatment of Rebar and Polymer Addition to Concrete," Cem. Concr. Res. 27(5), 643-648 (1997).
 40. Xuli Fu, Erming Ma, D.D.L. Chung, and W.A. Anderson, "Self-Monitoring in Carbon Fiber Reinforced Mortar by Reactance Measurement," Cem. Concr. Res. 27(6), 845-852 (1997).
 41. Xuli Fu and D.D.L. Chung, "Reversible Decrease of the Flexural Dynamic Modulus of Cement Pastes Upon Heating," Cem. Concr. Res. 27(6), 839-844 (1997).
 42. Zeng-Qiang Shi and D.D.L. Chung, "Improving the Abrasion Resistance of Mortar by Adding Latex and Carbon Fibers," Cem. Concr. Res. 27(8), 1149-1153 (1997).
 43. Xuli Fu and D.D.L. Chung, "Effect of Curing Age on the Self-Monitoring Behavior of Carbon Fiber Reinforced Mortar," Cem. Concr. Res. 27(9), 1313-1318 (1997).
 44. Xuli Fu and D.D.L. Chung, "Effects of Silica Fume, Latex, Methylcellulose, and Carbon Fibers on the Thermal Conductivity and Specific Heat of Cement Paste," Cem. Concr. Res. 27(12), 1799-1804 (1997).
 45. Xuli Fu and D.D.L. Chung, "Improving the Bond Strength between Steel Rebar and Concrete by Increasing the Water/Cement Ratio," Cem. Concr. Res. 27(12), 1805-1809 (1997).
 46. Xuli Fu and D.D.L. Chung, "Effect of Corrosion on the Bond Between Concrete and Steel Rebar," Cem. Concr. Res. 27(12), 1811-1815 (1997).
 47. Xuli Fu and D.D.L. Chung, "Decrease of the Bond Strength Between Steel Rebar and Concrete with Increasing Curing Age," Cem. Concr. Res. 28(2), 167-169 (1998).
 48. Xuli Fu, and D.D.L. Chung, "Improving the Bond Strength of Concrete to Reinforcement by Adding Methylcellulose to Concrete," ACI Mater. J. 95(5), 601-608 (1998).
 49. Xuli Fu, W. Lu and D.D.L. Chung, "Improving the Strain Sensing Ability of Carbon Fiber Reinforced Cement by Ozone

- Treatment of the Fibers," Cem. Concr. Res. 28(2), 183-187 (1998).
50. Xuli Fu and D.D.L. Chung, "Combined Use of Silica Fume and Methylcellulose as Admixtures in Concrete for Increasing the Bond Strength Between Concrete and Steel Rebar," Cem. Concr. Res. 28(4), 487-492 (1998).
 51. Xiaohui Li and D.D.L. Chung, "Improving Silica Fume for Concrete by Surface Treatment," Cem. Concr. Res. 28(4), 493-498 (1998).
 52. Xuli Fu, Weiming Lu and D.D.L. Chung, "Ozone Treatment of Carbon Fiber for Reinforcing Cement," Carbon 36(9), 1337-1345 (1998).
 53. Weiming Lu and D.D.L. Chung, "Effect of Rust on the Wettability of Steel by Water," Cem. Concr. Res. 28(4), 477-480 (1998).
 54. Xuli Fu and D.D.L. Chung, "Submicron-Diameter-Carbon-Filament Cement-Matrix Composites," Carbon 36(4), 459-462 (1998).
 55. Xuli Fu and D.D.L. Chung, "Radio Wave Reflecting Concrete for Lateral Guidance in Automatic Highways," Cem. Concr. Res. 28(6), 795-801 (1998).
 56. Xuli Fu and D.D.L. Chung, "Sensitivity of the Bond Strength to the Structure of the Interface Between Reinforcement and Cement, and the Variability of This Structure," Cem. Concr. Res. 28(6), 787-793 (1998).
 57. Weiming Lu, Xuli Fu, and D.D.L. Chung, "A Comparative Study of the Wettability of Steel, Carbon and Polyethylene Fibers by Water," Cem. Concr. Res. 28(6), 783-786 (1998).
 58. Xuli Fu, Xiaohui Li, and D.D.L. Chung, "Improving the Vibration Damping Capacity of Cement," J. Mater. Sci. 33, 3601-3605 (1998).
 59. Xuli Fu and D.D.L. Chung, "Effects of Water-Cement Ratio, Curing Age, Silica Fume, Polymer Admixtures, Steel Surface Treatments, and Corrosion on Bond between Concrete and Steel Reinforcing Bars," ACI Mater. J. 95(6), 725-734 (1998).
 60. Zeng-Qiang Shi and D.D.L. Chung, "Carbon Fiber Reinforced Concrete for Traffic Monitoring and Weighing in Motion," Cem. Concr. Res. 29(3), 435-439 (1999).
 61. Yinhui Wang and D.D.L. Chung, "Effect of Embedded Steel on the Compressive Damage Behavior of Cement Mortar," Cem. Concr. Res. 29(3), 427-428 (1999).
 62. Sihai Wen and D.D.L. Chung, "Piezoresistivity in Continuous Carbon Fiber Cement-Matrix Composite," Cem. Concr. Res. 29(3), 445-449 (1999).
 63. Xuli Fu and D.D.L. Chung, "Effect of Admixtures on the Thermal and Thermomechanical Behavior of Cement Paste," ACI Mater. J. 96(4), 455-461 (1999).
 64. Yinhui Wang and D.D.L. Chung, "Effects of Sand and Silica Fume on the Vibration Damping Behavior of Cement," Cem. Concr. Res. 28(10), 1353-1356 (1998).
 65. Yinhui Wang and D.D.L. Chung, "Spatial Distribution of Mechanical and Electrical Properties of Cement Mortar Prior to Loading," Cem. Concr. Res. 28(10), 1373-1378 (1998).
 66. Yunsheng Xu and D.D.L. Chung, "Improving the Workability and Strength of Silica Fume Concrete by Using Silane Treated Silica Fume," Cem. Concr. Res. 29(3), 451-453 (1999).
 67. Yunsheng Xu and D.D.L. Chung, "Carbon Fiber Reinforced Cement Improved by Using Silane-Treated Carbon Fibers," Cem. Concr. Res. 29(5), 773-776 (1999).
 67. Xuli Fu and D.D.L. Chung, "Interface Between Steel Rebar and Concrete, Studied by Electromechanical Pull-out Testing," Composite Interfaces 6(2), 81-92 (1999).
 68. Sihai Wen and D.D.L. Chung, "Carbon Fiber-Reinforced Cement as a Thermistor," Cem. Concr. Res. 29(6), 961-965 (1999).
 69. Yunsheng Xu and D.D.L. Chung, "Effect of Carbon Fibers on the Vibration Reduction Ability of Cement," Cem. Concr. Res. 29(7), 1107-1109 (1999).
 70. Yunsheng Xu and D.D.L. Chung, "Increasing the Specific Heat of Cement Paste by Admixture Surface Treatments," Cem. Concr. Res. 29(7), 1117-1121 (1999).
 71. Sihai Wen and D.D.L. Chung, "Seebeck Effect in Carbon Fiber Reinforced Cement," Cem. Concr. Res., 29(12), 1989-1993 (1999); Erratum, 34(12), 2341-2342 (2004).
 72. Yunsheng Xu and D.D.L. Chung, "Effect of Sand Addition on the Specific Heat and Thermal Conductivity of Cement," Cem. Concr. Res. 30(1), 59-61 (2000).
 73. Jiangyuan Hou and D.D.L. Chung, "Effect of Admixtures in Concrete on the Corrosion Resistance of Steel Reinforced Concrete," Corrosion Sci. 42(9), 1489-1507 (2000).
 74. Yunsheng Xu and D.D.L. Chung, "Cement-Based Materials Improved by Surface Treated Admixtures," ACI Mater. J. 97(3), 333-342 (2000).
 75. Sihai Wen and D.D.L. Chung, "Enhancing the Vibration Reduction Ability of Concrete by Using Steel Reinforcement and Steel Surface Treatments," Cem. Concr. Res. 30(2), 327-330 (2000).
 76. Xiangcheng Luo and D.D.L. Chung, "Concrete-Concrete Pressure Contacts under Dynamic Loading, Studied by Contact Electrical Resistance Measurement," Cem. Concr. Res. 30(2), 323-326 (2000).
 77. Yunsheng Xu and D.D.L. Chung, "Reducing the Drying Shrinkage of Cement Paste by Admixture Surface Treatments," Cem. Concr. Res. 30(2), 241-245 (2000).
 78. D.D.L. Chung, "Carbon Fiber Cement-Matrix Composites," TANSO, No. 190, 300-312 (1999).
 79. D.D.L. Chung, "Cement Reinforced with Short Carbon Fibers: a Multifunctional Material," Composites: Part B 31(6-

