

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

POSCO FUTURE M CO., LTD,

Petitioner

v.

TIAX LLC,

Patent Owner

U.S. PATENT NO. 9,391,317 B2

Title: Polycrystalline Metal Oxide, Methods of Manufacture Thereof, and Articles
Comprising The Same

DECLARATION OF DORON AURBACH, PH.D
IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW

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TABLE OF EXHIBITS

EXHIBIT	TITLE
1001	U.S. Patent No. 9,391,317 (“the ’317 Patent”)
1002	Expert Declaration of Doron Aurbach, Ph.D
1003	Declaration of Hyunkuk Noh, Ph.D
1004	Prosecution file history for U.S. Patent No. 9,391,317
1005	Prosecution file history for U.S. Patent No. 9,209,455
1006	U.S. Provisional Application No. 61/575,115
1007	U.S. Pat No. 6,921,609 to Lampe-Onnerud et al., issued July 26, 2005 (“Lampe-Onnerud”)
1008	U.S. Publ. App. No. 2011/0143209 to Park et al., published June 16, 2011, filed December 1, 2010, and issued as U.S. Patent No. 8,586,247, claiming priority to Prov App. No. 61/285,785 filed December 11, 2009 (“Park”)
1009	Japanese Published Application No. JP 2003-059489 to Takagi et al, published February 28, 2003 (“Takagi”)
1010	Certified translation of JP 2003-059489 (“Takagi”)
1011	Zheng et al., Microstructural Changes in $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ Positive Electrode Material During the First Cycle, Journal of the Electrochemical Society, 158 (4) A357-A362 (2011) (Published February 9, 2011) (“Zheng”)

1012	Fergus, Recent Developments in Cathode Materials For Lithium Ion Batteries, Journal of Power Sources 195 (2010) 939-954 (“Fergus”)
1013	Kalyani et al., Various Aspects of LiNiO ₂ Chemistry: A Review, Science and Technology of Advanced Materials 6 (2005) 689-703 (“Kalyani”)
1014	Volovich et al., Percolation Models of Grain Boundary Wetting in Polycrystalline Materials, Russian Journal of General Chemistry, 2008, Vol. 78, No. 11, pp. 2182-2190 (“Volovich”)
1015	Wittingham, Lithium Batteries and Cathode Materials, American Chemical Society, Chemical Reviews 2004, Vol. 104, No. 10, pp. 4271-4301 (“Wittingham”)
1016	Ghiji et al., A Review of Lithium-Ion Battery Fire Suppression, <i>Energies</i> 2020, 13, 5117. (“Ghiji”)
1017	Muto et al., Capacity-Fading Mechanisms of LiNiO ₂ -Based Lithium Ion Batteries, Journal of the Electrochemical Society, 156 (5) A371-A377 (2009) (“Muto”)
1018	Liu et al., Comparison of Structure and Electrochemistry of Al- and Fe-doped LiNi _{1/3} Co _{1/3} Mn _{1/3} O ₂ , Electrochimica Acta 51 (2006) 4199-4203 (“Liu”)
1019	Ellis et al., Positive Electrode Materials for Li-Ion and Li-Batteries, Chemistry of Materials Review, 2010, 22, 691-714 (“Ellis”)
1020	Turner et al., Surface Analysis: X-ray Photoelectron Spectroscopy, Auger Electron Spectroscopy, and Secondary Ion Mass Spectrometry, Anal Chem, 1982, Vol. 54, pp. 293-322 (“Turner”)

1021	U.S. Published Patent Appl No. 2009/0104530 to Shizuka et al
1022	U.S. Publ. App. No. 2011/0033750 to Hosokawa et al., published February 10, 2011, filed March 3, 2010 (“Hosokawa”)
1023	Japanese Published App. No. JP 2010/047466 A (issued as Japanese Patent JP 5451228 B2), Lithium Transition Metal Oxide With Layer Structure, published March 4, 2010 (“Kagei”)
1024	Certified translation of Kagei excerpt
1025	File History for Lampe-Onnerud
1026	US Provisional App. 61/285,785
1027	U.S. Pat No. 7,381,496 to Onnerud et al., issued June 3, 2008 (“Onnerud”)
1028	Declaration of Michael A. Oblon

I, Doron Aurbach, do hereby declare:

1. I have been retained by POSCO Future M Co. Ltd. (“POSCO Future M”) as an independent expert in this *inter partes* review (IPR) proceeding before the United States Patent and Trademark Office (USPTO) concerning U.S. Patent No. 9,391,317 (the ’317 patent).

2. I am a Professor of Chemistry and Electrochemistry at Bar-Ilan University in Israel. I am over the age of 18 and otherwise competent to make this declaration. I am not, nor have I ever been, an employee of POSCO Future M. I am being compensated for my time in connection with this declaration at my standard consulting rate. My compensation is not affected by the outcome of this IPR proceeding or any other legal proceeding.

3. I have been asked to provide my opinions on various issues regarding whether the subject matter claimed in the ’317 patent had already been published, disclosed, or known, and whether such subject matter would have been obvious to those of ordinary skill.

4. In forming my opinions and preparing this declaration I rely on my knowledge and experience and on the documents and information referenced in this declaration and the exhibit list, and also the Declaration of Hyunkuk Noh, Ph.D.

I. Background and Qualifications

5. My qualifications and credentials are set forth in my *curriculum vitae* which I understand is being filed with this declaration. I am a professor emeritus, having been a full professor from 1996-2020 of chemistry and electrochemistry at Bar Ilan University. Beginning in 2021, I am a research professor at the university. I specialize and am an expert in the fields of electrochemical, surface and material sciences, including intercalation processes, passivation phenomena, and complex solution chemistry. I run a research and development laboratory that works with a wide variety of power sources, specifically including lithium ion batteries. Over the course of my career, I have conducted research, authored, or co-authored over 800 papers, provided lectures, and provided technical consulting in my field, and I continue to do so.

A. Academic Background

6. I earned a Bachelor of Science in Chemistry (Magna cum Laude) from Bar Ilan University in Ramat Gan, Israel, in 1977, and a Bachelors of Science in Chemical Engineering (Summa cum Laude) from the Israel Institute of Technology, Technion, in Haifa, Israel in 1982. I earned a Master of Science in Physical Organic Chemistry (Summa cum Laude) from Bar Ilan University in 1979. I also earned a Ph.D in Physical Organic Chemistry (with Highest Distinction) from Bar Ilan University in 1983. I was a Post-Doctoral Research

Fellow in 1983 -1985 at Case Western Reserve University in Cleveland, Ohio, conducting research in “Electrochemistry of lithium and nonaqueous electrochemistry,” studying under Professor E.B. Yeager.

B. Academic and Research Positions

7. At Bar Ilan University, I have been the Chairman of the Department of Chemistry and Head of the Electrochemistry Group in the Department of Chemistry. I have also been a Senate member at the university.

8. From 2012-2021, I was the leader of the Israel Research Center for Electrochemical Propulsion, which includes 28 research groups from seven academic institutions, attending to research on advanced batteries and fuel cells for electric vehicles and large energy storage. I have been a member of the international boards of the International Meetings of Li Batteries and Li Batteries Discussion. I have also been Associate Editor of the ECS-Electrochemistry Letters journal and Topical Editor for the Journal of Solid-State Electrochemistry. I have been Associate Editor of the Journal of the Electrochemical Society and Senior Editor in charge of batteries and energy storage. I am also a Board Member and Director in IMLB-LLC, the official organization of the International Lithium Battery Community.

9. I also have worked on sponsored research projects with corporations. As examples, from 1997-2010 I collaborated with Merck KGaA/Germany on

research and development of novel systems for lithium-ion batteries and ionic liquids. From 1998-2012 I worked on a collaboration with LG Corporation on the study of Li-ion batteries. From 2002-2023 I worked on a collaboration with General Motors on advanced power sources for electric vehicles.

C. Expertise Relating to the '317 Patent

10. I have reviewed the '317 patent and its claims. The subject matter of the patent generally pertains to a lithium nickel oxide-based (LiNO_2) polycrystalline material. This subject matter is within the scope of my education, expertise and professional experience.

11. My research and teaching focuses on electrochemistry, which pertains to chemical processes that cause electrons to move. Physical electrochemistry explores fundamental physical principles underlying electrochemical processes. There are a variety of applications for electrochemistry, such as fuel cells power generators, electrochemical methods for water desalination and removal of pollutants from water, supercapacitors, and batteries. During my career I have focused on many applications, which all provide a background at some level to the subject matter in the '317 patent, and in particular, my research regarding batteries is particularly relevant.

12. Throughout my career, I have engaged in substantial study and research regarding techniques and processes to increase energy density, prolong

life, improve cycling, and decrease costs in batteries. This includes, for example, studying and experimenting with lithium manganese-rich NCM cathode materials, nickel-rich cathode materials, and cobalt-free cathode materials. I have also studied the potential benefits of lithium-sulfur (Li-S) batteries, and I have considered alternatives to lithium-ion batteries, such as batteries based on sodium, magnesium and zinc as the active materials of the negative electrodes in energetic rechargeable batteries.

13. I understand that the application for the '317 patent was based on a US patent application filed in 2012 and that it claims priority to a US provisional application filed in 2011. Prior to this timeframe, I had authored many research papers regarding lithium-ion batteries, concerning, for example, analyzing rechargeable Li-ion batteries after prolonged cycling, the cathode-electrolyte interface, cycling behavior and ageing in $\text{Li}[\text{NiCoMn}]\text{O}_2$ electrodes (at various stoichiometries of the transition metals in the formulae), cycling and storage performance at elevated temperatures, electrochemical behavior of electrodes comprising particles of $\text{Li}[\text{NiCoMn}]\text{O}_2$ materials, and evaluating advanced Li-ion batteries for EV applications.

14. The '317 patent claims do not mention cathodes but throughout the patent specification, it is evident that the patent pertains to lithium nickel oxide-based cathode materials. For well over twenty years, I have published

articles, taught classes, conducted research, worked with corporate industry, and generally studied this subject area.

15. Accordingly, I am an expert in the field of electrochemistry and the design of lithium-ion batteries and characterization of materials in the batteries. Based on my educational background, experience, teaching, and research, I believe that I meet the criteria of a person of ordinary skill in the art (“POSITA” or “skilled artisan”) for the ’317 patent as outlined below, as I have extensively taught and worked with others who meet the criteria of such a person, and I can provide opinions from the perspective of what would be understood by such a person. As such, I am qualified to provide opinions about what a person of ordinary skill would have understood, known, or concluded as of the priority date for the ’317 patent.

II. Relevant Legal Standards

16. I have been asked to provide my opinions as to whether the claims of the ’317 patent were already known or described by others in a publication, or would have been obvious to a person of ordinary skill in the art at the time of the invention in view of the prior art and what was known in the art.

17. In this report, I am providing opinions about technical issues that involve the application of my knowledge, experience, and understandings from the perspective of a person of ordinary skill in the art, to the evaluation of certain prior

art with respect to the '317 patent. I have requested the attorneys from Jones Day, who represent POSCO Future M, to provide me with guidance as to the applicable patent law in this matter. The paragraphs below express my understanding of how I must apply current principles related to patent validity to my analysis.

18. It is my understanding that in determining whether a patent claim is unpatentable, the Patent Office must interpret the claim as it would be understood from the perspective of a person of ordinary skill in the art, in light of the specification and prosecution history. For the purposes of this review, I have construed each claim term in accordance with its plain and ordinary meaning except where particular constructions are discussed.

19. I understand that a claim in an issued patent is unpatentable if the claimed subject matter was already in the public domain before the earliest effective filing date for the patent. As an example, if an article was published or an earlier patent was filed beforehand, that can be evidence of unpatentability based on prior art. Also, it has been explained to me that if the prior art article does not expressly disclose the claimed subject matter, the claim is nonetheless unpatentable if it is inherent from the teachings in that article. An inherent characteristic necessarily flows from the teachings of the applied prior art.

20. It is my understanding that a claim is also unpatentable if the claimed subject matter as a whole would have been obvious to a person of ordinary skill in

the art at the time of the invention. I also understand that an obviousness analysis takes into account the scope and content of the prior art, the differences between the claimed subject matter and the prior art, and the level of ordinary skill in the art at the time of the invention.

21. To assess the differences between prior art and the claimed subject matter, it is my understanding that the law requires the claimed invention to be considered as a whole.

22. It is my further understanding that there are several rationales for combining references or modifying a reference to show obviousness of claimed subject matter. Some of these rationales include: combining prior art elements according to known methods to yield predictable results; simple substitution of one known element for another to obtain predictable results; a predictable use of prior art elements according to their established functions; applying a known technique to a known device (method or product) ready for improvement to yield predictable results; choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success; 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.

23. It has been explained to me that whether a reference qualifies as prior art to a patent depends on the effective filing date of the patent. The patent's effective filing date can be earlier than its actual filing date if it is a "continuation application," which means that it claims "priority" to an earlier patent application that had the same disclosure. Also, a patent can claim priority to a "provisional application," which is basically a placeholder application that is not examined. For the patent's effective filing date to go back to the date of the provisional application, the patent claims must be adequately supported by the earlier disclosure in the provisional application.

24. I also understand that whether a reference qualifies as prior art depends on its publication date, or if it is a patent, when it was filed. If the prior art patent claimed priority to a provisional application, then its effective date can extend back to the date of that provisional application if its own claims are supported by that earlier disclosure.

III. Technology Background and Context for Understanding the '317 Patent

25. In this section, I provide a brief tutorial about what was already known in the art prior to the 2011 timeframe concerning lithium-ion batteries and their components, how particles are synthesized for cathode materials, and how those materials are characterized, based on publications and my knowledge of the field. With this context, I can explain whether the subject matter of the patent

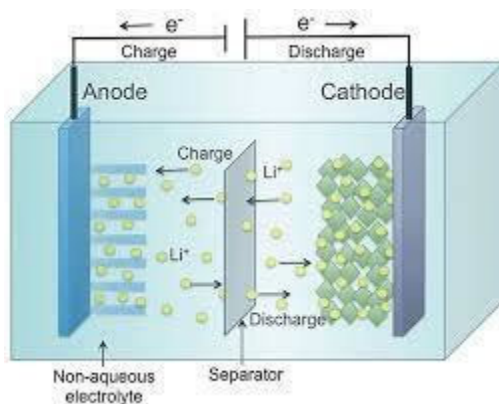
claims were already known or would have been obvious to a person of ordinary skill in the art by the 2011 timeframe.

A. Lithium Ion Batteries

26. Lithium-ion (or “Li-ion”) batteries are rechargeable and store energy by using the reversible intercalation of Li^+ ions into electronically conducting solids. In the field of chemistry, the process of reversible intercalation refers to the insertion and removal of molecules or ions into/out of solid-state host materials.