- 7), 511-526 (2000).
80. Sihai Wen and D.D.L. Chung, "Seebeck Effect in Steel Fiber Reinforced Cement", Cem. Concr. Res. 30(4), 661-664 (2000).
81. Dragos-Marian Bontea, D.D.L. Chung and G.C. Lee, "Damage in Carbon Fiber Reinforced Concrete, Monitored by Electrical Resistance Measurement", Cem. Concr. Res. 30(4), 651-659 (2000).
82. D.D.L. Chung, "Cement-Matrix Composites for Smart Structures", Smart Mater. Struct. 9(4), 389-401 (2000).
83. Zhen Mei and D.D.L. Chung, "Effects of Temperature and Stress on the Interface between Concrete and its Carbon Fiber Epoxy-Matrix Composite Retrofit, studied by Electrical Resistance Measurement", Cem. Concr. Res. 30(5), 799-802 (2000).
84. Yunsheng Xu and D.D.L. Chung, "Cement of High Specific Heat and High Thermal Conductivity, Obtained by Using Silane and Silica Fume as Admixtures", Cem. Concr. Res. 30(7), 1175-1178 (2000).
85. Sihai Wen and D.D.L. Chung, "Uniaxial Tension in Carbon Fiber Reinforced Cement, Sensed by Electrical Resistivity Measurement in Longitudinal and Transverse Directions", Cem. Concr. Res. 30(8), 1289-1294 (2000).
86. Yunsheng Xu and D.D.L. Chung, "Improving Silica Fume Cement by Using Silane", Cem. Concr. Res. 30(8), 1305-1311 (2000).
87. Sihai Wen and D.D.L. Chung, "Enhancing the Seebeck Effect in Carbon Fiber Reinforced Cement by Using Intercalated Carbon Fibers", Cem. Concr. Res. 30(8), 1295-1298 (2000); Erratum, 34(12), 2341-2342 (2004).
88. Sihai Wen and D.D.L. Chung, "Damage Monitoring of Cement Paste by Electrical Resistance Measurement", Cem. Concr. Res. 30(12), 1979-1982 (2000).
89. D.D.L. Chung, "Corrosion Control of Steel Reinforced Concrete", J. Mater. Eng. Perf. 9(5), 585-588 (2000).
90. Sihai Wen and D.D.L. Chung, "Electrical Behavior of Cement-Based Junctions Including the pn-Junction", Cem. Concr. Res. 31(2), 129-133 (2001).
91. D.D.L. Chung, "Cement-Based Electronics", J. Electroceramics 6(1), 75-88 (2001).
92. D.D.L. Chung, "Functional Properties of Cement-Matrix Composites", J. Mater. Sci. 36, 1315-1324 (2001).
93. Sihai Wen and D.D.L. Chung, "Electric Polarization in Carbon Fiber Reinforced Cement", Cem. Concr. Res. 31(2), 141-147 (2001).
94. Sihai Wen and D.D.L. Chung, "Cement-Based Thermocouples", Cem. Concr. Res. 31(3), 507-510 (2001).
95. Sihai Wen and D.D.L. Chung, "Effect of Stress on the Electric Polarization in Cement", Cem. Concr. Res. 31(2), 291-295 (2001).
96. Sihai Wen and D.D.L. Chung, "Uniaxial Compression in Carbon Fiber Reinforced Cement, Sensed by Electrical Resistivity Measurement in Longitudinal and Transverse Directions", Cem. Concr. Res. 31(2), 297-301 (2001).
97. Sihai Wen and D.D.L. Chung, "Cement as a Thermoelectric Material", J. Mater. Res. 15(12), 2844-2848 (2000). Erratum: 19(4), 1294 (2004).
98. Jingyao Cao and D.D.L. Chung, "Improving the Dispersion of Steel Fibers in Cement Mortar by the Addition of Silane", Cem. Concr. Res. 31(2), 309-311 (2001).
99. D.D.L. Chung, "Cement-Matrix Composites for Thermal Engineering", Applied Thermal Engineering 21(ER16), 1607-1619 (2001).
100. D.D.L. Chung, "Interface Engineering for Cement-Matrix Composites", Composite Interfaces 8(1), 67-82 (2001).
101. Jingyao Cao and D.D.L. Chung, "Degradation of the Bond Between Concrete and Steel under Cyclic Shear Loading, Monitored by Contact Electrical Resistance Measurement", Cem. Concr. Res. 31(4), 669-671 (2001).
102. Sihai Wen and D.D.L. Chung, "Effect of Admixtures on the Dielectric Constant of Cement Paste", Cem. Concr. Res. 31(4), 673-677 (2001).
103. Sihai Wen and D.D.L. Chung, "Defect Dynamics of Cement Paste Under Repeated Compression, Studied by Electrical Resistivity Measurement", Cem. Concr. Res. 31(10), 1515-1518 (2001).
104. Jingyao Cao and D.D.L. Chung, "Defect Dynamics and Damage of Concrete Under Repeated Compression, Studied by Electrical Resistance Measurement", Cem. Concr. Res. 31 (11), 1639-1642 (2001).
105. Jingyao Cao, Sihai Wen and D.D.L. Chung, "Defect Dynamics and Damage of Cement-Based Materials, Studied by Electrical Resistance Measurement", J. Mater. Sci. 36(18), 4351-4360 (2001).
106. Jingyao Cao and D.D.L. Chung, "Cementitious Bond Degradation During Cyclic Shear Loading, Studied by Contact Electrical Resistance Measurement", J. Mater. Sci. 36(18), 4345-4349 (2001).
107. Sihai Wen and D.D.L. Chung, "Rectifying and Thermocouple Junctions Based on Portland Cement", J. Mater. Res. 16(7), 1989-1993 (2001). Erratum: 19(4), 1294 (2004).
108. Sihai Wen and D.D.L. Chung, "Carbon Fiber-Reinforced Cement as a Strain-Sensing Coating", Cem. Concr. Res. 31(4), 665-667 (2001).
109. Jingyao Cao and D.D.L. Chung, "Minor Damage of Cement Mortar During Cyclic Compression, Monitored by Electrical Resistivity Measurement", Cem. Concr. Res., 31(10), 1519-1521 (2001).
110. Jingyao Cao and D.D.L. Chung, "Carbon Fiber Reinforced Cement Mortar Improved by Using Acrylic Dispersion as an Admixture", Cem. Concr. Res., 31(11), 1633-1637 (2001).
111. Jingyao Cao and D.D.L. Chung, "Degradation of the Bond between Old and New Mortar under Cyclic Shear Loading, Monitored by Contact Electrical Resistance Measurement", Cem. Concr. Res. 31(11), 1647-1651 (2001).
112. Sihai Wen and D.D.L. Chung, "Cement-Based Controlled Electrical Resistivity Materials", J. Electron. Mater. 30(11), 1448-1451 (2001).

113. Sihai Wen and D.D.L. Chung, "Piezoelectric Cement-Based Materials with Large Coupling and Voltage Coefficients", Cem. Concr. Res. 32(3), 335-339 (2002).
114. Jingyao Cao and D.D.L. Chung, "Defect Dynamics of Cement Mortar under Repeated Loading, Studied by Electrical Resistivity Measurement", Cem. Concr. Res. 31(11), 379-385 (2002).
115. D.D.L. Chung, "Improving Cement-Based Materials by Using Silica Fume", J. Mater. Sci. 37(4) 673-682 (2002).
116. D.D.L. Chung, "Electrical Conduction Behavior of Cement-Matrix Composites", J. Mater. Eng. Perf. 11(2), 194-204 (2002).
117. Sihai Wen and D.D.L. Chung, "Origin of the Thermoelectric Behavior of Steel Fiber Cement Paste", Cem. Concr. Res. 32 (5), 821-823 (2002).
118. Jingyao Cao and D.D.L. Chung, "Effect of Strain Rate on Cement Mortar under Compression, Studied by Electrical Resistivity Measurement", Cem. Concr. Res. 32(5), 817-819 (2002).
119. Sihai Wen and D.D.L. Chung, "Thermoelectric Behavior of Carbon-Cement Composites", Carbon 40(13), 2495-2497 (2002).
120. Sihai Wen and D.D.L. Chung, "Cement-Based Materials for Stress Sensing by Dielectric Measurement", Cem. Concr. Res. 32(9), 1429-1433 (2002).
121. Jingyao Cao and D.D.L. Chung, "Damage Evolution During Freeze-Thaw Cycling of Cement Mortar, Studied by Electrical Resistivity Measurement", Cem. Concr. Res. 32(10), 1657-1661 (2002).
122. D.D.L. Chung, "Piezoresistive Cement-Based Materials for Strain Sensing", J. Intelligent Material Systems and Structures 13(9), 599-609 (2002).
123. D.D.L. Chung, "Structural Composite Materials Tailored for Damping", J. Alloys Compounds 355(1-2), 216-223 (2003).
124. Sihai Wen and D.D.L. Chung, "Effect of Fiber Content on the Thermoelectric Behavior of Cement", J. Mater. Sci. 39(13), 4103-4106 (2004).
125. Jingyao Cao and D.D.L. Chung, "Colloidal Graphite as an Admixture in Cement and as a Coating on Cement for Electromagnetic Interference Shielding", Cem. Concr. Res. 33(11), 1737-1740 (2003).
126. Sihai Wen and D.D.L. Chung, "Pyroelectric Behavior of Cement-Based Materials", Cem. Concr. Res. 33(10), 1675-1679 (2003).
127. Jingyao Cao and D.D.L. Chung, "Coke Powder as an Admixture in Cement for Electromagnetic Interference Shielding", Carbon 41(12), 2433-2436 (2003).
128. Sihai Wen and D.D.L. Chung, "A Comparative Study of Steel- and Carbon-Fibre Cement as Piezoresistive Strain Sensors", Adv. Cem. Res. 15(3), 119-128 (2003).
129. D.D.L. Chung, "Damage in Cement-Based Materials, Studied by Electrical Resistance Measurement", Mater. Sci. Eng. R 42(1), 1-40 (2003).
130. Sihai Wen and D.D.L. Chung, "Electromagnetic Interference Shielding Reaching 70 dB in Steel Fiber Cement", Cem. Concr. Res. 34(2), 329-332 (2004).
131. Jingyao Cao and D.D.L. Chung, "Electric Polarization and Depolarization in Cement-Based Materials, Studied by Apparent Electrical Resistance Measurement", Cem. Concr. Res. 34(3), 481-485 (2004).
132. Shoukai Wang, Sihai Wen and D.D.L. Chung, "Resistance Heating Using Electrically Conductive Cements", Adv. Cem. Res. 16(4), 161-166 (2004).
133. D.D.L. Chung, "Cement-Matrix Structural Nanocomposites", Metals and Materials Int. 10(1), 55-67 (2004).
134. D.D.L. Chung, "Use of Polymers for Cement-Based Structural Materials", J. Mater. Sci. 39(9), 2973-2978 (2004).
135. Jingyao Cao and D.D.L. Chung, "Use of Fly Ash as an Admixture for Electromagnetic Interference Shielding", Cem. Concr. Res. 34(10), 1889-1892 (2004).
136. Jingyao Cao and D.D.L. Chung, "Microstructural Effect of the Shrinkage of Cement-Based Materials during Hydration, as Indicated by Electrical Resistivity Measurement", Cem. Concr. Res. 34(10), 1893-1897 (2004).
137. Jingyao Cao and D.D.L. Chung, "Role of Moisture in the Seebeck Effect in Cement-Based Materials", Cem. Concr. Res. 35(4), 810-812 (2005).
138. D.D.L. Chung, "Electrically Conductive Cement-Based Materials", Adv. Cem. Res. 16(4), 167-176 (2004).
139. D.D.L. Chung, "Dispersion of Short Fibers in Cement", J. Mater. Civil Eng. 17(4), 379-383 (2005).
140. Sihai Wen and D.D.L. Chung, "Strain Sensing Characteristics of Carbon Fiber Reinforced Cement", ACI Mater. J. 102(4), 244-248 (2005).
141. Jingyao Cao and D.D.L. Chung, Reply to Discussion by Peter J. Tumidajski of the paper "Colloidal Graphite as an Admixture in Cement and as a Coating on Cement for Electromagnetic Interference Shielding", Cem. Concr. Res. 35, 616-617 (2005).
142. Sihai Wen and D.D.L. Chung, "Effects of Strain and Damage on the Strain Sensing Ability of Carbon Fiber Cement", J. Mater. Civil Eng. 18(3), 355-360 (2006).
143. Sihai Wen and D.D.L. Chung, "Spatially Resolved Self-Sensing of Strain and Damage in Carbon Fiber Cement", J. Mater. Sci. 41(15), 4823-4831 (2006).
144. D.D.L. Chung, "Discussion of 'Resistance Changes during Compression of Carbon Fiber Cement Composites' by Farhad Reza, Gordon B. Batson, Jerry A. Yamamuro and Jong S. Lee", J. Mater. Civil Eng. 17(5), 605 (2005).
145. Sihai Wen and D.D.L. Chung, "Self-Sensing of Flexural Damage and Strain in Carbon Fiber Reinforced Cement and Effect of Embedded Steel Reinforcing Bars", Carbon 44(8), 1496-1502 (2006).
146. Sihai Wen and D.D.L. Chung, "Model of Piezoresistivity in Carbon Fiber Cement", Cem. Concr. Res. 36(10), 1879-

- 1885 (2006).
147. Sihai Wen and D.D.L. Chung, "The Role of Electronic and Ionic Conduction in the Electrical Conductivity of Carbon Fiber Reinforced Cement", Carbon 44(11), 2130-2138 (2006).
 148. Sirong Zhu and D.D.L. Chung, "Theory of Piezoresistivity for Strain Sensing in Carbon Fiber Reinforced Cement Under Flexure", J. Mater. Sci. 42(15), 6222-6233 (2007).
 149. Sihai Wen and D.D.L. Chung, "Partial Replacement of Carbon Fiber by Carbon Black in Multifunctional Cement-Matrix Composites", Carbon 45(3), 505-513 (2007) (Published on line in 2006).
 150. Sihai Wen and D.D.L. Chung, "Piezoresistivity-Based Strain Sensing in Carbon Fiber Reinforced Cement", ACI Mater. J. 104(2), 171-179 (2007).
 151. Sihai Wen and D.D.L. Chung, "Electrical-Resistance-Based Damage Self-Sensing in Carbon Fiber Reinforced Cement", Carbon 45(4), 710-716 (2007).
 152. Sihai Wen and D.D.L. Chung, "Double Percolation in the Electrical Conduction in Carbon Fiber Reinforced Cement-Based Materials", Carbon 45(2), 263-267 (2007) (Published on line in 2006).
 153. Sirong Zhu, Zhuoqiu Li, Xianhui Song and D.D.L. Chung, "Deformation Adjustment of Concrete Beams Laminated with Carbon Fiber Mats", Construction and Building Materials 21(3), 621-625 (2007) (Published online in 2006).
 154. D.D.L. Chung, "Discussion from the September-October 2006 ACI Materials Journal/Page 340 (103-M38) 'Monitoring Fiber Dispersion in Fiber-Reinforced Cementitious Materials: Comparison of AC-Impedance Spectroscopy and Image Analysis' Paper by Nilufer Ozyurt, Leta Y. Woo, Thomas O. Mason, and Surendra P. Shah", ACI Mater. J. 104(4), 434-437 (2007).
 155. Sirong Zhu and D.D.L. Chung, "Numerical Assessment of the Methods of Measurement of the Electrical Resistance in Carbon Fiber Reinforced Cement", Smart Mater. Struct. 16, 1164-1170 (2007).
 156. D.D.L. Chung, "Comment on 'Cement based electromagnetic shielding and absorbing building materials' by Guan et al.", Cement and Concrete Composites 30(2), 152 (2008).
 157. Sihai Wen and D.D.L. Chung, "Effect of Moisture on the Piezoresistivity of Carbon Fiber Reinforced Cement", ACI Materials J. 105(3), 274-280 (2008).
 158. Chiung-Yi Huang, Shoukai Wang and D.D.L. Chung, "Cement-Based Piezoelectret", Materials and Structures 42, 541-557 (2009) (Online First, Sept. 2008).
 159. Chiung-Yi Huang and D.D.L. Chung, "Controlling and Increasing the Inherent Voltage in Cement Paste", Adv. Cem. Res. 21(1), 31-37 (2009).
 160. D.G. Meehan, Shoukai Wang and D.D.L. Chung, "Electrical-Resistance-Based Sensing of Impact Damage in Carbon Fiber Reinforced Cement-Based Materials", J. Intell. Mater. Systems Struct. 21(1), 83-105 (2010).
 161. Sivaraja Muthusamy, Shoukai Wang and D.D.L. Chung, "Unprecedented Vibration Damping with High Values of Loss Modulus and Loss Tangent, Exhibited by Cement-Matrix Graphite Network Composite", Carbon 48(5), 1457-1464 (2010).
 162. Sivaraja Muthusamy and D.D.L. Chung, "Carbon Fiber Cement-Based Materials for Electromagnetic Interference Shielding", ACI Mater. J. 107(6), 602-610 (2010).
 163. F.J. Baeza, D.D.L. Chung, E. Zornoza, L.G. Andión, P. Garcés, "Triple Percolation in Concrete Reinforced with Carbon Fiber", ACI Mater. J. 107(4), 396-402 (2010).
 164. Qiaoli Meng and D.D.L. Chung, "Battery in the Form of a Cement-Matrix Composite", Cem. Concr. Composites 32, 829-839 (2010).
 165. Po-Hsiu Chen and D.D.L. Chung, "Mechanical Energy Dissipation Using Cement-Based Materials with Admixtures", ACI Mater. J. 110(3), 279-290 (2013).
 166. Po-Hsiu Chen and D.D.L. Chung, "Comparative evaluation of cement-matrix composites with distributed versus networked exfoliated graphite", Carbon 63, 446-453 (2013).
 167. Po-Hsiu Chen, Chi Xu and D.D.L. Chung, "Sound absorption enhancement using solid-solid interfaces in a non-porous cement-based structural material", Composites, Part B, 95, 453-461 (2016).
 168. Yulin Wang, D.D.L. Chung. Effect of the fringing electric field on the apparent electric permittivity of cement-based materials. Composites, Part B, 126, 192-201 (2017).
 169. Alexander S. Haddad and D.D.L. Chung, "Decreasing the electric permittivity of cement by graphite particle incorporation", Carbon 122C, 702-709 (2017).
 170. Yulin Wang and D.D.L. Chung. Capacitance-based defect detection and defect location determination for cement-based material. Materials and Structures 50, 237 (2017). <https://doi.org/10.1617/s11527-017-1094-7>
 171. Yulin Wang and D.D.L. Chung. Capacitance-based nondestructive detection of aggregate proportion variation in a cement-based slab. Composites, Part B, 134, 18-27 (2018).
 172. Min Wang and D.D.L. Chung. Understanding the increase of the electric permittivity of cement caused by latex addition. Composites, Part B, 134, 177-185 (2018).
 174. Min Wang and D.D.L. Chung. High electric permittivity of polymer-modified cement due to the capacitance of the interface between polymer and cement. J. Mater. Sci. 53(10), 7199-7213 (2018).
 175. D.D.L. Chung and Yulin Wang. Capacitance-based stress self-sensing in cement paste without requiring any admixture. Cement and Concrete Composites 94, 255-263 (2018).
 176. Kairong Shi and D.D.L. Chung. Piezoelectricity-based self-sensing of compressive and flexural stress in cement-based materials without admixture requirement and without poling. Smart Mater. Struct. 27(10), 105011

- (20 pp) (2018).
177. Xiang Xi and D.D.L. Chung. Deviceless cement-based structures as energy sources that enable structural self-powering. *Applied Energy* 280, 115916 (2020).
 178. D.D.L. Chung. Self-sensing concrete: from resistance-based sensing to capacitance-based sensing (Invited Paper). *Int. J. Smart and Nano Mater.* 12(1), 1-19 (2021). DOI:10.1080/19475411.2020.1843560.
 179. Murat Ozturk and D.D.L. Chung. Enhancing the electromagnetic interference shielding effectiveness of carbon-fiber reinforced cement paste by coating the carbon fiber with nickel. *J. Building Engineering* 41, 102757 (2021).
 180. Xiang Xi, Murat Ozturk and D.D.L. Chung. DC electric polarization of cured cement paste being unexpectedly hindered by free water. *J. American Ceramic Society* 105(2), 1074-1082 (2022).
 181. D.D.L. Chung and Murat Ozturk. Electromagnetic skin depth of cement paste and its thickness dependence. *J. Building Eng.* 52, 104393 (2022).
 182. D.D.L. Chung. A critical review of electrical-resistance-based self-sensing in conductive cement-based materials. *Carbon* 203, 311-325 (2023).
 183. D.D.L. Chung. First review of capacitance-based self-sensing in structural materials. *Sensor Actuators A* 354, 114270 (2023).
 184. D.D.L. Chung, Xiang Xi. A review of cement-based materials as electroceramics. *Ceramics Int.* 49, 24621-24642 (2023).
 185. Murat Ozturk, D.D.L. Chung. Piezopermittivity of cement mortar with various water contents and its application to capacitance-based structural self-sensing of stress. *Sensors Actuators A* 369, 115206 (2024).
 186. Min Kyoung Kim, Mohammad A. Al-Qaralleh, D.D.L. Chung. Strong piezoresistivity and piezopermittivity of cement-based material without functional admixture and their correlation. *Cem. Concr. Composites* 151, 105587 (2024).
 187. D.D.L. Chung. A review of microwave absorption and reflection by cement-based materials, with emphasis on electromagnetic interference shielding and admixture effects. *Adv. Funct. Mater.* 2408220 (2024).
 188. D.D.L. Chung, Murat Ozturk. Spatially resolved capacitance-based stress self-sensing in concrete. *ISA Trans.* 152, 299-307 (2024). <https://authors.elsevier.com/a/1jOja4LK%7Er7IF>
 189. Mohammad A. Al-Qaralleh and D.D.L. Chung. Inductance and piezoinductance of steel wire rope, with relevance to inductance-based structural self-sensing of stress. *Construction and Building Materials* 470, 140599 (2025).

POLYMER-MATRIX COMPOSITES (129 journal papers)

1. S. Fang, D.D.L. Chung, Carbon fibre composites with improved fatigue resistance due to the addition of tin-lead alloy particles. *Composites* 21(5), 419-424 (1990).
2. Mingguang Zhu and D.D.L. Chung, "Resilient Composite of Silicone and Foamed Tin as a New Material for Electrical Contacts and Thermal Contacts", *Composites* 22(3), 219-226 (1991).
3. Lin Li and D.D.L. Chung, "Electrically Conducting Powder Filled Polyimidesiloxane", *Composites* 22(3), 211-218 (1991).
4. Mingguang Zhu and D.D.L. Chung, "Nickel Fiber Silicone-Matrix Composites as Resilient Electrical Conductors", *J. Electronic Packaging* 113, 417-420 (1991).
- 5.. Mingguang Zhu and D.D.L. Chung, "A Three-Dimensionally Interconnected Metal Spring Network in a Silicone Matrix as a Resilient and Electrically Conducting Composite Material", *Composites* 23(5), 355-364 (1992).
6. Lin Li and D.D.L. Chung, "Electrical and Mechanical Properties of Electrically Conductive Polyethersulfone Composite", *Composites* 25(3), 215-224 (1994).
7. Lin Li, Pay Yih and D.D.L. Chung, "Effect of the Second Filler Which Melted During Composite Fabrication on the Electrical Properties of Short Fiber Polymer-Matrix Composites", *J. Electronic Mater.* 21(11), 1065-1071 (1992).
8. Mingguang Zhu and D.D.L. Chung, "Resilient Metal Spring Network Silicone-Matrix Composite for Separable Interconnections", *J. Electron.Mater.* 23(7), 641-647 (1994).
9. Lin Li and D.D.L. Chung, "Tin-Lead Flake Polyether Sulfone Composite Formed by In-Situ Melt Processing of Tin-Lead Particles", *Polymer Composites* 14(5), 361-366 (1993).
10. Lin Li and D.D.L. Chung, "Effect of Viscosity on the Electrical Properties of Conducting Thermoplastic Composites Made by Compression Molding of a Powder Mixture", *Polymer Composites* 14(6), 467-472 (1993).
11. Lin Li and D.D.L. Chung, "Thermally Conducting Polymer-Matrix Composites Containing both AlN Particles and SiC Whiskers", *J. Electron. Mater.* 23(6), 557-564 (1994).
12. Xiaoping Shui and D.D.L. Chung, "Submicron Nickel Filaments Made by Electroplating Carbon Filaments as a New Filler Material for Electromagnetic Interference Shielding", *J. Electron.Mater.* 24(2), 107-113 (1995).
13. Xiaojun Wang and D.D.L. Chung, "Short Carbon Fiber Reinforced Epoxy as a Piezoresistive Strain Sensor", *Smart Mater.Struct.* 4, 363-367 (1995).
14. Xiaojun Wang and D.D.L. Chung, "Continuous Carbon Fiber Epoxy-Matrix Composite as a Sensor of Its Own Strain", *Smart Mater.Struct.* 5(6), 796-800 (1996).
15. Xiaoping Shui and D.D.L. Chung, "Piezoresistive Carbon Filament Polymer-Matrix Composite Strain Sensor," *Smart*