27. A conventional lithium-ion battery has four components. The cathode materials make up the positive electrode, the anode materials make up the negative electrode, and these components are inserted into a container with an electrolyte solution (often in liquid form) and a separator between the cathode and anode. An arrangement of an anode, cathode, electrolyte, and separator is illustrated below.

Ex_1016, p.2. This illustration is from a recent article, but the basic arrangement of the cathode, anode, and separator are conventional from well before the 2011 timeframe.



28. The anode is typically made of graphite particles which are coated onto metal foils. Graphite has a structure that enables it to store lithium ions between its layers while charging, and release the lithium ions while discharging, in a reversible fashion, without destabilizing. The separator is typically a thin, insulating membrane that prevents short circuits by keeping the anode and cathode apart. The separator is permeable to allow for the transport of the lithium ions. Conventional separators are chemically and electrically inert. The electrolyte solution conducts Li ions, thus allowing their migration between anode and cathode under an electrical field. Conventional electrolyte solutions often comprise lithium salts (usually LiPF_6) dissolved in solvent mixtures. Ex_1015, p.4272.

29. When a battery charges, positively charged lithium ions move out of sites in the cathode that are atomic-sized spaces within a layered crystal structure of active material. The lithium ions migrate through an electrolyte solution and are then inserted into available sites at the anode. The discharging process occurs in reverse, such that the positive lithium ions move out of sites on the anode through an electrolyte and into available sites of the cathode. *Id.*, p.4274.

30. The efficiency associated with the intercalation process depends on the materials that are used, including the selected metals and the stoichiometric ratios of each metal present relative to the lithium and oxygen atoms.

B. Known Cathode Materials and Criteria for Material Selection

31. Cathodes are typically made of polycrystalline material, or polycrystals. These are solids made of small grains, or crystallites, of different sizes and orientations. The crystallites, which are also referred to as primary particles, are agglomerated (clustered together under heat) to form a polycrystalline particle, referred to as a secondary particle. Ex_1008, ¶12

32. Grain boundaries form naturally as defects in the polycrystalline material where primary particles agglomerate into a secondary particle. Because they are the interface of adjacent particles (where grains that are oriented in different directions meet), grain boundaries are structurally the least stable area of the polycrystalline material. Ex_1022, ¶14.

33. Cathode materials are conventionally composed of metal oxides, usually a stoichiometric ratio of lithium with one or more transition metals and oxygen atoms. Ex_1015, pp.4280-4296.

34. As early as the 1980s, it was known that using LiCoO_2 as the primary cathode material could provide high stability and energy density even after multiple cycling processes for rechargeable battery use. Ex_1015, pp. 4274, 4280. Using cobalt as the sole transition metal in the oxide lattice was not ideal, however, due to its high cost as a relatively rare metallic species, and its limitations in electrical capacity. Ex_1017, p.A371; Ex_1012, p.940.

35. Nickel was found to be a less expensive and an especially promising substitute for cobalt in lithium oxide batteries given its lowest cost and greater capacity, which pertains to its ability to store and provide power. Unfortunately, the benefits provided by the nickel substitution were limited due to issues with LiNiO₂ longevity and stability. Ex_1013, pp.698-699. Pure LiNiO₂ cathodes were found to degrade significantly and become thermally unstable after multiple electrochemical cycles. *Id.*

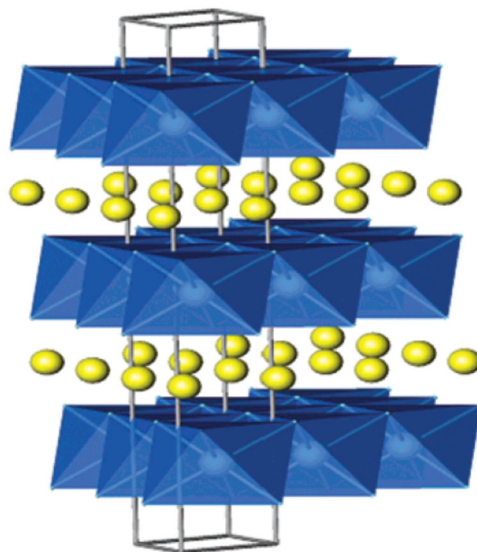
36. Further efforts to develop lithium oxide batteries included mixing/doping the LiNiO₂ materials with other metals including Co, Mn, Mg, B, Al, and many others. Ex_1012, p.944-945; Ex_1007, 2:20-25; Ex_1018, pp.4199-4203; Ex_1011, A362. These are referred to as lithium nickel oxide-based materials because nickel is the primary metal and there is a small amount of one or more other metals. The purpose of mixing/doping is to maintain the high capacity and energy density benefits of pure Ni- based cells while reducing structural stability issues. Ex_1018, p.4199. Doping is a process of adding in smaller amounts of a component into a solid structure, usually distributed uniformly throughout the crystal phase, to enhance the chemical or structural properties of the bulk material.

C. Layered Structure of Crystals and Cracking

37. The basic structure of lithium nickel oxide-based materials is called an “ α -NaFeO₂-type” layered rock salt crystal, composed of a rhombohedral basis with trigonal symmetry, of the R-3m space group. Ex_1007, 3:45-49.

38. There are 3 distinct layers that each extend in a regular pattern in two-dimensional space, and alternate in the vertical direction. A layer of metal ions (usually transition metals, and often Ni or Co) makes up one layer, which coordinates with a layer of oxygen anions or negatively charged atoms, and a third layer of lithium ions. A 3-layer structure of this type is often seen in three-dimensional compounds composed of sodium, iron, and oxygen (NaFeO₂), and therefore solids that assume this type of layered structure are denoted either as R3m (rhombohedral with 3 layers), or as α -NaFeO₂. Ex_1015, p.4272.

39. The following illustrates how a lithium nickel oxide-based material has layers of lithium ions in yellow that are in between transition metal oxide sheets. The blue portions represent a bilayer of nickel and oxygen, where every nickel atom is conjugated to two oxygen atoms.



Ex_1015, p.4273 (Fig. 1).

40. The unit cell, which is the basic repeat structural unit of a solid consists of 3 layers; a face-centered cubic sublattice of oxygen anions with alternating layer planes of Ni/Co (or other transition metals if included) and Li cations. In solid state chemistry characterization of different types of solids, a unit cell is used to provide a basis for reconstructing an entire solid framework, by providing a set of lengths and angles that represent the atoms in the structure and their relationships with each other. During the discharging/charging process, Li^+ ions (also called Li cations) intercalate/deintercalate from their lattice positions, and the ability of the Li^+ ions to reversibly populate their positions in the lattice is crucial to maintain capacity after multiple cycling. *Id.*, pp.4272-4273.

41. It was well known that lithium nickel oxide -based cathodes and also lithium cobalt oxide - based cathodes both have an “ α -NaFeO₂ type” structure. *Id.*, pp.4280-81.

42. In pure lithium nickel oxide cathodes (LiNiO₂), i.e., with no additional transition metals added, the reversibility of Li ion intercalation erodes. This is because empty sites that had been occupied by Li ions are replaced with neighboring, freely mobile Ni ions, which have a similar diameter as lithium ions and thereby can diffuse/migrate to empty Li sites after deintercalation of LiNiO₂ cathodes. As the lithium ions leave the cell during discharge, the Ni ions migrate to and irreversibly populate the lattice positions of the Li ions. This alters the values of the lattice parameters of the α -NaFeO₂ structure, which depend both on the unique attractions of each metal ion with the oxygen atoms in the alternating layers, and the repulsion of the intralayer metal ions. Ex_1013, pp.691, 695, 698-699.

43. The fluctuations in unit cell values (which are the parameters which define the repeat unit’s shape through lengths and angles) changes the cell’s electronic structure and deforms its volume. Ex_1011, A357-62. This creates stresses on the crystalline structures and initiates microcracking inside the cathode’s active mass particles. Once cracks reach the surface of a particle (primary and/or secondary), chemically reactive species which belong to the

battery's electrolyte solution can seep into the cathode's active mass structure, causing further damage through side reactions with the negatively charged oxygen atoms and the metal ions. Such side reactions may involve dissolution of transition metal cations, evolution of molecular oxygen, irreversible formation of surface species and loss of active Li ions. Evolution of oxygen and simultaneous dissolution of metallic cations mean a continuous degradation of the cathode's active mass. Ex._1013, pp. 697-698. Additionally, the expansion and contraction of the volume of the primary particles during the electrochemical cycling causes stress at the edges of the primary particles where individually-directed grains meet, causing strains and cracking between primary particles (intergranular cracking). Ex_1011, p.A362.

44. In areas of the crystal where more Ni ions move into the Li ion positions after repeated cycling, the lattice will convert into a cubic or spinel structure, which does not allow the free passage of Li ions into and out of the system, therefore rendering portions of the material inactive electrochemically. Ex_1013, p.697. The lattice will convert from a layered structure with Ni and Li in distinct planes into cubic or spinel structures where Ni has adopted locations in the Li layer due to diffusion during deintercalation as described above. (A spinel structure is a form of cubic lattice.) Since the layered α -NaFeO₂ unit cell which gives rise to the crystalline three-dimensional structure is defined as having a

simple ratio of one nickel atom in the first layer, two oxygen atoms in the second layer and one lithium atom in the third layer, any movement of nickel atoms into the third layer destroys the specificity of the 3-layer structure and creates alternative types of symmetry. In the grain boundary there is already a lack of regular structure, due to the mechanical stresses on the two individually oriented grains as they combine to become secondary particles, and additionally, the edges of the crystals are also the locations of maximum intercalation/deintercalation restructuring. Therefore, the edges of the particles experience the most crumbling and rearrangement of the layered structure into a cubic form. Therefore, some areas in grain boundaries will have the layered α -NaFeO₂ structure, while other areas will have a more disordered, cubic structure. *Id.*; Ex._1017, pp. A371-A374

45. In contrast to a lithium nickel oxide structure, in an LiCoO₂ crystal structure, Co ions cannot replace Li⁺ ions in the lattice positions because there are distinct size differences between cobalt and lithium ions. Particularly, the diameter of a cobalt ion is generally too large to fit into a site that was vacated by a lithium ion. Therefore, the Li⁺ ions typically are fully and reversibly re-inserted into the 3a positions of the lattice during every cycle. In comparison with a pure lithium nickel oxide, a LiCoO₂ cathode material has greater longevity because it can maintain its structural integrity after long-term use. Ex._1015, pp.4280-4281; Ex_1019, p.704.

D. Known Techniques for Reducing Microcracking

46. As I explained in the previous section, microcracks tend to form within particles (both within primary and secondary particles) of conventional LiNO_2 -based cathode material. This is caused by stresses developed within the active mass (related to phase transition processes) due to charge/discharge cycling, namely, repeated Li ions deintercalation/intercalation processes. Ex_1011, pp.A357-62. Microcracks that form within the bulk of a secondary particle can propagate toward its surface and enable percolation of the electrolyte solution into the material active mass. This leads to capacity losses. Therefore, it has been well known since before the 2011 timeframe to mitigate capacity fading by reducing cracking and preventing propagation of microcracks to the secondary particle surface.

47. There were a few known approaches as of 2011 to improve Li ion battery performance for lithium nickel oxide-based materials by preventing microcracking.

48. As I described above, because there are stability issues associated with pure lithium nickel oxide cathodes but it is too expensive to make cathodes purely of cobalt, it was known to dope nickel-based cathode materials to have smaller amounts of other metals, such as Co, Mn, Mg, B, and Al. Doping lithium nickel oxide cathode materials with other metals maintains the layered structure by

preventing at least some of the nickel ions from diffusing into lithium sites, thereby preventing some microcracking and maintaining electrochemical function. Even if the additional transition metal is uniformly distributed throughout the material, this doping makes the material at least somewhat more stable, but there is still some microcracking and deformation. Ex_1012, pp. 939-946.

49. It was also well-known to coat secondary particles with a material to insulate them from the electrolyte solution. This is known as the core-shell approach, and usually involves the addition of a second material to protect the active material from side reactions with the electrolyte solution. The coating helps prevent detrimental dissolution of transition metal cations into the electrolyte solution and evolution of oxygen gas. Ex._1015, p. 4281.

50. As I will describe below, the '317 patent describes reducing microcracking in a lithium nickel oxide-based material while still using less cobalt overall by increasing the cobalt concentration in certain regions, rather than having a uniform distribution of doped cobalt throughout a secondary particle. But this was known before the '317 patent. The Lampe-Onnerud, Park, and Takagi references are examples of prior art that disclose this same principle.

E. Techniques for Characterization of Materials:

51. There are multiple techniques for characterizing 3-D solid structures. As of the 1990s and early 2000s, the most commonly used methods to characterize

surfaces were Auger Electron Spectroscopy (AES), X-Ray Photoelectron Spectroscopy (XPS) and Scanning Electron Microscopy (SEM) together with element analysis by EDS. XPS and AES techniques use energy of excited electrons emitted from the surface to identify chemical elements present in a sample. Auger spectroscopy uses an electron beam as the excitation source while XPS uses X-ray beams for excitation. Ex_1020, pp. 293R-305R.

52. AES and XPS techniques are both somewhat limited to the characterization of the surface layers of the sample. *Id.* X-ray diffraction analysis (“XRD”), on the other hand, can be used to probe solid particles and provide information related to particle’s crystal structures and sizes, cell parameters and defects. However, XRD cannot be effectively utilized for analysis of materials with amorphous phases or multiple/ill-defined structures. Also, XRD cannot provide location-specific information about where any asymmetries occur within the material, so it is usually not used without a companion technique for definitive structural information.

53. Polycrystalline materials can be effectively analyzed at high resolution by preparing a thin-layer cross-section of the sample using Focused Ion Beam excision (FIB). The cross-section sample can be scanned in 2-D by high resolution Transmission Electron Microscopy (TEM) or by Scanning Electron Microscopy (SEM), followed by elemental analysis of the chemical composition at

distinctly mapped positions using Energy-Dispersive X-ray Spectrometry (“EDS”). EDS provides quantitative and qualitative elements analysis at the examined surfaces/samples in conjunction with surface imaging by SEM or TEM.

IV. Summary of the ’317 Patent

54. I understand that the ’317 patent was filed on September 25, 2015, and was issued on July 12, 2016. In the “Related U.S. Application Data” section on the face of the patent, it states that the application for the ’317 patent is a “division” of an application filed on July 27, 2012, and issued as U.S. Patent No. 9,209,455 (the “’455 patent”). Ex_1001. It has been explained to me that a “divisional” application has the same specification as the original application and the same effective filing date but is issued with different claims. The “Related U.S. Application Data” section also refers to Provisional application No. 61/575,115, filed on August 16, 2011. It has been explained to me that a provisional application is a placeholder that is not substantively examined by the Patent Office but is pending for one year to provide an opportunity for the applicant to file a non-provisional patent application to be examined.