- Mater.Struct.5, 243-246 (1996).
16. Steven W. Hudnut and D.D.L. Chung, "Use of Submicron Diameter Carbon Filaments for Reinforcement between Continuous Carbon Fiber Layers in a Polymer-Matrix Composite," Carbon 33(11), 1627-1631 (1995).
 17. Steven W. Hudnut and D.D.L. Chung, "Enhancing the Loss Modulus of Carbon Fiber Polymer-Matrix Composites by Addition of Particles in the Interlaminar Region," Plastics, Rubber and Composites Processing and Applications 25(2), 77-81 (1996).
 18. Xiaoping Shui and D.D.L. Chung, "Nickel Filament Polymer-Matrix Composites with Low Surface Impedance and High Electromagnetic Interference Shielding Effectiveness," J. Electron.Mater., 26(8), 928-934 (1997).
 19. Xiaoping Shui and D.D.L. Chung, "Magnetic Properties of Nickel Filament Polymer-Matrix Composites," J. Electron.Mater.25(6), 930-934 (1996).
 20. Xiaoping Shui and D.D.L. Chung, "A New Electromechanical Effect in Discontinuous-Filament Elastomer-Matrix Composites," Smart Mater.Struct.6, 102-105 (1997).
 21. Lin Li and D.D.L. Chung, "Z-Axis Anisotropic Electrically Conducting Polymer-Matrix Composite Film," J. Electronic Packaging 119(4), 255-259 (1997).
 22. Xiaoping Shui and D.D.L. Chung, "0.4 μm Diameter Nickel Filament Silicone-Matrix Resilient Composites for Electromagnetic Interference Shielding," J. Electron.Packaging 119(4), 236-238 (1997).
 23. Xiaojun Wang and D.D.L. Chung, "Real-Time Monitoring of Fatigue Damage and Dynamic Strain in Carbon Fiber Polymer-Matrix Composite by Electrical Resistance Measurement," Smart Mater.Struct.6, 504-508 (1997).
 24. Xiaojun Wang and D.D.L. Chung, "Sensing Delamination in a Carbon Fiber Polymer-Matrix Composite During Fatigue by Electrical Resistance Measurement," Polymer Composites, 18(6), 692-700 (1997).
 25. Xiaojun Wang and D.D.L. Chung, "Self-Monitoring of Fatigue Damage and Dynamic Strain in Carbon Fiber Polymer-Matrix Composite," Composites: Part B, 29B(1), 63-73 (1998).
 26. Xiaojun Wang and D.D.L. Chung, "An Electromechanical Study of the Transverse Behavior of Carbon Fiber Polymer-Matrix Composite," Composite Interfaces 5(3), 191-199 (1998).
 27. Xiaojun Wang and D.D.L. Chung, "Residual Stress in Carbon Fiber Embedded in Epoxy, Studied by Simultaneous Measurement of Applied Stress and Electrical Resistance," Composite Interfaces 5(3), 277-281 (1998).
 28. Xiaojun Wang, Xuli Fu, and D.D.L. Chung, "Electromechanical Study of Carbon Fiber Composites," J. Mater. Res. 13(11), 3081-3092 (1998).
 29. Xiaojun Wang and D.D.L. Chung, "Short Carbon Fiber Reinforced Epoxy Coating as a Piezoresistive Strain Sensor for Cement Mortar," Sensors and Actuators A 71(3), 208-212 (1998).
 30. Zhen Mei and D.D.L. Chung, "Effect of Heating on the Structure of Carbon Fiber Polyphenylenesulfide-Matrix Composite, as Studied by Electrical Resistance Measurement," Polymer Composites, 19(6), 709-713 (1998).
 31. Shoukai Wang and D.D.L. Chung, "Interlaminar Shear in Carbon Fiber Polymer-Matrix Composites, Studied by Measuring the Contact Electrical Resistance of the Interlaminar Interface During Shear," Composite Interfaces 6(6), 507-518 (1999).
 32. D.D.L. Chung and Shoukai Wang, "Carbon Fiber Polymer Matrix Structural Composite as a Semiconductor and Concept of Optoelectronic and Electronic Devices Made From It," Smart Mater. Struct.8, 161-166 (1999).
 33. Shoukai Wang and D.D.L. Chung, "Interlaminar Interface in Carbon Fiber Polymer-Matrix Composites, Studied by Contact Electrical Resistivity Measurement," Composite Interfaces 6(6), 497-506 (1999).
 34. Xiaojun Wang, Shoukai Wang, and D.D.L. Chung, "Sensing Damage in Carbon Fiber and Its Polymer-Matrix and Carbon-Matrix Composites by Electrical Resistance Measurement," J. Mater. Sci. 34(11), 2703-2714 (1999).
 35. Shoukai Wang and D.D.L. Chung, "Carbon Fiber Polymer-Matrix Composite Interfaces as Thermocouple Junctions," Composite Interfaces 6(6), 519-530 (1999).
 36. Yunsheng Xu and D.D.L. Chung, "Z-Axis Anisotropic Electrical Conductor Films in Adhesive and Standalone Forms for Electrical Interconnections," J. Electronic Mater. 28(11), 1307-1313 (1999).
 37. Zhen Mei and D.D.L. Chung, "Kinetics of Autohesion of Thermoplastic Carbon-Fiber Prepregs," Int. J. Adh. Adh. 20, 173-175 (2000).
 38. Shoukai Wang and D.D.L. Chung, "Apparent Negative Electrical Resistance in Carbon Fiber Composites," Composites: Part B 30(6), 579-590 (1999).
 39. Shoukai Wang and D.D.L. Chung, "Electrical Behavior of Carbon Fiber Polymer-Matrix Composites in the Through-Thickness Direction," J. Mater. Sci. 35(1), 91-100 (2000).
 40. Martin Segiet and D.D.L. Chung, "Discontinuous Surface-Treated Submicron-Diameter Carbon Filaments as an Interlaminar Filler in Carbon Fiber Polymer-Matrix Composites for Vibration Reduction", Composite Interfaces 7(4), 257-276 (2000).
 41. Shoukai Wang and D.D.L. Chung, "Temperature/Light Sensing Using Carbon Fiber Polymer-Matrix Composite", Composites: Part B 30(6), 591-601 (1999).
 42. Zhen Mei and D.D.L. Chung, "Thermal Stress Induced Thermoplastic Composite Debonding, Studied by Contact Electrical Resistance Measurement", Int. J. Adh. Adh. 20, 135-139 (2000).
 43. Xiaojun Wang and D.D.L. Chung, "Fiber Breakage in Polymer-Matrix Composite During Static and Dynamic Loading, Studied by Electrical Resistance Measurement", J. Mater. Res. 14(11), 4224-4229 (1999).
 44. Zhen Mei and D.D.L. Chung, "Effect of Heating Time Below the Melting Temperature on Polyphenylene Sulfide Joint Development", Int. J. Adh. Adh. 20, 273-277 (2000).

45. Xiaoping Shui and D.D.L. Chung, "Submicron Diameter Nickel Filaments and Their Polymer-Matrix Composites", J. Mater. Sci. 35, 1773-1785 (2000).
46. Yunsheng Xu and D.D.L. Chung, "Increasing the Thermal Conductivity of Boron Nitride and Aluminum Nitride Particle Epoxy-Matrix Composites by Particle Surface Treatment", Composite Interfaces 7(4), 243-256 (2000).
47. Xiangcheng Luo and D.D.L. Chung, "Carbon Fiber Polymer-Matrix Composites as Capacitors", Composites Sci. Tech. 61, 885-888 (2001).
48. Shoukai Wang and D.D.L. Chung, "Piezoresistivity in Continuous Carbon Fiber Polymer-Matrix Composite", Polymer Composites 21(1), 13-19 (2000).
49. Zhen Mei and D.D.L. Chung, "Glass Transition and Melting Behavior of Carbon Fiber Reinforced Thermoplastic Composite, Studied by Electrical Resistance Measurement", Polymer Composites 21(5), 711-715 (2000).
50. Shoukai Wang and D.D.L. Chung, "Consolidation of Carbon Fiber Laminates During Polymer-Matrix Composite Fabrication, Studied by Electrical Resistance Measurement", Polymer Composites 22(1), 42-46 (2001).
51. Xiangcheng Luo and D.D.L. Chung, "Interface in Mechanically Fastened Polymer Joint, Studied by Contact Electrical Resistance Measurement", Polymer Eng. Sci. 40(7), 1505-1509 (2000).
52. D.D.L. Chung, "Polymer-Matrix Composites for Microelectronics", Polymers & Polymer Composites 8(4), 219-229 (2000).
53. Zhen Mei and D.D.L. Chung, "Cold-Crystallization of Polyphenylene Sulfide, Studied by Measuring the Electrical Resistance of a Carbon-Fiber Polyphenylene-Sulfide-Matrix Composite", Polymers & Polymer Composites 8(5), 319-324 (2000).
54. D.D.L. Chung, "Continuous Carbon Fiber Polymer-Matrix Composites and Their Joints, Studied by Electrical Measurements", Polymer Composites 22(2), 250-270 (2001).
55. D.D.L. Chung, "Thermal Analysis of Carbon Fiber Polymer-Matrix Composites by Electrical Resistance Measurement", Thermochim. Acta 364, 121-132 (2000).
56. Zongrong Liu and D.D.L. Chung, "Calorimetric Evaluation of Phase Change Materials for Use as Thermal Interface Materials", Thermochim. Acta 366(2), 135-147 (2001).
57. Zhen Mei and D.D.L. Chung, "Thermal History of Carbon Fiber Polymer-Matrix Composite, Evaluated by Electrical Resistance Measurement", Thermochim. Acta 369 (1-2), 87-93 (2001).
58. Shoukai Wang and D.D.L. Chung, "Thermal Fatigue in Carbon Fiber Polymer-Matrix Composite, Monitored in Real Time by Electrical Resistance Measurement", Polymers & Polymer Composites 9(2), 135-140 (2001).
59. Zhen Mei and D.D.L. Chung, "Improving the Flexural Modulus and Thermal Stability of Pitch by the Addition of Silica Fume", J. Reinf. Plastics Composites, 21(1), 91-95 (2002).
60. Yunsheng Xu, D.D.L. Chung and Cathleen Mroz, "Thermally Conducting Aluminum Nitride Polymer-Matrix Composites", Composites, Part A, 32, 1749-1757 (2001).
61. Shoukai Wang, Sang-il Lee, D.D.L. Chung and Joung-Man Park, "Load Transfer from Fiber to Polymer Matrix, Studied by Measuring the Apparent Elastic Modulus of Carbon Fiber Embedded in Epoxy", Composite Interfaces 8(6), 435-441 (2001).
62. Shoukai Wang and D.D.L. Chung, "Mechanical Damage in Carbon Fiber Polymer-Matrix Composite, Studied by Electrical Resistance Measurement", Composite Interfaces 9(1), 51-60 (2002).
63. Shoukai Wang, Zhen Mei and D.D.L. Chung, "Interlaminar Damage in Carbon Fiber Polymer-Matrix Composites, Studied by Electrical Resistance Measurement", Int. J. Adh. Adh. 21(ER6), 465-471 (2001).
64. D.D.L. Chung, "Thermal Analysis by Electrical Resistivity Measurement", J. Thermal Analysis and Calorimetry 65, 153-165 (2001).
65. Yunsheng Xu, Xiangcheng Luo and D.D.L. Chung, "Lithium Doped Polyethylene-Glycol-Based Thermal Interface Pastes for High Thermal Contact Conductance", J. Electron. Packaging 124(3), 188-191 (2002).
66. Daniel P. Kowalik and D.D.L. Chung, "Carbon Black Filled Silicone as a Compliant Thermoelectric Material", J. Reinf. Plastics Compos. 21(17), 1587-1590 (2002).
67. Zhen Mei, Victor H. Guerrero, Daniel P. Kowalik and D.D.L. Chung, "Reverse Piezoelectric Behavior of Carbon Fiber Thermoplastic-Matrix Composite", Polymer Composites 23(5), 697-701 (2002).
68. Zhen Mei, Victor H. Guerrero, Daniel P. Kowalik and D.D.L. Chung, "Mechanical Damage and Strain in Carbon Fiber Thermoplastic-Matrix Composite, Sensed by Electrical Resistivity Measurement", Polymer Composites 23(3), 425-432 (2002).
69. Zhen Mei and D.D.L. Chung, "Thermoplastic Matrix Phase Transitions in a Carbon Fiber Composite, Studied by Contact Electrical Resistivity Measurement of the Interface between Two Unbonded Laminates", Polymer Composites 23(5), 824-827 (2002).
70. Shoukai Wang, Daniel P. Kowalik and D.D.L. Chung, "Effects of the Temperature, Humidity and Stress on the Interlaminar Interface of Carbon Fiber Polymer-Matrix Composites, Studied by Contact Electrical Resistivity Measurement", J. Adhesion 78(2), 189-200 (2002).
71. Shoukai Wang, and D.D.L. Chung, "Effect of Moisture on the Interlaminar Interface of a Carbon Fiber Polymer-Matrix Composite, Studied by Contact Electrical Resistivity Measurement", Composite Interfaces 9(5), 453-458 (2002).
72. Junhua Wu and D.D.L. Chung, "Decreasing the Electromagnetic Observability of Carbon Fiber Polymer-Matrix Composites by Using Epoxy-Coated Carbon Fibers", Composite Interfaces 9(4), 389-393 (2002).
73. Victor H. Guerrero and D.D.L. Chung, "Enhancement of the Absolute Thermoelectric Power of Carbon Fiber Polymer-