55. As it has been explained to me, whether a later-filed non-provisional patent application is entitled to the earlier filing date of the provisional application depends on whether the subject matter recited in the patent claims was adequately disclosed in the provisional application. Therefore, depending on the adequacy of

the disclosure in the Provisional application, the date for which prior art is to be evaluated for the '317 patent is either August 16, 2011 or July 27, 2012. Ex_1001.

A. Specification of the '317 Patent

56. The “Background of the Invention” section acknowledges that performance characteristics of lithium nickel oxide (LiNiO_2) and lithium cobalt oxide (LiCoO_2) when used as cathode materials were already known. Particularly, the '317 patent notes that lithium nickel oxide materials having a layered structure were known to be desirable for lithium battery cathode materials in that they cost less and have higher capacity as compared with lithium cobalt oxide materials, but they exhibit poor electrochemical stability and cycling performance. This section also acknowledges that it already was known to improve cycling stability for LiNiO_2 materials by substituting Ni with limited amounts of other metals, such as cobalt, for nickel. The Background section further notes that, because cobalt is more expensive than nickel and has lower capacity and rate capability, “it would be desirable to use only as much Co as is required to confer sufficient stability to the LiNiO_2 .” The Background section then concludes that “there remains a need for a lower cost lithium battery cathode material that provides the desirable properties of LiNiO_2 at lower cost.” Ex_1001, 1: 20-45.

57. I agree that, by the 2011 timeframe, the disadvantages of using cobalt-free LiNiO_2 were known, and it also was known that LiCoO_2 was expensive.

In my opinion, techniques were already known for addressing these issues. It was well understood to substitute other metals, such as cobalt, for nickel, to improve stability while using only as much cobalt as needed to reach acceptable stability, keep the material reasonably cost-effective, and preserve the desirable properties of high specific capacity and rate capability of LiNO_2 . For this reason, before the '317 patent, it was already known how to synthesize cathode materials that were improvements over both LiNiO_2 and LiCoO_2 .

58. The Detailed Description of the Preferred Embodiments section begins by stating that “[t]he inventors have discovered that lithium nickel oxides having the layered $\alpha\text{-NaFeO}_2$ -type structure and having cobalt enriched grain boundaries are surprisingly stabilized.” Ex_1001, 3:10-12. I do not agree that the inventors of the '317 patent were the first to discover this or that this was an invention. It was well understood that cathode material comprised of lithium nickel oxides have a layered $\alpha\text{-NaFeO}_2$ -type structure. It also was already known to use cobalt in ways that caused there to be an increased cobalt concentration in grain boundaries. This was not new.

59. The specification refers to FIG. 1 as depicting a secondary particle that “comprises a plurality of crystallites,” with “a crystallite 10 comprising a first composition, and grain boundary 20 comprising a second composition.” Ex_1001, 4:44-53.

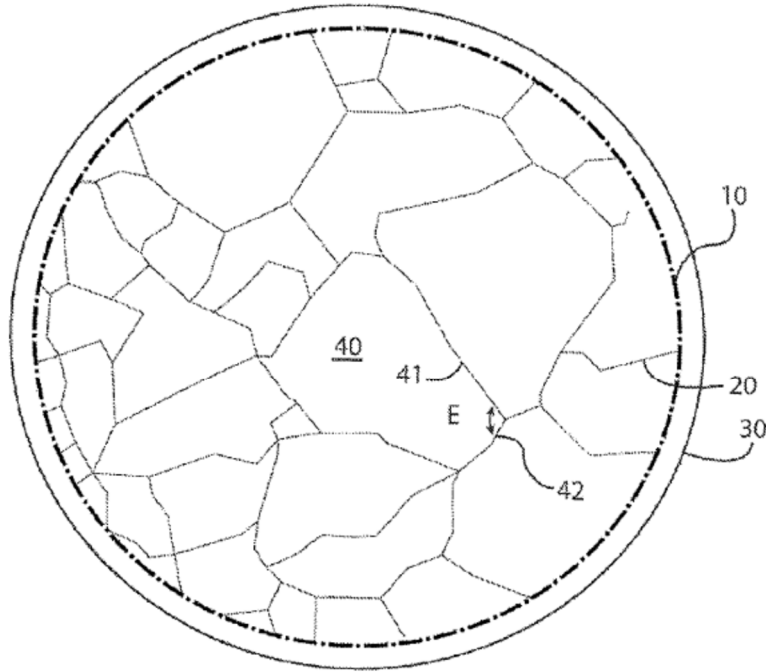


FIG. 1

60. This appears to be a sketch of a cross-sectional slice of a conventional secondary particle. A person of ordinary skill would understand from the sketch that the “first composition” refers to the bulk interior of a primary particle, whereas the “secondary composition” refers to areas at the edges of a primary particle where it is adjacent to another primary particle.

61. In the sketch, element 41 is labeled as being a grain boundary at the edge of two adjacent primary particles. Grain boundaries were well known to those of ordinary skill in the art at the time, and the named inventors of the '317 patent were not the first to discover grain boundaries or depict them.

62. The '317 patent states that the grain boundaries “may intersect to form an angle therebetween” and that “[t]he dimensions of the grain boundary are not

particularly limited.” Ex_1001, 6:47-7:10. I note that the ’317 patent does not disclose any particular method to cause the grain boundaries to have any particular shape or angles, as these characteristics are generally random. The patent describes very wide ranges of potential lengths, widths, thicknesses, etc. for the grain boundaries, again without disclosing any particular method to achieve them.

63. The specification notes that “[w]hile not wanting to be bound by theory, it is understood that the disclosed secondary particle is a dense polycrystalline agglomerate of submicron-sized primary crystallites.” Ex_1001, 11:27-29. This also was already well-understood prior to the ’317 patent. The patent also acknowledges that:

- “[I]t has been shown that in polycrystalline materials having the layered α -NaFeO₂-type structure, electrochemical cycling induces the layers of the transition metal atoms at the grain boundaries (e.g., edges of the crystallites) to reorganize into a NiO-type rock salt structure and/or to be reduced in oxidation state;”
- “These transformations are also associated with the appearance of cracks between adjacent crystallites,”
- the “resulting ... cracks in the grain boundaries between crystallites significantly degrade the electrochemical performance of these materials;” and

- “It is also understood that whereas Ni atoms at the grain boundaries undergo reduction in oxidation state as part of these transformations, Co atoms in the grain boundaries do not, suggesting that it is primarily the Ni atoms that are mobile and drive the undesirable structural rearrangements in the grain boundaries.”

Ex_1001, 11:27-45. In my opinion, these passages in the '317 patent acknowledge that it was already known, prior to 2011, that increasing the concentration of cobalt in the grain boundaries can stabilize them by substituting out nickel with cobalt. Given that the '317 patent also acknowledges that it also was well understood that cobalt is more expensive than nickel and diminishes capacity and rate capability, the patent appears to admit that cobalt enrichment of grain boundaries was not inventive.

64. The '317 patent provides a set of examples in which a lithium nickel oxide precursor is prepared and then coated to achieve cobalt-enriched grain boundaries. In some examples, the lithium nickel oxide base material includes a small amount of magnesium, or cobalt. The base material is prepared, for example, by dry mixing lithium hydroxide with lithium nitrate, adding $\text{NiCo}(\text{OH})_2$, shaking, and then heating. To enrich grain boundaries, the precursor is wetted with dissolved LiNO_3 and $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, dried, and then sintered in a timed progression of temperature ramps until a higher sintering temperature is achieved.

For example, in Example 2 of the '317 patent, after drying, the material is heated at 5°C/min to about 450° C and held for about 1 hour, then raised at about 2°C/min to about 700 °C and held for 2 hours. Ex_1001, 14:50-65. Prior to providing a series of examples, the '317 patent describes this process more broadly, with wide ranges of temperatures and heating times. Ex_1001, 9:29-10:4.

65. The specification also discloses that the “first composition” of the primary particle can include lithium “in an amount of about 0.1 to about 1.3 moles,” nickel “in an amount of about 0.1 to about 0.79 mole,” cobalt “in an amount of 0 to about 0.5 mole,” and oxygen “in an amount of about 1.7 to about 2.3 moles.” Ex_1001, 5:1-21. In my opinion, these ranges for lithium and nickel are so broad that they are meaningless. In fact, the range for cobalt is so broad that it includes having no cobalt at all. Finally, the disclosed range for oxygen is about 2, which is typical for an LiNiO₂ based material. With ranges this large for lithium and nickel, this is not inventive.

66. With regard to the “second composition,” the specification states that the grain boundaries can comprise lithium in a range of “0.1 to about 1.3 moles,” nickel in a range of “0.1 to about 0.95 mole,” cobalt in a range of “0.02 to about 0.99 mole,” and “oxygen in an amount of about 1.7 to about 2.3 moles.” Ex_1001, 12:39-49. Once again, the disclosed ranges for lithium, nickel, and cobalt are so broad that they are essentially meaningless. Moreover, they are basically the same

as the “first composition,” with the exception of the high end of the range for cobalt. These ranges are so broad that they could include a particle without any cobalt enrichment.

B. Claims of the '317 patent

67. The '317 patent has 17 claims. It has been explained to me that claims 1 and 17 are “independent” because they do not depend from anything else.

Claim 1 appears:

1. A particle, comprising:

a plurality of crystallites comprising a first composition having a layered α -NaFeO₂-type structure and comprising:

lithium, nickel, and oxygen;

a grain boundary between adjacent crystallites of the plurality of crystallites and comprising a second composition having the layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof,

wherein a concentration of cobalt in the grain boundary is greater than a concentration of cobalt in the crystallites.

68. I note that the claim is directed to a secondary particle of lithium nickel oxide-based material having a layered α -NaFeO₂-type structure and a grain boundary. As I explained above, the '317 patent specification acknowledges that

this was well-known, and this was discussed in literature pre-dating the earliest filing date for the '317 patent.

69. The claim also states that “a concentration of cobalt in the grain boundary is greater than a concentration of cobalt in the crystallites.” I note that the claim does not require that the concentration must be greater by any particular amount or percentage.

C. Summary of the Prosecution File History for the '317 Patent

1. Provisional Application

70. The '317 patent claims priority to the '455 patent, which claims priority to U.S. Provisional Application No. US 61/575,115 (the “'155 application”). Ex_1001. From my review of the provisional application, I note that several features of the claims in the '317 patent were not disclosed provisional filing. It has been explained to me that if the provisional application does not disclose claimed features, or does not describe how to achieve the claimed results, then the provisional application cannot be relied upon for its earlier filing date. In my opinion, that is the case here.

71. As one example, there is no mention of a “second composition” having a “layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof.” Ex_1006, pp.8-13.

72. Also, the '155 application also does not discuss any steps for manufacturing the polycrystalline material, such as heating regimes or precursors. There is no mention of heating at all. *Id.*

73. The '155 application also does not discuss the addition of any layers on the surface of the secondary particle containing the polycrystalline material. *Id.*

74. Other than the STEM images, the '155 application does not discuss the physical attributes of the grain boundary, such as the thickness, the length, or the direction of the crystallites in the polycrystalline material. *Id.*

2. Prosecution of the Application for the '455 Patent

75. I reviewed the prosecution history of the '455 patent and understand that the Primary Examiner allowed the application for the '455 patent without issuing any prior art rejections or Office Actions. In the Notice of Allowance dated August 13, 2015, the Examiner said that the closest prior art was a U.S. Patent Application No. 2009/0104530 to Shizuka et al ("Shizuka"). Ex_1004, pp.14-16. The Examiner explained that while Shizuka et al. discloses an α -NaFeO₂-type structure of Li oxide and Ni, it does not teach that the claimed grain boundary "between the crystallites" comprises a second composition with a higher concentration of Co than the claimed first composition. *Id.*

76. I reviewed Shizuka and in my opinion, it is not the closest prior art to the '317 patent claims. Ex_1021. Shizuka is directed to a technique for subjecting a

lithium transition metal compound to mercury intrusion. *Id.*, Abstract. Shizuka discloses characterizing the compound by a mercury intrusion curve obtained by mercury intrusion porosimetry. *Id.*, ¶¶336-346. While Shizuka also notes that LiCoO₂ and LiNiO₂ crystals have an α -NaFeO₂-type structure and that various elements can be incorporated into the crystal structure or localized on grain boundaries in the particles, these points were already well known and were not unique to Shizuka. *Id.*, ¶411 (“A typical crystal system of the layered compounds such as LiCoO and LiNiO having the α -NaFeO₂-type structure is a hexagonal system that is assigned to the space group R(-3)m layered structure' (the R(-3)m structure on a layer is as defined in the expression (4) described above) on the basis of symmetry thereof.”). As I describe below, there were other references that are more relevant.

3. Prosecution of the Application for the '317 Patent

77. I also reviewed the prosecution history of the '317 patent. The examiner did not issue any prior art rejections. The Examiner issued a Notice of Allowance with identical reasoning for allowing the claims to that included in the '455 patent. Ex_1005, pp.158-159. After the Examiner allowed the case, the applicant cited two prior art references, but they were not applied in a rejection.

V. Person of Ordinary Skill in the Art

78. It is my understanding that when interpreting the claims of the '317 patent I must do so based on the perspective of one of ordinary skill in the art at the relevant priority date. My understanding is that the earliest claimed priority date of the '317 patent is August 2011. In my opinion a person of ordinary skill in the art for the '317 patent would include a person, or more likely, a group of people, familiar with the design, development, and electrochemical operation of cathode materials for lithium-ion batteries, and in particular, lithium nickel oxide polycrystalline materials. Such a person, or group of people, would have at least a master's degree in chemistry, chemical engineering, or materials science, or related fields of study, and at least three years' experience in academia or industry researching, designing, or developing such cathode materials, which would include performing experiments to synthesize and characterize such polycrystalline materials and understand how such characterization pertains to their capabilities as materials for use in lithium-ion batteries. I understand that such a person or group of persons could be referred to as a "person of ordinary skill in the art," a "POSITA," or a "skilled artisan."

79. I qualify as a person of ordinary skill in the art, as my training and experience meet or exceed that of such a hypothetical person or group of persons. I have performed extensive research and authored numerous publications regarding

such polycrystalline materials, performed lab experimentation, supervised students in their study of these areas, and worked or consulted with industry scientists to develop improvements to such materials for their use in batteries. As a professor, I taught undergraduate and graduate courses concerning electrochemistry and its application to batteries.

VI. Claim Construction

80. I understand that the issue as to whether a claim is unpatentable is decided after first interpreting the meaning of the wording and terminology found in the claim. I understand that the interpretation should be made from the perspective of a person of ordinary skill in the art, at the time of the invention.

A. Grain Boundary

81. The word “grain boundary” appears in claims 1-5 and 15 and is used over 100 times in the ’317 patent specification.

82. In my opinion, a person of ordinary skill in the art would have understood that a grain boundary is a region located generally at the edges/surfaces of and between adjacent crystallites where they interface with each other.

83. Grain boundaries were known well before the ’317 patent and it is a term of art. It was well understood that a secondary particle comprises agglomerated primary particles, in contact with each other at grain boundaries. The

grain boundaries are defect areas where the surfaces of primary particles are bound to each other.

84. The '317 patent specification uses the term “grain boundaries” in a manner that is consistent with how a person of ordinary skill would understand it. The patent correctly notes that grain boundaries are at the “edges of the crystallites,” “on a surface of the crystallite,” and “between adjacent crystallites.” Ex_1001, 6:20-22; 11:32-33, 12:15-16.

85. Particularly, the '317 patent also describes that:

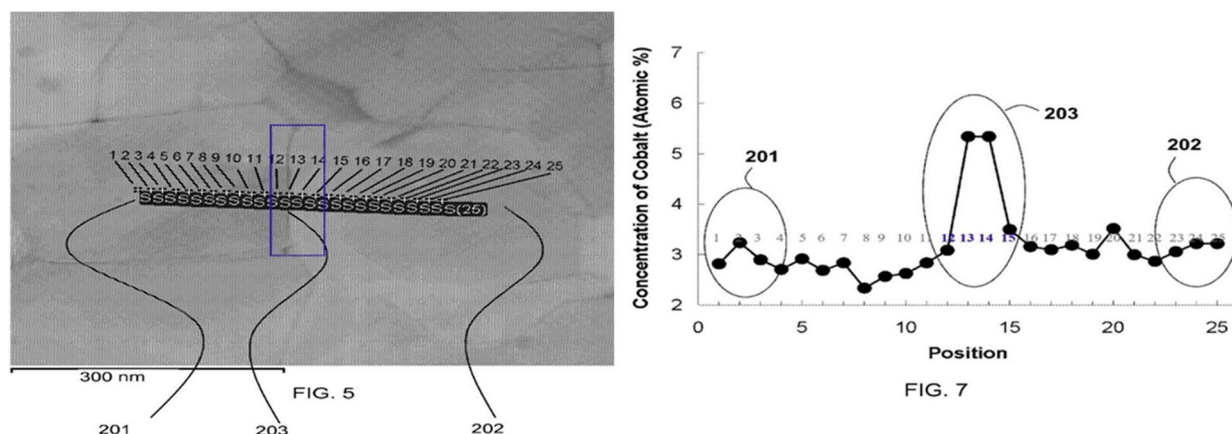
It has been shown that in polycrystalline materials having the layered α -NaFeO₂-type structure, electrochemical cycling induces the layers of the transition metal atoms **at the grain boundaries (e.g., edges of the crystallites)** to reorganize into a NiO-type rock salt structure and/or to be reduced in oxidation state. These transformations are also associated with the appearance of **cracks between adjacent crystallites**. While not wanting to be bound by theory, it is understood that the resulting NiO-type phase and **cracks in the grain boundaries between crystallites** significantly degrade the electrochemical performance of these materials.

Ex_1001, 11:29-40 (emphasis added). This passage from the '317 patent explains that at the primary particle's edge where it is adjacent to another primary particle, the layers can reorganize their structure and that causes cracking at the grain boundary.

86. The '317 patent also explains: “The grain boundary is between adjacent crystallites, **is on a surface of the crystallite**, and comprises the second

composition.” Ex_1001, 6:20-21 (emphasis added). In this sentence, the ’317 patent confirms that grain boundaries begin at the surfaces, or edges, of adjacent primary particles. It is part of and includes the surface.

87. The ’317 patent also includes figures that depict grain boundaries from experiments performed to synthesize polycrystalline materials. For example, FIG. 7 is a graph depicting the concentration of cobalt detected “in a grain boundary” and across a length spanning from the center of one crystallite to another one as seen in annotated FIG. 5 (reproduced below). *Id.*, 15:1-29. Specifically, the region within the oval 203 shown in FIG. 7 generally indicates the location and span of the grain boundary. *See id.*, 15:5-9, 24-29.



88. As can be seen from FIG. 7, the area 203, which is designated as the grain boundary, is not at a specific position. Rather, it is a broadly encircled area which corresponds to a region of locations where the surfaces of adjacent particles abut together.

89. FIG. 10 is an STEM of a thin cross-section of a secondary particle prepared in Example 6, and FIG. 13 is a cobalt EDS map of the same section that “shows that the cobalt is concentrated at the grain boundaries,” in which “[a]n average thickness of the grain boundaries in FIG. 13 is about 100 nm, and the thickness of the grain boundaries range from 50 nm to 150 nm. Ex_1001, 17:1-8. The two figures are presented side by side below:

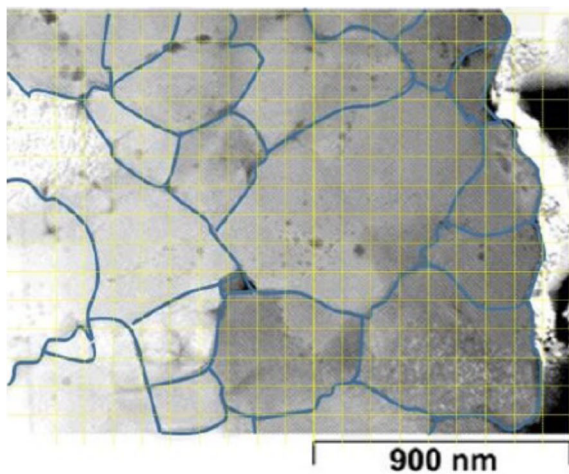


FIG. 10

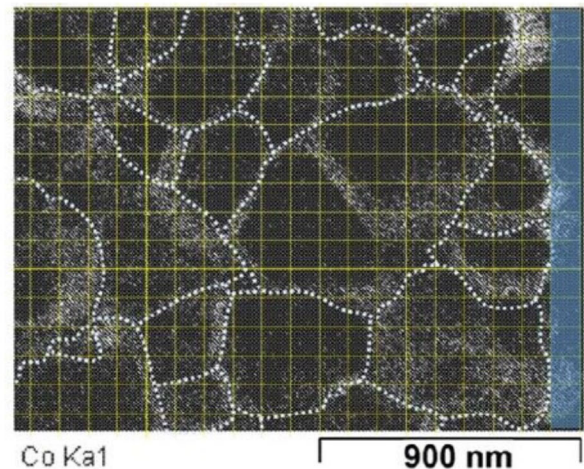


FIG. 13

90. From these images, it can be seen that the grain boundaries, which have an average thickness of 100 nm, are depicted as the white-shaded areas in FIG. 13 (the white shading indicates increased cobalt concentration), and are much thicker than the narrow lines in FIG. 10. From this experimental data, a person of ordinary skill in the art would appreciate that the increased cobalt has diffused into the surfaces of the adjacent primary particles, and that the '317 patentees consider these surfaces to be part of the grain boundaries, as that term is used throughout the patent.

91. I note that in FIG. 1, the '317 patentees point to a thin line as being the grain boundary, whereas in FIG. 13, it is much wider and has an average thickness of 100 nm, which can be up to 10% of the diameter of a primary particle as defined in the specification. The thin lines in FIG. 1 are much, much thinner than 100 nm as shown using the measurement bars provided in the images. In my opinion, a person of ordinary skill in the art would have understood that a grain boundary is a transition region that extends into the surface of the primary particles and does not have a specific thickness. Accordingly, the thin lines in FIG. 1 illustrate just part of the grain boundaries.

92. A review of literature during the relevant timeframe confirms that a person of ordinary skill in the art would have understood that grain boundaries are transition regions that include the surfaces of the primary particles.

93. As one example, Japanese Published Application No. JP 2010/047466 A, titled "Lithium Transition Metal Oxide With Layer Structure," which was filed in July 2009 and published in March 2010, states explicitly that grain boundaries include the outer circumferences, or surfaces, of the primary particles.

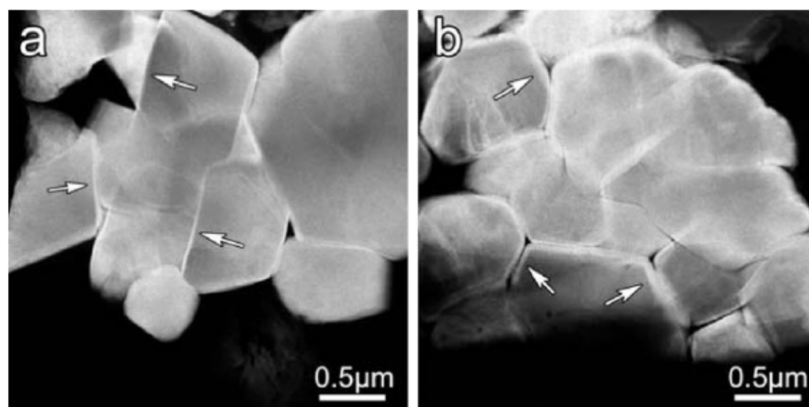
In the present invention, the smallest unit particle that is composed of a plurality of crystallites and is surrounded by grain boundaries when observed with a SEM (for example, 3000 times) is referred to as a "primary particle". Therefore, primary particles include single crystals and polycrystals. In addition, in the present invention, **particles that are agglomerated so that a plurality of primary particles share a part of their outer**

circumferences (grain boundaries) and are isolated from other particles are referred to as "secondary particles" or "agglomerated particles".

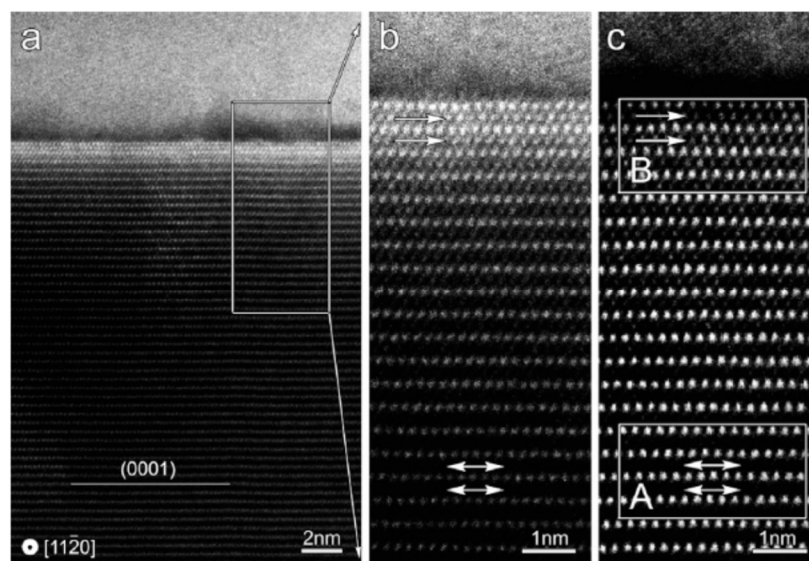
Ex_1024 (emphasis added). I agree that grain boundaries are the shared part of the outer circumferences of agglomerated primary particles.

94. Zheng, titled “Microstructural Changes in $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ Positive Electrode Material During the First Cycle,” provides images of the same grain boundaries after a particle was synthesized and after it underwent a first cycle (as part of a composite electrode). From these images, it can be seen that the grain boundary thickness significantly increases, and intergranular microcracks worsen. Zheng also notes that “from the grain interior to the grain boundary, the structure gradually changes from an ordered layer structure (α - NaFeO_2 -type) to a partially ordered structure and then to a disordered rock-salt structure.” Ex_1011, Abstract. Zheng concludes that “these microstructural changes are primarily responsible for the irreversible capacity during the first cycle.” *Id.*

95. Figure 5 of Zheng illustrates that grain boundaries are relatively thin in an original sample (labeled as “a”) but their thicknesses increase significantly after a single cycle (labeled as “b”). *Id.*, FIG. 5.

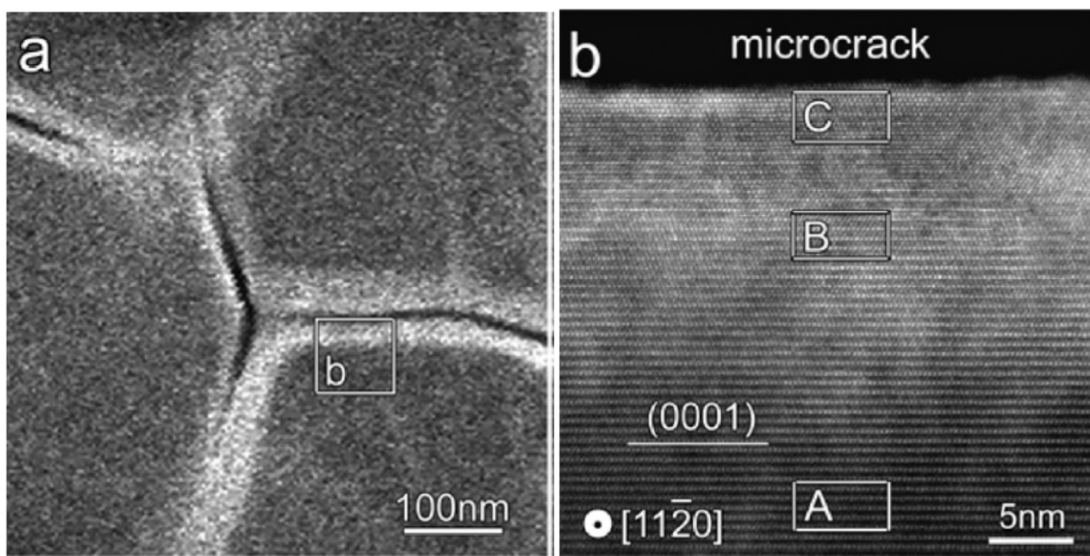


96. Figure 6 illustrates “a typical grain boundary in the original sample” (labeled as “a”), along with a magnified image (“b”) and an image at a different detection angle (“c”). Zheng explains that “[i]n (b) and (c), two Li layers each in the grain interior and grain boundary layer are indicated with double-headed arrows and single-headed arrows, respectively.” *Id.*, p.4, FIG. 6.



This shows that there is a gradual transition from the bulk of the primary particle to the grain boundary.

97. Finally, Figure 7 is a cross-sectional view of a grain boundary at lower and higher resolution p, once again illustrating the gradual transition from the surface of the primary particles into the bulk regions. From this image, it can be seen that when the thin lines in FIG. 1 of the '317 patent are magnified, there is a transition region. *Id.*, FIG. 7.



98. In my opinion, these discussions and images in the literature are consistent with the discussion and images in the '317 patent. Taken together, a person of ordinary skill would have understood that a “grain boundary” is a region formed at the edges/surfaces of the crystallites where two adjacent crystallites interface with or abut each other.