- Matrix Composite in the Through-Thickness Direction", Composite Interface 9(4), 395-401 (2002).
74. Victor H. Guerrero, Shoukai Wang, Sihai Wen and D.D.L. Chung, "Thermoelectric Property Tailoring by Composite Engineering", J. Mater. Sci. 37(19), 4127-4136 (2002).
 75. Victor H. Guerrero and D.D.L. Chung, "Interlaminar Interface Relaxation Upon Heating Carbon Fiber Thermoplastic-Matrix Composite, Studied by Electrical Resistance Measurement", Composite Interface 9(6), 557-563 (2002).
 76. D.D.L. Chung and Shoukai Wang, "Self-Sensing of Damage and Strain in Carbon Fiber Polymer-Matrix Structural Composites by Electrical Resistance Measurement", Polym. & Polym. Compos. 11(7), 515-525 (2003).
 77. Adam Fosbury, Shoukai Wang, Yat F. Pin and D.D.L. Chung, "The Interlaminar Interface of a Carbon Fiber Polymer-Matrix Composite as a Resistance Heating Element", Composites: Part A 34, 933-940 (2003).
 78. Jun Xiao and D.D.L. Chung, "Thermal and Mechanical Stability of Electrically Conductive Adhesive Joints", J. Electron. Mater. 34(5), 625-629 (2005).
 79. Jun Xiao and D.D.L. Chung, "Electrothermomechanical Analysis and Its Application to Studying Electrically Conductive Adhesive Joints", J. Thermal Analysis Calorimetry 74, 3-11 (2003).
 80. Dwayne A. Gordon, Shoukai Wang and D.D.L. Chung, "Piezoresistivity in Unidirectional Continuous Carbon Fiber Polymer-Matrix Composites: Single-Lamina Composite Versus Two-Lamina Composite", Composite Interfaces 11(1), 95-103 (2004).
 81. D.D.L. Chung, "Self-Heating Structural Materials", Smart Mater. Struct. 13(3), 562-565 (2004).
 82. Shoukai Wang, Daniel P. Kowalik and D.D.L. Chung, "Self-Sensing Attained in Carbon Fiber Polymer-Matrix Structural Composites by Using the Interlaminar Interface as a Sensor", Smart Mater. Struct. 13(3), 570-592 (2004).
 83. Junhua Wu and D.D.L. Chung, "Calorimetric Study of the Effect of Carbon Fillers on the Curing of Epoxy", Carbon 42(14), 3039-3042 (2004).
 84. Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Effects of Composite Lay-Up Configuration and Thickness on the Damage Self-Sensing Behavior of Carbon Fiber Polymer-Matrix Composite", J. Mater. Sci. 40(2), 561-568 (2005).
 85. Shoukai Wang and D.D.L. Chung, "The Interlaminar Interface of a Carbon Fiber Epoxy-Matrix Composite as an Impact Sensor", J. Mater. Sci. 40, 1863-1867 (2005).
 86. Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Impact Damage of Carbon Fiber Polymer-Matrix Composites, Monitored by Electrical Resistance Measurement", Composites: Part A, 36, 1707-1715 (2005).
 87. Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Self-Sensing of Damage in Carbon Fiber Polymer-Matrix Composite Cylinder by Electrical Resistance Measurement", Journal of Intelligent Material Systems and Structures 17(1), 57-62 (2006).
 88. Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Self-Sensing of Damage in Carbon Fiber Polymer-Matrix Composite by Measurement of the Electrical Resistance or Potential Away from the Damaged Region", J. Mater. Sci. 40(24), 6463-6472 (2005).
 89. Shoukai Wang and D.D.L. Chung, "Discussion on Paper 'The Electrical Resistance Response of Continuous Carbon Fibre Composite Laminates to Mechanical Strain' by N. Angelidis, C.Y. Wei and P.E. Irving, Composites: Part A 35, 1135-1147 (2004)", Composites: Part A, 37(9), 1490-1494 (2006).
 90. Chia-Ken Leong, Shoukai Wang and D.D.L. Chung, "Effect of Through-Thickness Compression on the Microstructure of Carbon Fiber Polymer-Matrix Composites, as Studied by Electrical Resistance Measurement", J. Mater. Sci. 41(10), 2877-2884 (2006).
 91. Shoukai Wang, Daojun Wang, D.D.L. Chung and Jaycee H. Chung, "Method of Sensing Impact Damage in Carbon Fiber Polymer-Matrix Composite by Electrical Resistance Measurement", J. Mater. Sci. 41(8), 2281-2289 (2006).
 92. Daojun Wang, Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Comparison of the Electrical Resistance and Potential Techniques for the Self-Sensing of Damage in Carbon Fiber Polymer-Matrix Composites", J. Intell. Mater. Syst. Struct. 17(10), 853-861 (2006).
 93. Daojun Wang, Shoukai Wang, D.D.L. Chung and Jaycee H. Chung, "Sensitivity of the Two-Dimensional Electric Potential/Resistance Method for Damage Monitoring in Carbon Fiber Polymer-Matrix Composite", J. Mater. Sci. 41(15), 4839-4846 (2006).
 94. Zongrong Liu and D.D.L. Chung, "Boron Nitride Particle Filled Paraffin Wax as a Phase-Change Thermal Interface Material", J. Electron. Packaging 128(4), 319-323 (2006).
 95. Yasuhiro Aoyagi, Chia-Ken Leong and D.D.L. Chung, "Polyol-Based Phase-Change Thermal Interface Materials", J. Electron. Mater. 35(3), 416-424 (2006).
 96. Shoukai Wang and D.D.L. Chung, "Self-Sensing of Flexural Strain and Damage in Carbon Fiber Polymer-Matrix Composite by Electrical Resistance Measurement", Carbon 44(13), 2739-2751 (2006).
 97. Daojun Wang and D.D.L. Chung, "Comparative Evaluation of the Electrical Configurations for the Two-Dimensional Electric Potential Method of Damage Monitoring in Carbon Fiber Polymer-Matrix Composite", Smart Mater. Struct. 15, 1332-1344 (2006).
 98. Shoukai Wang and D.D.L. Chung, "Negative Piezoresistivity in Continuous Carbon Fiber Epoxy-Matrix Composite", J. Mater. Sci. 42(13), 4987-4995 (2007).
 99. Shoukai Wang, Dick S. Pang and D.D.L. Chung, "Hygrothermal Stability of Electrical Contacts Made from Silver and Graphite Electrically Conductive Pastes", J. Electron. Mater. 36(1), 65-74 (2007).
 100. D.D.L. Chung, "Damage Detection Using Self-Sensing Concepts" (Invited Review), J. Aerospace Eng. (Proceedings of the Institution of Mechanical Engineers, Part G) 221(G4), 509-520 (2007).

101. Yasuhiro Aoyagi and D.D.L. Chung, "Effects of Antioxidants and the Solid Component on the Thermal Stability of Polyol-Ester-Based Thermal Pastes", *J. Mater. Sci.* 42(7), 2358-2375 (2007).
102. Sirong Zhu and D.D.L. Chung, "Analytical Model of Piezoresistivity for Strain Sensing in Carbon Fiber Polymer-Matrix Structural Composite under Flexure", *Carbon* 45(8), 1606-1613 (2007).
103. Daojun Wang and D.D.L. Chung, "Through-Thickness Stress Sensing of Carbon Fiber Polymer-Matrix Composite by Electrical Resistance Measurement", *Smart Mater. Struct.* 16, 1320-1330 (2007).
104. Chuangang Lin and D.D.L. Chung, "Nanostructured Fumed Metal Oxides for Thermal Interface Pastes", *J. Mater. Sci.*, 42(22), 9245-9255 (2007).
105. Yasuhiro Aoyagi and D.D.L. Chung, "Antioxidant-based phase-change thermal interface materials with high thermal stability", *J. Electron. Mater.* 37(4), 448-461 (2008). Published online: Jan. 25, 2008.
106. Junhua Wu and D.D.L. Chung, "Combined Use of Magnetic and Electrically Conductive Fillers in a Polymer Matrix for Electromagnetic Interference Shielding", *J. Electron. Mater.* 37(8), 1088-1094 (2008).
107. Chuangang Lin and D.D.L. Chung, "Nanoclay Paste as Thermal Interface Material for Smooth Surfaces", *J. Electron. Mater.* 37(11), 1698-1709 (2008).
108. Parisa Pour Shahid Saeed Abadi, Chia-Ken Leong and D.D.L. Chung, "Factors that Govern the Performance of Thermal Interface Materials", *J. Electron. Mater.* 38(1), 175-192 (2009).
109. Chuangang Lin and D.D.L. Chung, "Rheological Behavior of Thermal Interface Pastes", *J. Electron. Mater.* 38(10), 2069-2084 (2009).
110. Parisa Pour Shahid Saeed Abadi and D.D.L. Chung, "Numerical Modeling of the Performance of Thermal Interface Materials in the Form of Paste-Coated Sheets", *J. Electron. Mater.* 40(7), 1490-1500 (2011).
111. Seungjin Han and D.D.L. Chung, "Increasing the Through-Thickness Thermal Conductivity of Carbon Fiber Polymer-Matrix Composite by Curing Pressure Increase and Filler Incorporation", *Compos. Sci. Technol.* 71(16), 1944-1952 (2011).
112. Seungjin Han and D.D.L. Chung, "Mechanical Energy Dissipation Using Carbon Fiber Polymer-Matrix Structural Composites with Filler Incorporation", *J. Mater. Sci.* 47, 2434-2453 (2012).
113. Seungjin Han and D.D.L. Chung, "Through-thickness thermoelectric power of a carbon fiber/epoxy composite and decoupled contributions from a lamina and an interlaminar interface", *Carbon* 52, 30-39 (2013).
114. Seungjin Han and D.D.L. Chung, "Carbon fiber polymer-matrix structural composites exhibiting greatly enhanced through-thickness thermoelectric figure of merit", *Composites, Part A* 48, 162-170 (2013).
115. Daojun Wang and D.D.L. Chung, "Through-Thickness Piezoresistivity in a Carbon Fiber Polymer-Matrix Structural Composite for Electrical-Resistance-Based Through-Thickness Strain Sensing", *Carbon* 60(1), 129-138 (2013).
116. Seungjin Han and D.D.L. Chung, "Strengthening and stiffening carbon fiber epoxy composites by halloysite nanotubes, carbon nanotubes and silicon carbide whiskers", *Applied Clay Science*, 83-84, 375-382 (2013).
117. Yoshihiro Takizawa and D.D.L. Chung, "Through-thickness thermal conduction in glass fiber polymer-matrix composites and its enhancement by composite modification", *J. Mater. Sci.* 51, 3463-3480 (2016).
118. Yoshihiro Takizawa and D.D.L. Chung, "Continuous carbon fiber polymer-matrix composites in unprecedented antiferroelectric coupling providing exceptionally high through-thickness electric permittivity", *J. Mater. Sci.* 51(14), 6913-6932 (2016).
119. D.D.L. Chung, "Processing-structure-property relationships of continuous carbon fiber polymer-matrix composites", *Mater. Sci. Eng. R* 113, 1-29 (2017).
120. Asma A. Eddib and D.D.L. Chung, First report of capacitance-based self-sensing and in-plane electric permittivity of carbon fiber polymer-matrix composite. *Carbon* 140, 413-427 (2018).
121. D.D.L. Chung, Thermoelectric polymer-matrix structural and nonstructural composite materials. *Advanced Industrial and Engineering Polymer Research* 1, 61-65 (2018).
122. D.D.L. Chung, Development, design and applications of structural capacitors. *Applied Energy* 231, 89-101 (2018).
123. D.D.L. Chung and Asma A. Eddib, Effect of fiber lay-up configuration on the electromagnetic interference shielding effectiveness of continuous carbon fiber polymer-matrix composite. *Carbon* 141, 685-691 (2019).
124. D.D.L. Chung, A review of multifunctional polymer-matrix structural composites. *Composites, Part B*, 160, 644-660 (2019).
125. Xueping Wu, Junshuai Zhao, Xu Rao, D.D.L. Chung, Carbon fiber epoxy-matrix composites with hydrothermal-carbon-coated halloysite nanotube filler exhibiting enhanced strength and thermal conductivity. *Polymer Composites* 41(7), 2687-2703 (2020).
126. D.D.L. Chung, A critical review of piezoresistivity and its application in electrical-resistance-based strain sensing. *J. Materials Science* 55(32), 15367-15396 (2020).
127. Murat Ozturk, D.D.L. Chung, Capacitance-based stress self-sensing effectiveness of a model asphalt without functional component. *Construction and Building Materials* 294, 123591 (2021).
128. Murat Ozturk and D.D.L. Chung, Capacitance-based stress self-sensing in asphalt without electrically conductive constituents, with relevance to smart pavements. *Sensors and Actuators A* 342, 113625 (2022).
129. D.D.L. Chung, A review to elucidate the multi-faceted science of the electrical-resistance-based strain /temperature/damage self-sensing in continuous carbon fiber polymer-matrix structural composites. *J. Mater.*

METAL-MATRIX COMPOSITES (32 journal papers)

1. Jingyu Yang and D.D.L. Chung, "Casting Particulate and Fibrous Metal-Matrix Composites by Vacuum Infiltration of a Liquid Metal Under an Inert Gas Pressure", *J. Mater. Sci.* 24, 3605-3612 (1989).
2. Jingyu Yang and D.D.L. Chung, "Wear of Bauxite Particle Reinforced Aluminum Alloys", *Wear* 135, 53-65 (1989).
3. C.T. Ho and D.D.L. Chung, "Carbon Fiber Reinforced Tin-Superconductor Composites", *J. Mater. Res.* 4(6), 1339-1346 (1989).
4. Jeng-Maw Chiou and D.D.L. Chung, "Characterization of Metal-Matrix Composites Fabricated by Vacuum Infiltration of a Liquid Metal under an Inert Gas Pressure", *J. Mater. Sci.* 26, 2583-2589 (1991).
5. C.T. Ho and D.D.L. Chung, "Carbon Fiber Reinforced Tin-Lead Alloy as a Low Thermal Expansion Solder Preform", *J. Mater. Res.* 5(6), 1266-1270 (1990).
6. Jimin Cao and D.D.L. Chung, "Carbon Fiber Silver-Copper Brazing Filler Composites for Brazing Ceramics", *Welding J.* 71(1), 21-s - 24-s (1992).
7. Jeng-Maw Chiou and D.D.L. Chung, "Improving the Temperature Resistance of Aluminum-Matrix Composites by Using an Acid Phosphate Binder, Part I: Binders", *J. Mater. Sci.* 28, 1435-1446 (1993).
8. Jeng-Maw Chiou and D.D.L. Chung, "Improving the Temperature Resistance of Aluminum-Matrix Composites by Using an Acid Phosphate Binder, Part II: Preforms", *J. Mater. Sci.* 28, 1447-1470 (1993).
9. Jeng-Maw Chiou and D.D.L. Chung, "Improving the Temperature Resistance of Aluminum-Matrix Composites by Using an Acid Phosphate Binder, Part III: Aluminum-Matrix Composites", *J. Mater. Sci.* 28, 1471-1487 (1993).
10. Mingguang Zhu and D.D.L. Chung, "Active Brazing Alloy Containing Carbon Fibers for Metal-Ceramic Joining", *J. Am. Ceramic Society* 77(10), 2712-2720 (1994).
11. Shy-Wen Lai and D.D.L. Chung, "Fabrication of Particulate Aluminum-Matrix Composites by Liquid Metal Infiltration", *J. Mater. Sci.* 29(12), 3128-3150 (1994).
12. Shy-Wen Lai and D.D.L. Chung, "Phase Distribution and Associated Mechanical Property Distribution in Silicon Carbide Particle Reinforced Aluminum Fabricated by Liquid Metal Infiltration", *J. Mater. Sci.* 29(11), 2998-3016 (1994).
13. Shy-Wen Lai and D.D.L. Chung, "Consumption of SiC Whiskers by the Al-SiC Reaction in Aluminum-Matrix SiC Whisker Composites", *J. Mater. Chem.* 6(3), 469-477 (1996).
14. Pay Yih and D.D.L. Chung, "Copper-Matrix Molybdenum Composites Fabricated by Powder Metallurgy Using Copper Coated Molybdenum Particles", *J. Electron. Mater.* 24(7), 841-851 (1995).
15. Yuyong Chen and D.D.L. Chung, "Silicon/Aluminum Network Composites Fabricated by Liquid Metal Infiltration", *J. Mater. Sci.* 29, 6069-6075 (1994).
16. Shy-Wen Lai and D.D.L. Chung, "Superior High Temperature Resistance of Aluminum Nitride Particle Reinforced Aluminum Compared to Silicon Carbide or Alumina Particle Reinforced Aluminum", *J. Mater. Sci.* 29, 6181-6198 (1994).
17. Shy-Wen Lai and D.D.L. Chung, "Shaping Metal-Matrix Composites by Thixotropic Machining", *J. Mater. Proc. Tech.* 58, 67-69 (1996).
18. Yuyong Chen and D.D.L. Chung, "Ductile and Strong Aluminum-Matrix Titanium Aluminide Composite Formed In-Situ from Aluminum, Titanium Dioxide and Sodium Hexafluoroaluminate", *J. Mater. Sci.* 30, 4609-4616 (1995).
19. Yuyong Chen and D.D.L. Chung, "Nickel Aluminide (Ni_3Al) Fabricated by Reactive Infiltration", *J. Mater. Sci.* 31, 2117-2122 (1996).
20. Yuyong Chen and D.D.L. Chung, "In Situ Al/TiB Composite Obtained by Stir Casting", *J. Mater. Sci.* 31, 311-315 (1996).
21. Pay Yih and D.D.L. Chung, "Silicon Carbide Whisker Copper-Matrix Composites Fabricated by Hot Pressing Copper Coated Whiskers", *J. Mater. Sci.* 31, 399-406 (1996).
22. Yuyong Chen and D.D.L. Chung, "Aluminum-Matrix Silicon Carbide Whisker Composites Fabricated by Pressureless Infiltration", *J. Mater. Sci.* 31, 407-412 (1996).
23. Pay Yih and D.D.L. Chung, "Powder Metallurgy Fabrication of Metal Matrix Composites Using Coated Fillers", *Int. J. Powder Metallurgy* 31(4), 335-340 (1995).
24. Andrew V. Smith and D.D.L. Chung, "Titanium Diboride Particle Reinforced Aluminum with High Wear Resistance", *J. Mater. Sci.* 31, 5961-5973 (1996).
25. Zheng-Qiang Shi and D.D.L. Chung, "Sandwiching Superconductor by Carbon Fiber Metal-Matrix Composite for Improving the Mechanical Properties, Air Stability and Thermal Cycling Resistance", *Composites*, Part A, 28(1), 1-4 (1997).
26. Pay Yih and D.D.L. Chung, "Titanium Diboride Copper-Matrix Composites", *J. Mater. Sci.* 32(7), 1703-1709 (1997).
27. Jiangyuan Hou and D.D.L. Chung, "Corrosion Protection of Aluminum-Matrix Aluminum Nitride and Silicon Carbide Composites by Anodization", *J. Mater. Sci.* 32(12), 3113-3134 (1997).
28. Pay Yih and D.D.L. Chung, "A Comparative Study of the Coated Filler Method and the Admixture Method of Powder Metallurgy for Making Metal-Matrix Composites", *J. Mater. Sci.* 32(11), 2873-2894 (1997).
29. Mingguang Zhu and D.D.L. Chung, "Improving the Strength of Brazed Joints to Alumina by Adding Carbon Fibers", *J. Mater. Sci.* 32, 5321-5333 (1997).
30. Pay Yih and D.D.L. Chung, "Brass-Matrix Silicon Carbide Whisker Composites", *J. Mater. Sci.* 34, 359-364 (1999).

31. Y. Xu and D.D.L. Chung, "Low-Volume-Fraction Particulate Preforms for Making Metal-Matrix Composites by Liquid Metal Infiltration," J. Mater. Sci. 33(19), 4707-4710 (1998).
32. D.D.L. Chung, "Acid Aluminum Phosphate for the Binding and Coating of Materials", J. Mater. Sci. 38(13), 2785-2791 (2003).