VII. The '317 Patent Claims Were Known Or Would Have Been Obvious Over Known Technology

99. In this section, I describe prior art references that I believe are relevant and show that the claims of the '317 patent are unpatentable. In my

opinion, individual references taken by themselves teach everything in the '317 patent claims. Also, a person of ordinary skill in the art would have been motivated to combine the teachings from these references, and that combination discloses all of the claim limitations.

A. Lampe-Onnerud

100. The first reference that I discuss is U.S. Pat No. 6,921,609 to Lampe-Onnerud et al., issued July 26, 2005 (“Lampe-Onnerud”), titled “Gradient cathode material for lithium rechargeable batteries.” Ex_1007. The patent application was filed on February 11, 2002. This reference discloses a lithium nickel oxide-based cathode material that has a coating on the core with a greater ratio of cobalt to nickel than in the core.

101. Lampe-Onnerud notes that LiCoO₂-type materials were commonly used in the battery industry but were expensive. The reference also notes that conventional LiNiO₂-based materials have higher specific capacity than LiCoO₂ based materials but tend to be less safe and exhibit lower first cycle efficiency than LiCoO₂-type cathodes. Ex_1007, 1:11-34.

102. Lampe-Onnerud explains that “safety” refers to “structural stability or structural integrity; if a material decomposes during cycling or is easily decomposed or causes gassing at elevated temperatures, the material is considered unsafe.” Ex_1007, 7:19-22. When the reference explains that LiNiO₂-based

materials are less safe because they “exhibit more gassing” than LiCoO_2 -type materials, it is understood that a battery’s safety performance can deteriorate by gas evolution (particularly, molecular oxygen, alkenes, hydrogen, HF, and carbon dioxide), especially during its first cycle, and the gassing continues during subsequent high voltage cycles. *Id.*, 1:25-26. This can result in oxygen depleted regions near the cathode surface, and the release of lattice oxygen from the cathode that can initiate exothermal, dangerous oxidation of the electrolyte solution. *Id.*, 7:20-23.

103. By mentioning that conventional LiNiO_2 -based materials have reduced first cycle efficiency, Lampe-Onnerud is referring to degradation that occurs the first time that lithium ions are removed from the layers of the cathode material during deintercalation but cannot be completely re-intercalated in the second charging process. Put another way, during the first charge when lithium ions migrate to the anode, some of the active sites in the layers of the cathode are lost due to structural changes in the material. This is called irreversible capacity loss. Lampe-Onnerud defines “capacity” to mean “the number of Li ions that can reversibly be removed from the crystal structures of lithium-based materials.” *Id.*, 7:11-14. Similarly, Lampe-Onnerud defines “reversibility” to mean “that the structure substantially maintains its integrity and that Li ions can be fully intercalated back to restore the initial crystal structure.” *Id.*, 7:14-16. In my

opinion, these definitions reflect the understandings of a person of ordinary skill during the relevant timeframe.

104. Lampe-Onnerud provides a useful discussion about why conventional LiNiO_2 -based cathode materials tend to collapse during cycling. *Id.*, 7:32-8:35. As the reference explains, both LiNiO_2 and LiCoO_2 should have the same amount of lithium ions, but LiNiO_2 can reversibly remove more, when being charged up to 4.3V (a potential that does not lead to detrimental oxidation of the electrolyte solution). But when so much lithium is removed, it causes structural collapse. This happens when vacancies in the lithium layers are repopulated with nickel ions, which deforms the 3-D structure. *Id.*

105. Lampe-Onnerud also notes that replacing some of the Ni atoms by other metallic atoms (like cobalt) can stabilize the $\text{LiNi}_x\text{M}_y\text{O}_2$ crystal structure. *Id.*, 1:45-57. Lampe-Onnerud discloses an $\text{LiNi}_x\text{M}_y\text{O}_2$ synthesis process that results in a cobalt concentration gradient near the secondary particle's surface. *Id.*, 2:1-15. Lampe-Onnerud notes that the gradient material “typically has a matched lattice, which enables a fully functional material similar to the regular oxides in cycling properties, which enables the material to stay intact throughout the life of the battery.” *Id.*, 2:24-28.

106. For the base material, Lampe-Onnerud discloses examples of empirical formulas. One example is $\text{Li}_x\text{M}'_z\text{Ni}_{1-y}\text{M}''_y\text{O}_2$ wherein “x” is greater than

about 0.1 and equal to or less than about 1.3, “y” is greater than about 0.0 and equal to or less than about 0.5, and “z” is greater than about 0.0 and equal to or less than about 0.2. *Id.*, 3:56-67. In the formula, M' and M'' are different possible metals, where M' can be Na, K, Ni, Ca, Mg, or S, and M'' can be Co, Fe, Mn, Cr, V, Ti, Mg, Si, B, Al, or Ga. *Id.* The reference also notes that “[i]n a specific embodiment, M'' includes cobalt.” *Id.*, 4:1-2. Lampe-Onnerud describes that the coating can have similar composition as the core material, but the coating has a greater ratio of cobalt to nickel than the core. *Id.*, 4:45-60. Put another way, “the ratio of cobalt to nickel of the composition of the invention increases as a gradient from the core to an outer surface of the coating.” *Id.*, 4:14-16. Some examples of the core material include: $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$ and $\text{Li}_{1.1}\text{Ni}_{0.87}\text{Co}_{0.08}\text{Mn}_{0.05}\text{O}_2$. *Id.*, 4:29-31. Examples 1 and 6. Lampe-Onnerud correctly notes that the crystals have the structure of a “ α - NaFeO_2 -type.” *Id.*, 3:46-49, 6:30-52.

107. Lampe-Onnerud describes a process for synthesizing cathode material such that it has a cobalt concentration gradient. The reference discloses several examples of synthesized cathode material and steps for manufacturing it. All of the examples use the same process, with some small variations in the temperatures and heating times. The process that was described in the '317 patent is the same one that Lampe-Onnerud uses. To test the synthesized material, Lampe-Onnerud

performs x-ray diffraction (XRD) analysis to confirm that there is a cobalt concentration gradient. *Id.*, 10:7-11.

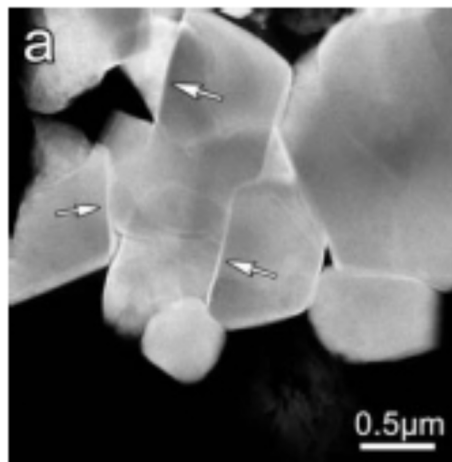
108. In my report, I focus on Example 1 from Lampe-Onnerud, because I understand that Dr. Noh replicated this particular experiment. In Example 1, the base material is wetted with a dissolved solution of LiNO_3 and $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$. The water is evaporated off and the coated material is temperature ramped at $5^\circ\text{C} / \text{minute}$ until 450°C and then held for an hour. Then it is further ramped at $2^\circ\text{C} / \text{minute}$ until 750°C and held for an hour. After the material is cooled, it is grinded such that the particle is between $1\text{-}50\ \mu\text{m}$ after grinding. *Id.*, 9:26-16:18.

109. In the next several paragraphs, I provide technical explanation, based on my expertise, about why performing the steps in Example 1 result in a secondary particle having a cobalt gradient. As I describe below, Lampe-Onnerud's process necessarily results in an increased cobalt concentration in the grain boundaries near the surface of the secondary particle, relative to crystallites. Again, the process disclosed in Lampe Onnerud of mixing, evaporating and heating in timed temperature ramps is the same as what is disclosed as being the process in the '317 patent. That is, in Lampe-Onnerud and also in the '317 patent (as I described in Paragraph 64), the base material is wetted with a dissolved solution of LiNO_3 and $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, the water is evaporated off and the coated material is sintered in a temperature ramp, then further sintered at a higher

temperature ramp. The two documents disclose the same process and all of the examples enumerated in Lampe-Onnerud are within the time and temperature ranges in the '317 disclosure. Ex._1001, 9:58- 10:3.

110. The Lampe-Onnerud process begins with a conventional lithium nickel oxide-base material. In some examples, such as Example 1, the material is a commercially available material that is simply acquired. Ex_1007, 9:31-35, 9:64-66. Such base material is known to be comprised of secondary particles having agglomerated primary particles and grain boundaries.

111. An image of such conventional, commercially available lithium nickel oxide-base material is depicted in Zheng, showing agglomerated primary particles and the grain boundaries (with white arrows pointing to them).



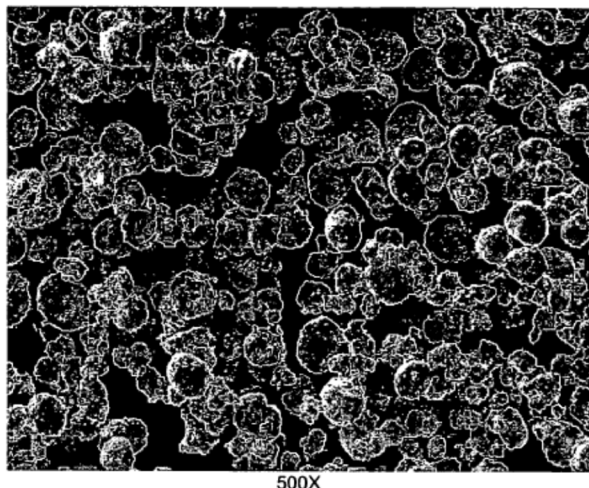
Ex_1011, FIG. 5.

112. Example 6 of Lampe-Onnerud discloses a process to synthesize the base material. Ex_1007, 13:1-18. To do this, Lampe-Onnerud begins with steps to

mix dry ingredients consisting of hydroxide, nitrate or carbonate salts (ionic compounds) of Ni, Li, Co (and optionally Mg or Mn etc.). The mixing (and sometimes additional grinding) produces powders that are mixed homogeneously in preparation for the heating process which will chemically combine them to form the layered crystalline structures. Next, the sintering/calcination steps are ramped. This allows the metal ions to interact with each other and begin to grow individual grains of layered Li-Ni(M)-O structure, and at the same time, to remove the associated anions and especially to further oxidize the hydroxides (by reacting with the oxygen molecules in the atmosphere at the high temperature, releasing water molecules) into pure oxides. As the hydrogen is removed (through water evolution) from the compounds, water gas molecules will bubble out of the mixture, thereby producing pores within the 3D crystal, which will be filled and repaired upon further high temperature heating. The material is next subjected to higher heating steps (from 700+ degrees C). This serves to further mold the morphology of the final structure by combining individually directed single grains of LiNi(M)O_2 into a polycrystalline material with grain boundaries. At the same time, each grain will also have enough driving force so that they achieve a more thermodynamically favorable state at this higher temperature.

113. Whether the base material is acquired or is synthesized as in Example 6 of Lampe-Onnerud, it is comprised of secondary particles, each made

of up agglomerated (clustered) primary particles. The Onnerud reference (which has some of the same authors as the Lampe-Onnerud reference) describes a very similar process to synthesize base material as in Example 6 of Lampe-Onnerud and provides an image of the resulting secondary particles. Ex_1027, 11:10-42.



Ex_1027, FIG. 1.

114. The next set of steps pertains to wetting (i.e., coating) the secondary particle base material with dissolved cobalt and lithium salts. In particular, I focus on Example 1 of Lampe-Onnerud.

115. In the first step in Example 1 of Lampe-Onnerud, lithium nitrate and cobalt nitrate (hydrated form) are dissolved in water, and the base material is added to the mixture. Ex_1007, 9:64-66. The added lithium and cobalt ions dissociate from their associated anions in an aqueous solution, and therefore are free to interact with the base material. The solution wets the surface of the secondary

particle and through percolation, the solution enters into grain boundaries at the surface and near the surface of the secondary particle.

116. This process of having the solution seep into the secondary particle can be referred to as percolation. Ex_1014, Title (“Percolation Models of Grain Boundary Wetting in Polycrystalline Materials”). The secondary particle contains generally defective lattice regions between the primary particles that allow extra space and a lower energy pathway for the liquid-phase molecules to travel into regions of the secondary particle. This is additionally aided by the unique cohesive/adhesive properties of water as the carrier for the ions.

117. The solution containing the dissolved ions will enter into/along the grain boundaries because they are more permeable than the bulk of the primary particles. Also, there are differences in the mobility of solution species, molecules, ions, in the grain boundaries of a material versus in the bulk of that same material. The diffusivity of a molecular and ionic species in the defect regions (e.g., along grain boundaries between primary particles) is higher relative to the bulk. This is due to the ease of transport for mobile species through less dense regions containing dislocations and misaligned 3-D crystal structure at the more loosely bound interfaces.

118. The surfaces of all of the particles (both primary and secondary as discussed above) are hydrophilic (i.e., attractive to polar water molecules) by

virtue of the charged species which make up the edges of the crystalline structure. As the water molecule manages to diffuse into the material, the cobalt and lithium ions will be present in their original concentrations in the solvent that transports them throughout the grain boundaries.

119. In the next step of Lampe-Onnerud Example 1, the substance is heated at low temperatures. Ex_1007, 9:66-67. This initial lower temperature heating step evaporates the water solvent, without destroying the particles' morphology due to undesirably vigorous bubbling. The “dried cake” that results is then grinded. *Id.*, 9:67-10:1.

120. The next step in Example 1 of Lampe-Onnerud heats the substance at intermediate temperatures (i.e., in the range of 450°C). *Id.*, 10:2-4. This is done to further evaporate any remaining water molecules and to form the LiCoO₂ coating material on the edges of both the primary and secondary particles. The stoichiometric ratio of Li to the other transition metals and oxygen in the coating material is crucial to the continued availability of Li ions for the electrochemical charging/discharging steps of the cathode material and also to the formation of the lithium transition metal oxide framework that matches the original stoichiometry of the active mass, which enables its long-term operation as a reversible cathode material.

121. The last step in Example 1 of Lampe-Onnerud is to ramp up to the elevated temperatures to 700°C or higher. *Id.*, 10:3-5. Lampe-Onnerud explains that “[w]hen subjected to the XRD, this material shown to have a gradient profile.” *Id.*, 10, 7-9. The cobalt ions in the grain boundary will replace some of the nickel ions in the 3b lattice positions, thereby creating a cobalt rich interphase near the surface of the primary particles. This is why the Example 1 process results in a higher concentration of cobalt in the grain boundary as compared with the crystallites. This gradient in cobalt concentration will diminish progressively from the outer surface of the crystals into the inner layers of the material. The low concentration of Ni ions at the edge of the crystals that results from the substitution of Ni for the above-described Co ions (both at the primary and secondary particle levels) will have the effect of increasing the stability of the cathode upon prolonged cycling. This is because the Ni ions at the surface diffuse into Li (3a) sites during deintercalation steps, which distorts the 3D structure of the primary crystals and create microcracks at the surface as described above.