3D PRINTING (9 journal papers)

1. Naga B. Gundrati, Patatri Chakraborty, Chi Zhou and D.D.L. Chung, "Effects of printing conditions on the molecular alignment of three-dimensionally printed polymer", Composites, Part B, 134, 164-168 (2018).
2. Naga B. Gundrati, Patatri Chakraborty, Chi Zhou and D.D.L. Chung, "First observation of the effect of the layer printing sequence on the molecular structure of three-dimensionally printed polymer, as shown by in-plane capacitance measurement", Composites, Part B, 140, 78-82 (2018).
3. Patatri Chakraborty, Naga B. Gundrati, Chi Zhou and D.D.L. Chung, "Effect of stress on the capacitance and electric permittivity of three-dimensionally printed polymer, with relevance to capacitance-based stress monitoring", Sensors and Actuators A, 263C, 380-385 (2017).
4. Patatri Chakraborty, Chi Zhou and D.D.L. Chung, "Piezoelectric behavior of three-dimensionally printed acrylate polymer without filler or poling", J. Mater. Sci. 53(9), 6819-6830 (2018).
5. D.D.L. Chung and Sanjaya Somaratna, "Laboratory simulation of capacitance-based layer-by-layer monitoring of three-dimensional printing", Sensors and Actuators A 268, 101-109 (2017).
6. Patatri Chakraborty, Guanglei Zhao, Chi Zhou, Chong Cheng and D.D.L. Chung. Decreasing the shear-stress-induced in-plane molecular alignment by unprecedented stereolithographic delay in three-dimensional printing. J. Mater. Sci. 54(4), 3586-3599 (2019). Cover art also published.
7. Patatri Chakraborty, Guanglei Zhao, Chi Zhou and D.D.L. Chung. Unprecedented sensing of interlayer defects in three-dimensionally printed polymer by capacitance measurement. Smart Mater. Struct. 27(11), 115012, 7 pp (2018).
8. Patatri Chakraborty, Chi Zhou and D.D.L. Chung. Enhancing the inherent piezoelectric behavior of three-dimensionally printed acrylate polymer by electrical poling. Smart Mater. Struct. 27(11), 115038/1-115038/727 (2018).
9. Patatri Chakraborty, Chi Zhou and D.D.L. Chung. Converse piezoelectric behavior of three-dimensionally printed polymer and comparison of the in-plane and out-of-plane behavior. Mater Sci Eng B 252, 114447 (2020).

METAL-SEMICONDUCTOR INTERFACES (12 journal papers)

1. Xian-Fu Zeng and D.D.L. Chung, "Correlation of the Crystal Structural and Microstructural Effects of the Interfacial Processes between Gold and Gallium Arsenide," Thin Solid Films 93 (1,2), 207 (1982).
2. Xian-Fu Zeng and D.D.L. Chung, "Structural Characterization of the Interfacial Reactions between palladium and Gallium Arsenide," J. Vac. Sci. Tech. 21 (2), 611 (1982).
3. Siu Leung, L.K. Wong, D.D.L. Chung and A.G. Milnes, "Physiochemical Effects of Heating Gold on Gallium Arsenide," J. Electrochemical Society 130, 462 (1983).
4. Siu Leung, D.D.L. Chung and A.G. Milnes, "X-Ray Diffraction (Pole Figure) Study of the Epitaxy of Gold Thin Films on Gallium Arsenide," Thin Solid Films 104 (1-2), 109-31 (1983).
5. R.A. Ginley, D.D.L. Chung and D.S. Ginley, "Structural Effects of Heating Gold-Based Contacts to Gallium Phosphide," Solid-State Electron. 27, 137-46 (1984).
6. Xian-Fu Zeng and D.D.L. Chung, "In Situ X-ray Diffraction Study of Melting in Gold Contacts to Gallium Arsenide," Solid-State Electron. 27 (4), 339-45 (1984).
7. D.D.L. Chung and Edward Beam III, "Gold on Gallium Arsenide: Its Crystallographic Orientation and Control on the Orientation of the Gold-Gallium Reaction Product," Thin Solid Films 128, 299-319 (1985).
8. Edward Beam III and D.D.L. Chung, "Phase Transitions in Gold Contacts to Gallium Arsenide," Thin Solid Films 128, 321-332 (1985).
9. Taeil Kim and D.D.L. Chung, "The Effects of Germanium Concentration on Phase Formation and Morphology of Gold-Germanium Ohmic Contacts to Gallium Arsenide," J. Vac. Sci. Tech. B 4(3), 762-768 (1986).
10. Taeil Kim and D.D.L. Chung, "In Situ X-ray Diffraction Study of the Effects of Germanium and Nickel Concentrations on Melting of Gold-Based Contacts to Gallium Arsenide," Thin Solid Films 147 (2), 177-192 (1987).
11. X-F. Zeng, D.D.L. Chung and Amir Lakhani, "Effect of Heating on the Structure of Au/GaAs Encapsulated with SiO₂", Solid-State Electron. 30(12), 1259-66 (1987).
12. Taeil Kim and D.D.L. Chung, "The Study of Interfacial Reactions in Gold-Based Contacts in Gallium Arsenide", Phil. Mag. A62(3), 283-317 (1990).

SILICON (6 journal papers)

1. R.V. Prasad, F.A. Selim and D.D.L. Chung, "Semi-Insulating Polysilicon: Growth, Processing and Structural Characterization," Mater. Lett. 4(2), 71-6 (1986).

2. J.Yi, R. Wallace, N. Sridhar, Z. Wang, K. Xie, D.D.L. Chung, C.R. Wie, K. Etemadi, W.A.Anderson, M. Periard, R.W. Cochrane, Y. Diawara, J.F. Currie and J. Coleman, "Crystallized Amorphous Silicon for Low-Cost Solar Cells", Solar Cells 30, 403-413 (1991).
3. Nagarajan Sridhar, D.D.L. Chung, W.A. Anderson, and J. Coleman, "Thermodynamics and Kinetics of Hydrogen Evolution from Hydrogenated Amorphous Silicon Films," J. Electron.Mater.24(10), 1451-1459 (1995).
4. Nagarajan Sridhar, D.D.L. Chung, W.A. Anderson, and J. Coleman, "Polysilicon Films of High Photoresponse, Obtained by Vacuum Annealing of Aluminum Capped Hydrogenated Amorphous Silicon," J. Appl. Phys. 78(12), 7304-7312 (1995).
5. Nagarajan Sridhar, D.D.L. Chung, W.A. Anderson, and J. Coleman, "Effect of Deposition Temperature on the Structural and Electrical Properties of Laser Crystallized Hydrogenated Amorphous Silicon Films," J. Applied Phys. 79(3), 1569-1577 (1996).
6. D.D.L. Chung, Dang Q. Duong. New method of measuring the permittivity of silicon wafer, with relevance to permittivity-based quality sensing, Mater. Chem. Phys. 299, 127516 (2023).

JOINTS (16 journal papers)

1. J.O.G. Parent, D.D.L. Chung and I.M. Bernstein, "Effects of Intermetallic Formation at the Interface between Copper and Tin-Lead Solder", J. Mater.Sci. 23, 2564-2572 (1988).
2. Mingguang Zhu and D.D.L. Chung, "Active Brazing Alloy Paste as a Totally Metal Thick Film Conductor Material", J. Electron.Mater.23(6), 541-549 (1994).
3. Xiangcheng Luo and D.D.L. Chung, "A Comparative Study of Silver-Epoxy and Tin-Lead Solder in Their Joints with Copper, through Mechanical and Electrical Measurements During Debonding," J. Mater. Sci 34, 273-276 (1999).
4. Xiangcheng Luo and D.D.L. Chung, "Interface in Mechanically Fastened Steel Joint, Studied by Contact Electrical Resistance Measurement", J. Materials Eng. Performance 9(1), 95-97 (2000).
5. Xiangcheng Luo and D.D.L. Chung, "Material Contacts under Cyclic Compression, Studied in Real Time by Electrical Resistance Measurement", J. Mater. Sci. 35(19), 4795-4802 (2000).
6. Xiangcheng Luo and D.D.L. Chung, "Degradation of Mechanically Fastened Stainless Steel Joint During Repeated Fastening and Unfastening", Adv. Eng. Mater. 3(1-2), 62-65 (2001).
7. Xiangcheng Luo and D.D.L. Chung "Irreversible Structural Change at the Interface Between Components During Fastening", Fastener Technology International 25(1), 86-87 (2002).
8. D.D.L. Chung, "Joints Obtained by Soldering, Adhesion, Autohesion and Fastening, Studied by Electrical Resistance Measurement", J. Mater. Sci. 36(11), 2591-2596 (2001).
9. Taejin Kim and D.D.L. Chung, "Effect of Stress on the Electrical Resistivity of Solder", J. Electron. Mater. 30(10), L29-L31 (2001).
10. Zongrong Liu and D.D.L. Chung, "Burnout of the Organic Vehicle in an Electrically Conductive Thick-Film Paste", J. Electron. Mater. 33(11), 1316-1325 (2004).
11. Zongrong Liu and D.D.L. Chung, "Effect of Firing Atmosphere on Air-Fireable Glass-Free Electrically Conductive Thick Film", J. Electron Mater. 34(3), 287-293 (2005).
12. Zongrong Liu and D.D.L. Chung, "Development of Glass-Free Metal Electrically Conductive Thick Films", J. Electron. Packaging 123(1), 64-69 (2001).
13. Zongrong Liu and D.D.L. Chung, "Low Temperature Air-Fireable Glass-Free Metallic Thick Film Electrical Conductor Materials", J. Electron. Mater. 30(11), 1458-1465 (2001).
14. Kyu Dong Kim and D.D.L. Chung, "Electrically Conductive Adhesive and Soldered Joints under Compression", J. Adh. Sci. Tech. 19(11), 1003-1023 (2005).
15. Kyu-Dong Kim and D.D.L. Chung, "Effect of Heating on the Electrical Resistivity of Conductive Adhesive and Soldered Joints", J. Electron. Mater. 31(9), 933-939 (2002).
16. Matthew Poeller and D.D.L. Chung, "Effect of Heating on the Structure of an Adhesive Joint, as Indicated by Electrical Resistance Measurement", J. Adhesion 79(6), 549-558 (2003).

CERAMICS (19 journal papers)

1. Mingguang Zhu and D.D.L. Chung, "On the Simultaneous Calcination and Sintering of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ in High-Magnetic Fields," Mater.Lett.18, 186-190 (1994).
2. Shoukai Wang and D.D.L. Chung, "Self-Monitoring of Strain in Silicon Carbide Whisker Reinforced Silicon Nitride," Smart Mater.Struct.6, 199-203 (1997).
3. Shuang Lu and D.D.L. Chung, "Viscoelastic behavior of silica particle compacts under dynamic compression", Journal of Materials in Civil Engineering 26(3), 551-553 (2014).
4. Shuang Lu and D.D.L. Chung, "Viscoelastic behavior of silica fume in the absence of a binder", ACI Materials J. 112(1), 137-146 (2015).
5. Shuang Lu and D.D.L. Chung, "Effect of organic intercalation on the viscoelastic behavior of clay", J. Mater. Sci. 49(8), 3189-3195 (2014).