122. At the end of the description of Example 1 of Lampe-Onnerud, the reference states that the material that results from performing the described process has “improved gassing characteristics and cycle efficiency.” *Id.*, 10, 15-17. The resulting material is still comprised of secondary particles having agglomerated primary particles and grain boundaries. The improvement that Lampe-Onnerud

notes is because the cobalt coating reduced cracks that tend to appear at the surface of the particles (both primary and secondary) and expose fresh cathode active mass to reactive electrolyte solution species. These cracks allow the electrolyte solution to percolate deeply inside the bulk of the particles and completely destroy the active cathode material from the inside due to several possible side reactions between the lithiated transition metal oxide active mass with a variety of solution species. Therefore, the coating or concentration gradient approach in Example 1 of Lampe-Onnerud protects the grain boundaries near the surfaces by replacing Ni ions with Co ions in the surface layers, increasing cobalt concentration in that region to thereby protect the edges of the particles from cracking and ultimate destruction of the secondary particles upon exposure to the electrolyte solution.

B. Applying Lampe-Onnerud to Claims 1-17 of the '317 Patent

123. In this section, I compare claims 1-17 of the '317 patent with the disclosures provided by Lampe-Onnerud.

1. Claim 1

- a) “A particle, comprising: a plurality of crystallites comprising a first composition having a layered α -NaFeO₂-type structure and comprising: lithium, nickel, and oxygen”**

124. In my opinion, a person of ordinary skill in the art would have understood that Lampe-Onnerud discloses a polycrystalline particle of cathode active material. This is disclosed, for example, where the reference refers to the “... Li_xNiO₂ crystal structure,” that “the invention is a composition, such as a

crystal ...”), and discusses “[t]he crystal structure of the core” *Id.*, 1:45-47; 3:46-48; 4:45-47. Also, a person of ordinary skill in the art would have understood from the process steps in the Examples that the cathode is made of polycrystalline material. In some examples, such as Example 1, the “core” material was acquired from an external source, and a person of ordinary skill in the art would have known it to be a polycrystalline material, as I described above in Paragraphs 110-111. In other examples, such as Example 6, the steps are provided for synthesizing the base material, and the steps of mixing, the heating times, and heating temperatures are in the usual range that is understood for synthesizing a polycrystalline material, as I describe above in Paragraphs 112-113. The subsequent steps for wetting the particle and synthesizing the gradient do not change it from being a polycrystalline material. The discussion in the examples that the particle size is up to 50 μm further confirms that it is a secondary particle, since it would not be known how to make a primary particle of that size by performing the disclosed process steps.

125. This claim requires that the first composition has lithium, nickel, and oxygen, which are part of the empirical formula disclosed in Lampe-Onnerud as $\text{Li}_x\text{A}_{x2}\text{Ni}_{1-y1-z1}\text{Co}_{y1}\text{Q}_z\text{O}_a$, which includes lithium (Li_{x1} , where “x1” is 0.1 to 1.3), nickel ($\text{Ni}_{1-y1-z1}$ where “y1” and “z1” are between 0 and 0.2) and oxygen (O_a , where “a” is greater than 1.5 and less than 2.1). *Id.*, 4:45-51. In my opinion, a person of ordinary skill in the art would have understood that this is a “first composition” of

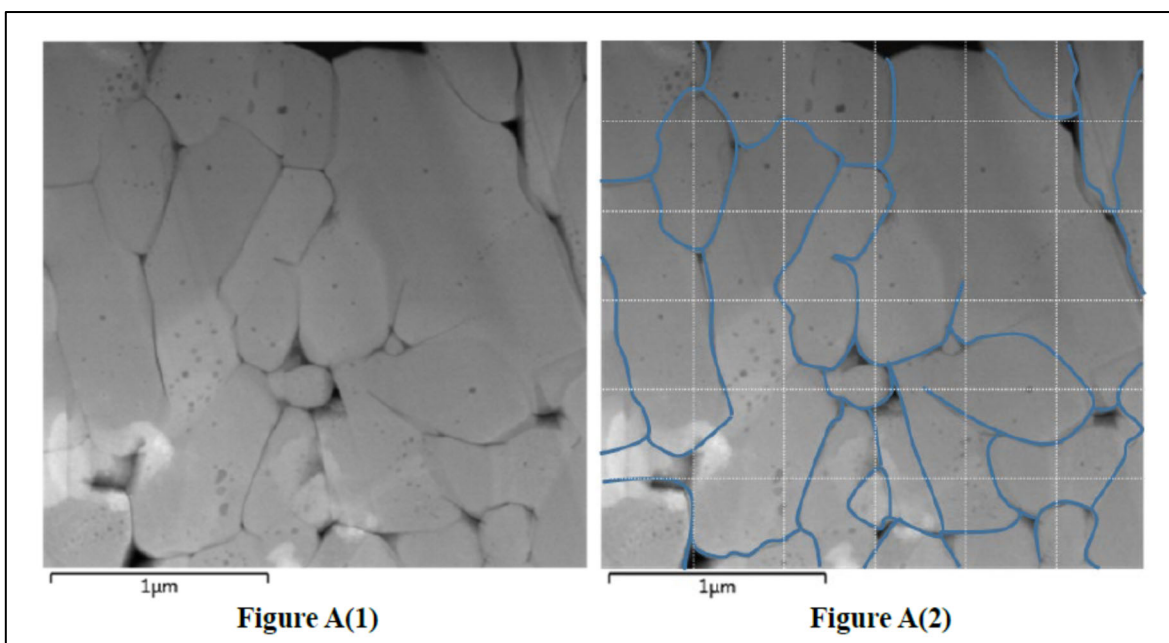
the particle. This is because it is in the core, and the purpose of having a coating is so that there will be two compositions.

126. The claim also requires that the first composition has a layered α -NaFeO₂-type structure. This is also explicitly disclosed in Lampe-Onnerud. One example is where it says that “[t]he crystal structure of the core ... is of an ‘ α -NaFeO₂-type.’” *Id.*, 3:46-48.

127. At the time, it already was commonly understood that such lithium nickel oxide-based cathode materials have a layered α -NaFeO₂-type structure. I have confirmed this by finding essentially the same disclosure in other references. Ex_1012, p.940 (“LiNiO₂, which also forms the α -NaFeO₂ structure ...”); Ex_1013, Section 1.1 (“LiNiO₂ atoms are arranged in a manner that leads to “a 2D layer structure, isostructural with α -NaFeO₂”).

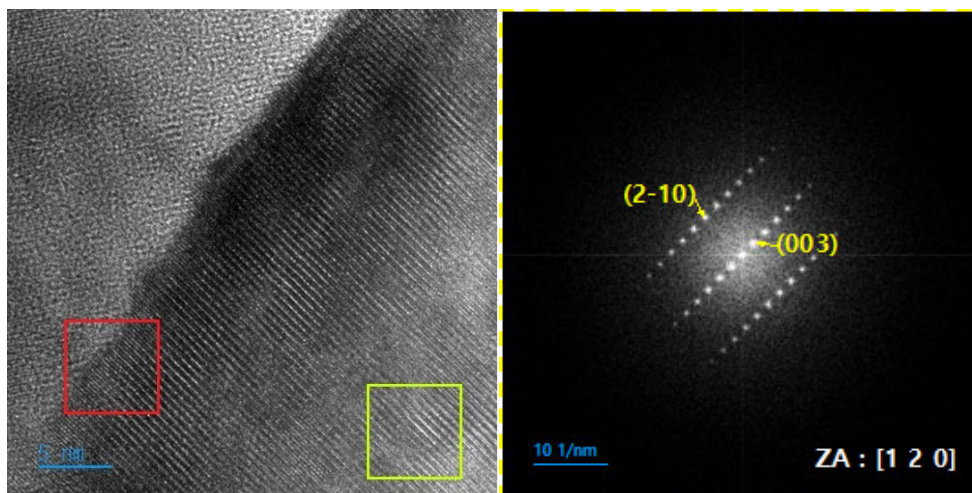
128. As I said above, Lampe-Onnerud teaches the same process disclosed in the ’317 patent (see Ex_1001, 13:63-14:18) and essentially the same temperatures and heating times disclosed in the examples of the ’317 patent. As I described above in Paragraphs 110-113, the examples of Lampe-Onnerud explain that the base material can be acquired or synthesized, and it is inherent that the material that results from process in Example 1 of Lampe-Onnerud is a polycrystalline material. And as I also describe in Paragraphs 108-109, the wetting process in Example 1 and the processes described in the examples of the ’317

patent are essentially the same and will not result in any difference relevant to the '317 patent claims. This is confirmed from Dr. Noh's declaration, which shows that Lampe-Onnerud's process necessarily results in secondary particles having a plurality of primary particles, or crystallites. I understand that Figure 1(A) from Dr. Noh's declaration is an SEM image generated from replicating Example 1 of Lampe-Onnerud. This image shows agglomerated primary particles. Ex_1003, ¶14, Figure A(1). From Lampe-Onnerud, I understand that Example 1 has a $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$ core, and so it is a first composition that includes lithium, nickel, cobalt, and oxygen. Although Lampe-Onnerud mentions $\text{LiNi}_{0.6}\text{Co}_{0.2}\text{O}_2$, this is a typographical error. The heading for this Example refers to "Synthesis of 10% (mol/mol) LiCoO_2 Gradient Having $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$ Core," and the specification also discloses that "[i]n a specific embodiment of the invention, the core material includes $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$." Ex._1007, 4:29-31. Also, the general formula requires that the sum total of the moles of Ni and Co are equal to one.



Ex_1003, ¶14, FIGS. A(1) (raw image), A(2) (image with traced blue lines to clearly delineate individual crystallites).

129. I understand that the following STEM images are also from Dr. Noh's replication of Example 1 of Lampe Onnerud. From these images, I note that the yellow square is from an area in the bulk of a primary particle. The slanted dotted lines (which represent a Fast Fourier Transform analysis of the STEM) in the image on the right indicate that this is a layered material, and it exhibits the classic pattern of a α -NaFeO₂ structure. *Id.*, ¶¶22-25, Figures E and G. This confirms the discussion in Lampe-Onnerud that the core material has an α -NaFeO₂ structure.



- b) **“a grain boundary between adjacent crystallites of the plurality of crystallites and comprising a second composition having the layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof,”**

130. In my opinion, Lampe-Onnerud discloses a material having grain boundaries of a second composition having a α -NaFeO₂ structure, a cubic structure, or a combination thereof. I refer back to my discussion above for claim 1(a) about why Lampe-Onnerud’s process as in Example 1 starts with a polycrystalline material and after the wetting/heating enrichment steps, it yields secondary particles with grain boundaries.

131. Referring again to Dr. Noh’s declaration, the image that he obtained by replicating Example 1 confirms that the resulting material will have grain boundaries throughout. Ex_1003, ¶14, Figure A(2). The traced blue lines are the interfaces of primary particles, where the grain boundaries are.

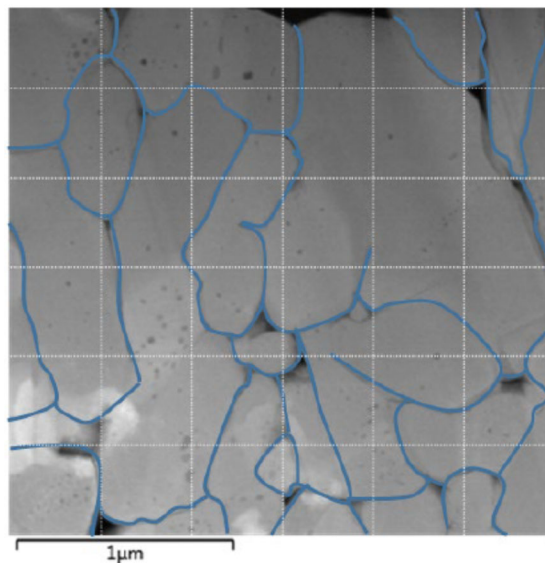
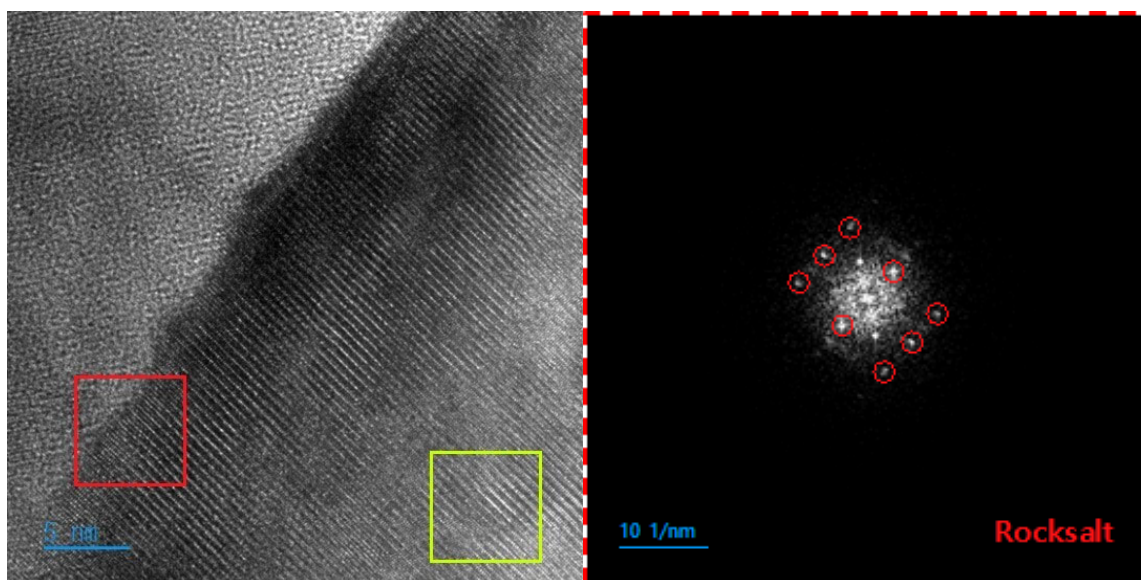


Figure A(2)

132. This image is what I would expect to see from replicating Example 1 in Lampe-Onnerud, because the steps result in a secondary particle of agglomerated primary particles, and grain boundaries will naturally form in random directions at the edges of the primary particles.

133. I understand from Dr. Noh’s declaration that he additionally tested the structure in a grain boundary region using Fast Fourier Transform analysis of the STEM image, as shown below (red square). I recognize this as having a cubic structure, as opposed to a layered structure. Ex_1003, ¶25, Figures E and F. It is standard language in the art to refer to crystal structures having a cubic lattice as “rocksalt.”



134. These images confirm what is inherent from Lampe-Onnerud's disclosure. As I have described above, grain boundaries are formed where primary particles interface. From Lampe-Onnerud's disclosure, a POSITA would have understood that the grain boundaries have a layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof. The process of producing a secondary particle produces areas of interface, ie. grain boundaries, which in some locations have structures similar to each primary particle, or layered structures. But in other places the process of sintering and fusing the particles together will produce interphase regions between the particles with irregularities in the layered structure, which adopt a more cubic structure, i.e. where there is no specific layering or distinction between the lithium and other metal positions in the crystal lattice. In addition, the heating process will at times remove some of the oxygen atoms, creating small areas where the stoichiometry is not exactly a ratio of 2 for O atoms.

The crystal structure thus formed resembles a cubic structure where there is no layering of separate lithium and metal atoms with a coordinated oxygen layer in between.

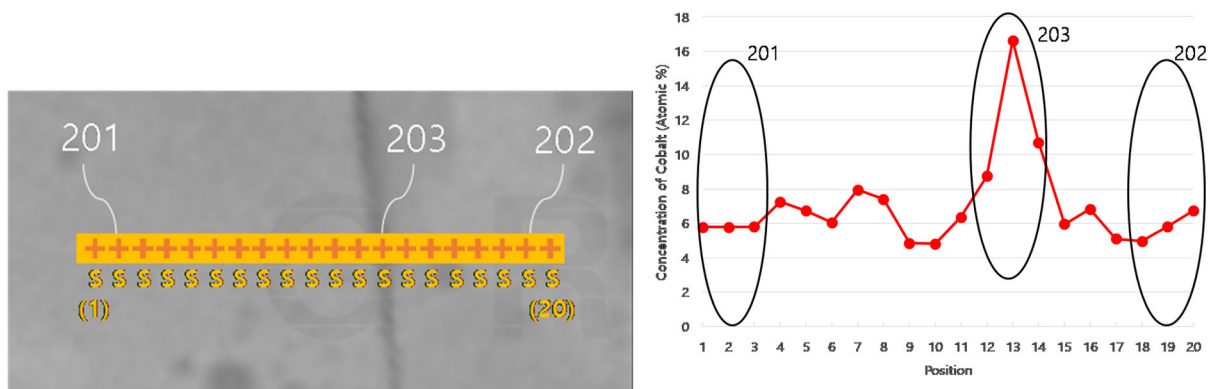
135. The wetting in Example 1 of Lampe-Onnerud coats the secondary particle, and the reference notes that “[t]he crystal structure of the core, and optionally of the coating, is of an ‘ α -NaFeO₂ type,’” and that the coating diffuses into the secondary particle forming a cobalt concentration gradient. Ex_1007, 3:45-49. Therefore, Lampe-Onnerud describes having a coating that is “of an ‘ α -NaFeO₂ type.’” Lampe-Onnerud also states it is an LiCoO₂-based coating, which is well understood to be a layered α -NaFeO₂-type structure. Ex_1012, p.940. As I described above in Paragraphs 115-117, the dissolved coating percolates into the grain boundaries, which then coats and creates a gradient in the primary particles at the grain boundaries. Ex_1014.

136. The final result of the coating layer after sintering is a second composition in the grain boundary which is a combination structure: a layered α -NaFeO₂-type structure in some regions resembling the primary particle crystal phase, as described above, and also a cubic structure in other regions, where the defect areas even after coating cannot adopt the perfectly regular layered structure due to space constraints and inexact matching, which make the ideal structure unattainable. This is confirmed by Dr. Noh’s replication of Example 1, where he

analyzed the structure of an area within the grain boundary and detected a cubic structure.

- c) **“wherein a concentration of cobalt in the grain boundary is greater than a concentration of cobalt in the crystallites.”**

137. As I described above with reference to paragraphs 108-109, the steps disclosed in Example 1 of Lampe-Onnerud are from the same process discussed in the '317 patent, and so the resulting material will have an increased cobalt concentration in the grain boundary just as it is stated in claim 1 of the '317 patent. I also described in paragraphs 114-122 why the process in Example 1 results in material having cobalt enrichment in the grain boundaries. Dr. Noh's declaration confirms that Example 1 of Lampe-Onnerud yields a “second composition” in the grain boundaries where there is a higher concentration of cobalt than in the bulk of primary particles. A set of 20 points were analyzed across an EDS line scan spanning across a grain boundary, as shown below.



Ex_1003, ¶¶17-18, 20-21, Figures C(2) and D(1).

138. From these images, I can see that the region where the grain boundary is crossed (203) has higher cobalt concentration than the bulk of the adjacent primary particles, or crystallites (201, 202). The graphs indicate that in the region where the grain boundaries are located, there is comparatively more cobalt than in the interiors of the adjacent particles.

139. I note that the graphs are quite similar to Fig. 7 in the '317 patent, which, again, is necessarily the case because the process disclosed is the same as in Example 1 of Lampe-Onnerud, including the heating steps, which are carried out at almost the same temperatures.

140. In my opinion, the graphs are also consistent with the discussion in Lampe-Onnerud about why conventional materials exhibited poor stability. As I described above, Lampe-Onnerud explains that by wetting and then sintering, less-stable nickel is replaced with more-stable cobalt where it percolated into the secondary particle (at the grain boundaries). That makes those areas less likely to collapse (which damages the battery) when the lithium moves out of the structure during battery use. Ex_1007, 6:53-67. In my opinion, just from the disclosures in Lampe-Onnerud, it is inherent that the coating percolates into the grain boundaries and with sintering, the cobalt substitutes for nickel, causing increased concentrations of cobalt in the region.

141. I also refer to other references that discuss wetting polycrystalline materials according to percolation models. Ex_1014. These references confirm that, prior to the 2011 timeframe, it was already understood that percolating solutions containing desirable ions is a technique for enriching grain boundaries with these ionic compounds (e.g., LiMO_2 species, M being a desirable metallic atom or mixture of atoms). Similarly, I reviewed the data produced by Dr. Noh in replicating Examples 1 and 7 of U.S. Patent No. 7,381,496 (“Onnerud”), which appears to closely related to Lampe-Onnerud. Both examples provide the same process as discussed in the ’317 patent and Lampe-Onnerud, with similar temperatures and heating times. In replicating these two examples, the data shows that the resulting secondary particle includes a higher concentration of Co in the grain boundary regions relative to inner core of the crystallites. Ex_1003, 45-53, Figures Q(2) and (R).

2. Claim 2

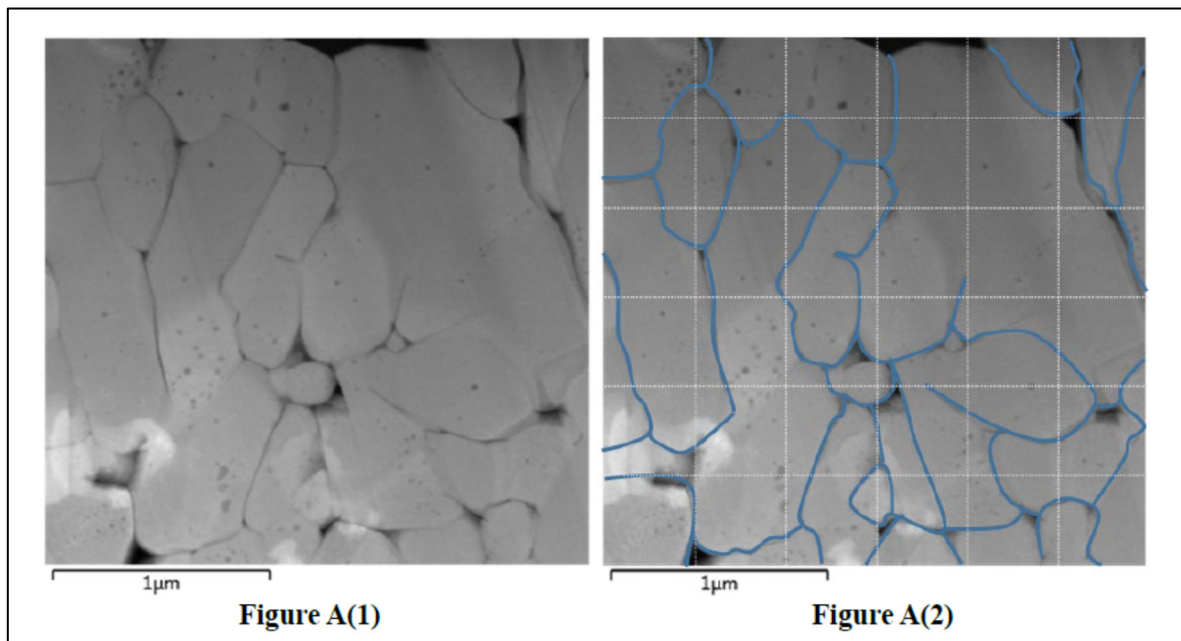
142. I understand that claim 2 is dependent from claim 1. Claim 2 additionally states that the grain boundary is substantially rectilinear in cross-section. In my opinion this is also disclosed by Lampe-Onnerud.

143. As a first matter, in my opinion, the cross-sectional shape of a grain boundary is not something that is novel or inventive. From my review of the ’317 Patent disclosure, I do not see any discussion at all about using any particular

process that would cause a grain boundary's cross-sectional shape. I also see no discussion about any consequence there might be to what geometric shape the grain boundary's cross section has, or that it has any impact on the particle's capability or performance as part of a cathode active material.

144. The '317 patent discloses that "[e]ach crystallite may have any suitable shape," "[b]ecause of its crystalline nature, the crystallite may be faceted, and a shape of the crystallite may approximate a geometric shape" and that "[t]he crystallite may have a rectilinear shape, and when viewed in cross-section, a portion of or an entirety of the crystallite may be rectilinear." Ex_1001., 6:1-13. The patent also discloses that "[t]he shape of the grain boundary is defined by the shape of the crystallite adjacent the grain boundary," "[t]he shape of the grain boundary may approximate a geometric shape," and "[t]he grain boundary may have a rectilinear shape." *Id.*, 6:28-31. Essentially, the '317 patent concludes that crystallites naturally might form with a rectilinear cross-section and so grain boundaries adjacent to them would necessarily have a rectilinear cross-section as well. Lampe-Onnerud also discloses forming crystallites, which would therefore have a "crystalline nature" and facets inherent to crystals as understood in the art. Therefore at least some of the grain boundaries that form at their interfaces will necessarily have rectilinear cross-sections, i.e. the grain boundaries will have linear portions when viewed as a two-dimensional cut through the secondary particle.

145. A person of ordinary skill would have understood that the lithium nickel oxide-based polycrystalline material in Lampe-Onnerud will have at least some grain boundaries with substantially rectilinear cross-sections. This is because at least some intersections of primary particles, which have three-dimensional geometric shapes, will be substantially rectilinear. There will be a large number of primary particles formed by performing the technique in the examples of Lampe-Onnerud, and so if their shapes are random, at least some of the grain boundaries formed therebetween will have a substantially rectilinear shape when view as a cross-section. This is confirmed by Dr. Noh's replication of Example 1 of Lampe-Onnerud, which shows that several of the traced blue lines are substantially rectilinear.



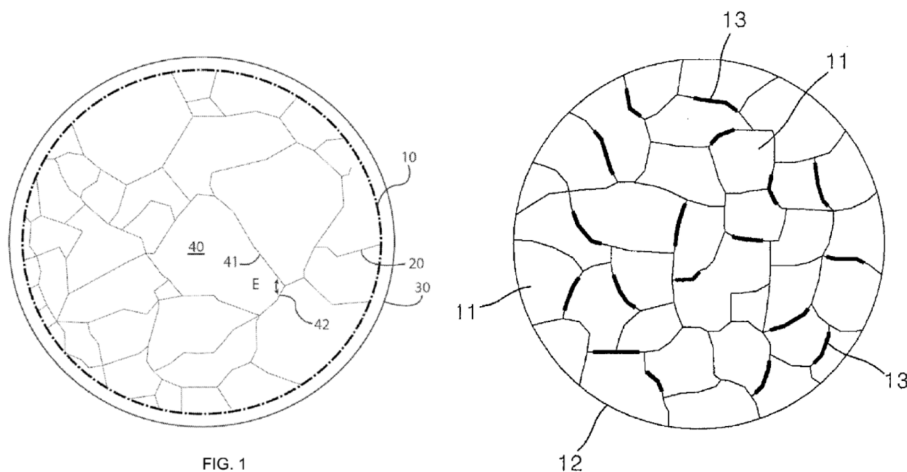
Ex_1003, FIGS A(1), A(2).

3. Claim 3

146. Claim 3 depends from claim 1. This claim additionally states “wherein a direction of a surface of the grain boundary is different than a direction of a tangent of a nearest outer surface of the particle.” Ex_1001, 17:39-41.

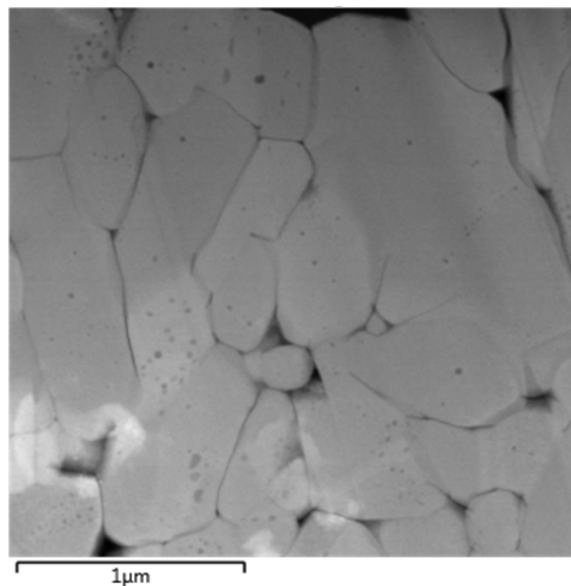
147. In my opinion, this also is not novel or inventive. A person of ordinary skill in the art would have understood that a lithium nickel oxide-based polycrystalline material, such as that disclosed by Lampe-Onnerud, yields many grain boundaries inside the secondary particle and that they form naturally and irregularly and run in various different directions. Many of them will be in some different direction than a tangent of the secondary particle’s outer surface.

148. The only figure relied upon in the ’317 patent for supporting this claim is Figure 1. This illustrates a cross-section of a conventional secondary particle of a polycrystalline material, as shown in the prior art, such as in the Park reference.



Ex_1001, FIG. 1; Ex_1008, FIG. 1. In both figures, the grain boundaries form in various random directions. In the same manner, because Lampe-Onnerud discloses a polycrystalline material, just as in FIG. 1 of the '317 patent and the Park reference, at least one of the grain boundaries therein necessarily is in a direction that is different from a tangent at the cross-sectional surface of the secondary particle.