6. Yoshihiro Takizawa, and D.D.L. Chung, "Fumed-alumina-derived nanoporous alumina as a new low-k dielectric material for microelectronic packaging", J. Electronic Mater. 44(7), 2211-2220 (2015).
7. Xinghua Hong, Daojun Wang and D.D.L. Chung, "Boron nitride nanotube mat as a low-k dielectric material with relative dielectric constant ranging from 1.0 to 1.1", J. Electronic Mater. 45(1), 453-461 (2016).
8. Xinghua Hong, Daojun Wang and D.D.L. Chung, "Strong Viscous Behavior Discovered in Nanotube Mats, as Observed in Boron Nitride Nanotube Mats", Composites, Part B, B91, 56-64 (2016).
9. D.D.L. Chung, "Comment on "Piezoresistive Effect in SiOC Ceramics for Integrated Pressure Sensors", J. Am. Ceramic Soc., 94(1), 289 (2011).
10. Yong Fu and D.D.L. Chung, "Coagulation of Oil in Water Using Sawdust, Bentonite and Calcium Hydroxide to Form Floatable Sheets", Appl. Clay Sciences 53, 634-641 (2011).
11. Tianlei Sun and D.D.L. Chung, "Coagulation of Oil in Water Using Sawdust and Bentonite and the Formation of a Floating Coagulated Material", J. Environmental Engineering 139, 1470-1481 (2013).
12. Sihai Wen and D.D.L. Chung, "Effect of Stress on the Dielectric Constant of Alumina", J. Electron. Packaging 127(3), 235-236 (2005).
13. Shoukai Wang and D.D.L. Chung, "Piezoresistivity in Silicon Carbide Fibers", J. Electroceramics 10, 147-152 (2003).
14. Zongrong Liu and D.D.L. Chung, "Comparative Study of Electrically Conductive Thick Films With and Without Glass", J. Electron. Mater. 33(3), 194-202 (2004).
15. Sihai Wen and D.D.L. Chung, "Effect of Stress on the Dielectric Constant of Alumina", J. Electron. Packaging 127, 235-236 (2005).
16. Yunsheng Xu, Xiangcheng Luo and D.D.L. Chung, "Sodium Silicate Based Thermal Pastes for High Thermal Contact Conductance", J. Electron. Packaging 122(2), 128-131 (2000). Erratum: J. Electron. Packaging 123, 159 (2001).
17. J.A. Fernando and D.D.L. Chung, "Pore Structure and Permeability of an Alumina Fiber Filter Membrane for Hot Gas Filtration", J. Porous Materials 9(3), 211-219 (2002).
18. J.A. Fernando and D.D.L. Chung, "Improving an Alumina Fiber Filter Membrane for Hot Gas Filtration using an Acid Phosphate Binder", J. Mater. Sci. 36(21), 5079-5085 (2001).
19. J.A. Fernando and D.D.L. Chung, "Thermomechanical Properties of Alumina Fiber Membrane", Ceramics Int. 31, 453-460 (2005).

METALS (22 journal papers)

1. Jian Wang and D.D.L. Chung, "A Comparative Study of the Vibration Damping Capacity of Superalloys", J. Materials Eng. Performance 8, 577-578 (1999).
2. D.D.L. Chung and Kairong Shi, "Sensing the stress in steel by capacitance measurement", Sensors and Actuators A 274, 244-251 (2018).
3. Xiang Xi and D.D.L. Chung, "Piezoresistivity and piezoelectricity discovered in aluminum, with relevance to structural self-sensing", Sensors and Actuators A 289, 144-156 (2019).
4. Kairong Shi and D.D.L. Chung, "Unprecedented capacitance-based nondestructive evaluation of steels", J. Mater. Eng. Perf. 28(5), 2573-2587 (2019).
5. Xiang Xi and D.D.L. Chung, "Electret, piezoelectret and piezoresistivity discovered in steels, with application to structural self-sensing and structural self-powering", Smart Mater. Struct. 28(7) 075028 (18 pp) (2019).
6. Xiang Xi and D.D.L. Chung, "Piezoelectret-based and piezoresistivity-based stress self-sensing in steel beams under flexure", Sensors Actuators A 301, 111780 (2020).
7. D.D.L. Chung and Murat Ozturk. Radio-wave absorption by aluminum and its dependence on the absorption distance. J. Mater. Sci. 56(15), 9263-9273 (2021).
8. Xiang Xi and D.D.L. Chung, "Piezoresistivity and piezoelectricity, dielectricity discovered in solder", J. Mater. Sci.: Mater. Electronics 30(5), 4462-4472 (2019).
9. Wenyi Yang and D.D.L. Chung. Electric polarization and depolarization of solder, and their effects on electrical conduction. J. Mater. Sci.: Mater. Electronics 32(5), 6214-6227 (2021). Correction: Journal of Materials Science: Materials in Electronics, 32(10), 14113-14114 (2021).
10. Wenyi Yang and D.D.L. Chung. Effect of temperature on the electrical conduction and dielectric behavior of solder. J. Mater. Sci.: Mater. Electronics 32(5), 6511-6519 (2021).
11. Wenyi Yang and D.D.L. Chung. Effect of the cooling rate in solidification on the electrical behavior of solder. J. Mater. Sci.: Mater. Electronics 32(6), 7867-7874 (2021).
12. Wenyi Yang and D.D.L. Chung. First report of the ferroelectric behavior of a metal, as shown for solder. J. Mater. Sci.: Mater. Electronics 32(12), 16979-16989 (2021).
13. Murat Ozturk and D.D.L. Chung. Radio-wave shielding behavior of steel structures. J. Electromagnetic Waves and Applications 35(11), 1407-1419 (2021).
14. Xiang Xi and D.D.L. Chung. Effects of cold work, stress and temperature on the dielectric behavior of copper. Mater. Chem. Phys. 270, 124793 (2021).
15. Wenyi Yang and D.D.L. Chung. Electret behavior discovered in solder, specifically tin-silver. J. Mater. Sci.: Mater. Electronics 32(14), 19145-19156 (2021).
16. Wenyi Yang and D.D.L. Chung. Effect of water on the dielectric behavior of solder. J. Mater. Sci.: Mater.

- Electronics 32, 22196–22204 (2021).
17. Garrett C. Thomas and D.D.L. Chung. Dielectric behavior of an electrically conductive metal-particle thick film. *J. Electron. Mater.* 51, 3005–3013 (2022).
 18. D.D.L. Chung, Xiang Xi. New concept of electret-based capacitance, as shown for solder and other conductors. *J. Mater. Sci.: Materials in Electronics* 33, 27022–27039 (2022).
 19. D.D.L. Chung, Xiang Xi. Introducing solder-based electronics, with solder functioning as resistor, capacitor and power source. *J. Mater. Sci.: Materials in Electronics* 24, 131 (2023).
 20. Min Kyoung Kim, D.D.L. Chung. Inductance-based and inductance-capacitance-based structural self-sensing of shape-changing deformation in aluminum. *Sensors Actuators A* 365, 114926 (2024).
 21. D.D.L. Chung. Comments on “Electromagnetic interference (EMI) shielding effectiveness (SE) of pure aluminum: an experimental assessment for 5G (SUB 6GHZ)”. *J. Mater. Sci.: Materials in Electronics* 35, 521 (2024).
 22. Min Kyoung Kim, D.D.L. Chung. Inductance-based sensing of surface roughness, with application to wear sensing. *J. Mater. Sci.* 59, 15816–15829 (2024). <https://rdcu.be/dQR0t>
<https://link.springer.com/article/10.1007/s10853-024-10094-9>

POLYMERS (2 journal papers)

1. Wenhai Fu and D.D.L. Chung, "Vibration Reduction Ability of Polymers, Particularly Polymethylmethacrylate and Polytetrafluoroethylene", *Polymers & Polymer Composites* 9(6), 423-426 (2001).
2. Yu-Cheng Liu, Yasuhiro Aoyagi and D.D.L. Chung, "Development of Epoxy-Based Electrets", *J. Mater. Sci.* 43(5), 1650-1663 (2008).

OTHER TOPICS (22 journal papers)

1. D.D.L. Chung, "Electrical Behavior of Solids," *J. Educational Modules for Mat. Sci. Eng.* 2, 747 (1980).
2. D.D.L. Chung, "Materials for Electromagnetic Interference Shielding", *J. Materials Eng. Performance* 9(3), 350-354 (2000).
3. D.D.L. Chung, "Thermal Interface Materials", *J. Mater. Eng. Performance* 10(1), 56-59 (2001).
4. D.D.L. Chung, "Materials for Thermal Conduction", *Applied Thermal Engineering* 21 (E16), 1593-1605 (2001).
5. Xiangcheng Luo, Yunsheng Xu and D.D.L. Chung, "Thermal Stability of Thermal Interface Pastes Evaluated by Thermal Contact Conductance Measurement", *J. Electronic Packaging* 123(3), 309-311 (2001).
6. Xiangcheng Luo and D.D.L. Chung, "Effect of the Thickness of a Thermal Interface Material (Solder) on Heat Transfer Between Copper Surfaces", *Int. J. Microcircuits Electronic Packaging* 24(2), 141-147 (2001).
7. D.D.L. Chung, "Materials for Vibration Damping", *J. Mater. Sci.* 36(24), 5733-5738 (2001).
8. D.D.L. Chung, "Composites Get Smart", *Materials Today* 5(1), 30-35 (2002).
9. Taejin Kim and D.D.L. Chung, "Thermoelectric Behavior of Solder", *J. Electronic Packaging* 125(1), 161-162 (2003).
10. Junhua Wu and D.D.L. Chung, "Pastes for Electromagnetic Interference Shielding", *J. Electron. Mater.* 34(9), 1255-1258 (2005).
11. Taejin Kim and D.D.L. Chung, "Mats and Fabrics for Electromagnetic Interference Shielding", *J. Mater. Eng. Perf.* 15(3), 295-298 (2006).
12. D.D.L. Chung, "Advances in Thermal Interface Materials", *Advancing Microelectronics* 33(4), 8-11 (2006).
13. Qiaoli Meng, Yibadan Kenayeti and D.D.L. Chung, "Battery in the form of a soil-matrix composite", *J. Energy Engineering*, 141(3), 04014013 (2015); online first (2012).
14. D.D.L. Chung, "Mildred S. Dresselhaus (1930-2017)", *Nature* 543, 316 (2017).
15. Robert H. Hurt, D.D.L. Chung, Mauricio Terrones, Katsumi Kaneko, Peter Thrower, Morinobu Endo, Hui-Ming Cheng, Michael Strano. Mildred S. Dresselhaus (1930 – 2017) – A Tribute from the Carbon Journal. *Carbon* 119, 573-577 (2017).
16. D.D.L. Chung, "Thermal interface materials", *J. Electron. Mater.* 49(1), 268-270 (2020).
17. D.D.L. Chung. Materials for electromagnetic interference shielding (Feature Article). *Mater. Chem. Phys.* 255, 123587 (2020).
18. D.D.L. Chung. Pitfalls and methods in the measurement of the electrical resistance and capacitance of materials. *J. Electron. Mater.* 50(2), 6567-6574 (2021).
19. D.D.L. Chung. Pitfalls in electromagnetic skin-depth determination. *J. Electron. Mater.* 51, 1893-1899 (2022).
20. D.D.L. Chung. Performance of thermal interface materials. *Small* 18(16), 2200693 (2022).
21. D.D.L. Chung. Pitfalls in piezoresistivity testing. *J. Electronic Mater.* 51, 5473-5481 (2022).
22. Min Kyoung Kim, D.D.L. Chung. Electrical-connection-related stray inductance causing overassessment of the electrical resistance measured by using the two-probe method. *J. Electron. Mater.* 53, 1026–1034 (2024).