149. Additionally, because the process in Example 1 of Lampe-Onnerud is essentially the same as in the examples of the '317 patent, the resulting product will have the same claimed characteristics. Dr. Noh's declaration confirms this. From his replication of Example 1, the cross-sectional STEM view shows thin lines in various directions for grain boundaries. As can be seen, most of these lines are in different directions, and therefore, many are in a different direction than a tangent of the secondary particle's outer surface.

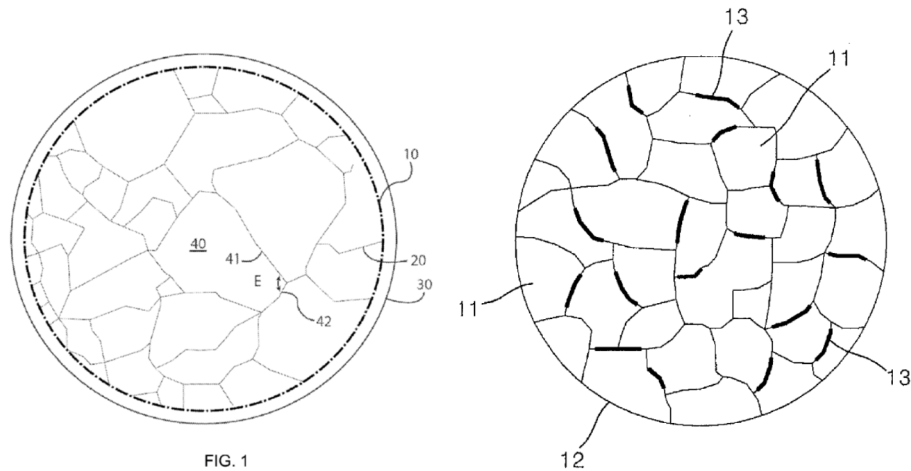


Ex_1003, ¶14, Figure A(1). In other words, assuming that the cross-sectional outer surface is a circle, at least some of the various directions for the grain boundaries shown in Figure A(1) is a different direction than a tangent at the outer surface.

4. Claim 4

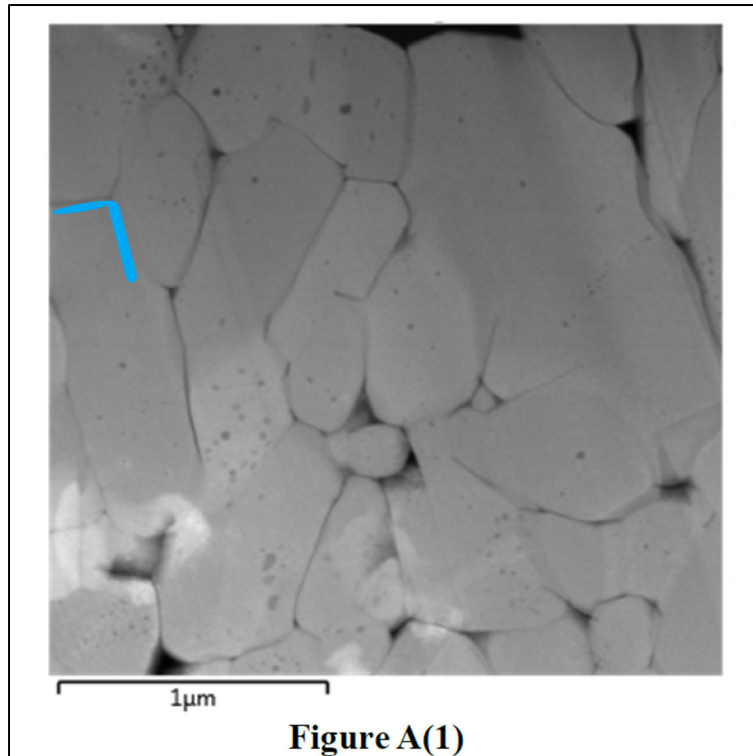
150. Claim 4 also depends from claim 1. The claim additionally recites that two grain boundaries are on the same crystallite and intersect at an angle determined by the crystal structure of the first composition. The claim does not specify any range of values for the angle, or even whether it needs to be an acute or obtuse angle. The claim also does not specify how an angle is “determined by the crystal structure,” but a person of ordinary skill in the art would understand that a crystallite will have a geometrical cross-sectional shape and that each edge will interface with other crystallites.

151. The '317 patent refers to “angle E” in FIG. 1 as example of how two grain boundaries of a cross-sectional view will intersect at an angle. In the same manner, the Park prior art reference discloses that a cross-sectional image of a conventional secondary particle has crystallites with edges that form geometrical shapes, with adjacent edges intersecting an angle. Ex_1001, FIG. 1, Ex_1008, FIG. 1.



152. In the same manner, a cross-sectional view of a secondary particle formed by the process disclosed in Lampe-Onnerud includes crystallites of geometric shapes, where adjacent edges of a crystallite intersect at an angle determined by the crystallite's structure.

153. Additionally, because the process in Example 1 of Lampe-Onnerud is essentially the same as in the examples of the '317 patent, the resulting product will have the same claimed characteristics. Dr. Noh's declaration confirms this. From his replication of Example 1, in FIG. 1(A), where two grain boundaries are highlighted that are on the same crystallite, they intersect at an angle according to the shape of the crystallite.



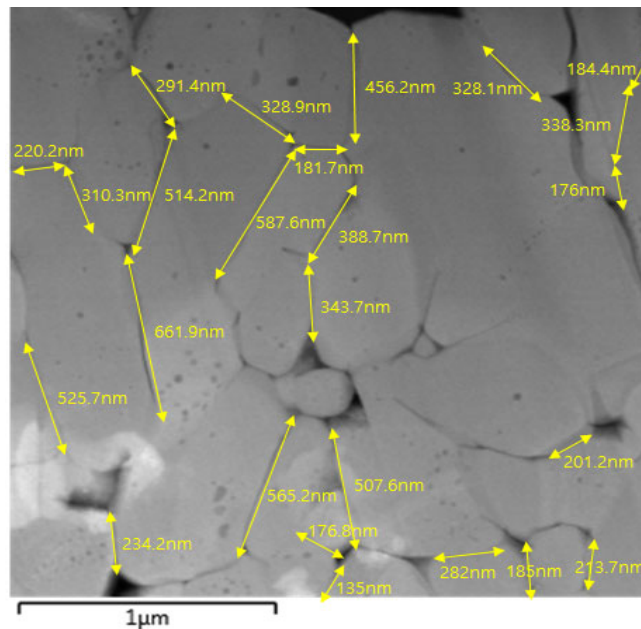
Ex_1003, ¶14, Figure A(1) (annotated).

154. The above image (Figure A(1)) reflects a very expected and regular cross section image of a secondary particle (a partial view of the secondary particle), demonstrating abutting primary particles, fused together, forming grain boundaries, where grain boundaries at adjacent edges of the same crystallite intersect at an angle based on the structure/shape of that crystallite.

5. Claim 5

155. Claim 5 depends from claim 1. This claim additionally recites wide ranges for a grain boundary length (“about 50 to about 1000 nanometers”) and thickness (“about 1 to about 200 nanometers”).

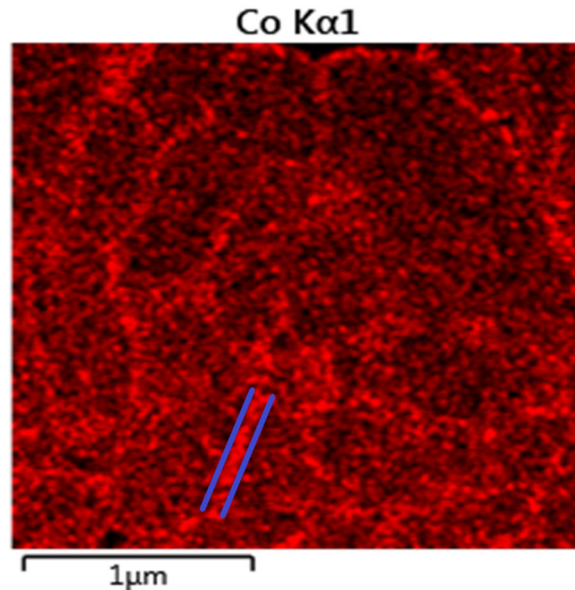
156. Because the process used in Example 1 of Lampe-Onnerud is the same as in the '317 patent (with very similar temperatures and heating times), from my expertise in this field I know that the resulting product will have grain boundaries with the same claimed characteristics. Dr. Noh's declaration confirms this. From his replication of Example 1, in Figure 1(A), with a the scale of 1 μm , I can see that there are several grain boundaries that are between 250 nm and 1000 nm in length. Several examples are provided in Figure C(3) in the declaration.



Ex_1003, ¶19, Figure C(3) (annotated). In this image, all of the grain boundaries are between about 50 to about 1000 nanometers.

157. Dr. Noh's declaration also confirms that there are grain boundaries having a thickness within the wide range that is claimed, particularly between 1 nm

to 200 nm. In the image, an example thickness is illustrated with blue lines, and appear to be approximately 100 nm.



Ex_1003, ¶15, Figure B(1) (annotated).

158. Again, Dr. Noh’s experimentation yielded results so similar to the ’317 patent because the process disclosed in the ’317 patent is the same as what Lampe-Onnerud discloses, and any differences in temperatures or heating times is very minor and not material.

6. Claim 6

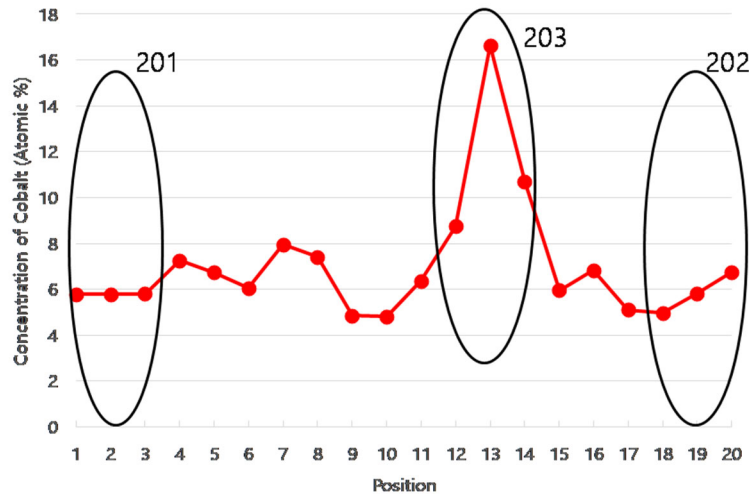
159. Lampe-Onnerud discloses claim 6, which depends from claim 1. This claim additionally states that the “second composition” (in a grain boundary) has very wide ranges of possible amounts of lithium, nickel, cobalt, and oxygen.

160. In my opinion, Lampe-Onnerud discloses the ranges of amounts found in claim 6. First, it explains that the core and coating can have the empirical

formula $\text{Li}_x\text{A}_{x2}\text{Ni}_{1-y1-z1}\text{Co}_{y1}\text{Q}_z\text{O}_a$ that includes lithium (Li_{x1} , where “x1” is 0.1 to 1.3), nickel ($\text{Ni}_{1-y1-z1}$ where “y1” and “z1” are between 0 and 0.2), cobalt (where “y1” is between 0 and 0.2), and oxygen (O_a , where “a” is greater than 1.5 and less than 2.1), arranged such that “[t]he coating has a greater ratio of cobalt to nickel than the core.” Ex_1007, 4:45-60. This results in “a gradient of diminishing nickel concentration from the core to surface of each particle.” *Id.*, 6:45-47. From this, in my opinion, a person of ordinary skill would have understood that the coating impacts the concentrations of nickel and cobalt. I also note that the coating will not appreciably change the lithium and oxygen. With regard to oxygen, Lampe-Onnerud discloses other empirical formulas where the oxygen amount is 2, and in each of the examples, the amount is 2.

161. Once again, Dr. Noh’s experiment confirms that, because the process used for performing in Example 1 is the same as that in the ’317 patent, the resulting material has same characteristics as what is claimed. From Dr. Noh’s experiment of Example 1, the concentration of cobalt in the grain boundary can be approximately 1.5x - 2x of the cobalt concentration in the primary particles.

Ex_1003, Figure D(1)



162. To better illustrate this, the chart below shows that the “second composition” in Lampe-Onnerud is within the claimed ranges:

	Claim 6 ranges	Lampe-Onnerud Grain Boundary
Lithium	0.1 - 1.3	Li_{x1} , where “x1” is 0.1 to 1.3 (Example 1 is 1)
Nickel	0.1 - 1	Core is 0.6-1.0 ($Ni_{1-y1-z1}$ where “y1” and “z1” are between 0 - 0.2) So Grain Boundary is an amount less than 0.6 - 1 (up to about 2x less), which is within the range
Cobalt	0.02 - 0.99	Core is 0 - 0.2 (Co_{y1} , where “y1” is between 0 - 0.2) (Example 1 is 0.2) So Grain Boundary is an amount that is greater (up to about 2x greater), which is within the range
Oxygen	1.7 - 2.3	O_a , where “a” is greater than 1.5 and less than 2.1 (Example 1 is 2)

7. Claim 7

163. Claim 7 depends from claim 1. It further recites that the first and second composition have an additional metal, in a very wide range from 0.01 to about 0.9 moles.

164. I note that Lampe-Onnerud's empirical formula for the core and for the coating can include any of several additional metals recited in claim 7, including Mg, V, Ti, B, Cr, Fe, and Mn. The reference discloses that the amount of a selected additional metal can range from 0.0 to 0.5 or 0.0 to 0.2. Ex_1007, Abstract. For instance, in Example 7, the core is $\text{LiMg}_{0.01}\text{N}_{0.87}\text{Co}_{0.08}\text{Mn}_{0.05}\text{O}_2$, so both Mg (at 0.01) and Mn (at 0.05) are within the claimed ranges. From this, a person of ordinary skill would have understood that by including this metal in the precursor and in the coating, the additional metal will be present in primary particles and also in grain boundaries among primary particles, in ranges according to the empirical formula, which are within the claimed ranges of 0.01 to about 0.9.

8. Claim 8

165. Claim 8 depends from claims 1 or 7 and further requires that the "first composition" contains cobalt in a range of 0 to about 0.5 mole.

166. I note that Lampe-Onnerud's empirical formula for the core can include Co in an amount that can range from 0.0 to 0.2. Ex_1007, 4:45-60. Also, I see that Examples 1 and 2 include 0.2 mole of cobalt, and Examples 3, 4, and 12

have 0.1 mole of cobalt, and Examples 6, 7, and 11 have 0.08 moles of cobalt, all in the core, which includes primary particles.

9. Claim 9

167. Claim 9 depends from claim 8 and additionally requires that the cobalt concentration ranges from 0.0 to about 0.3. As I explained above, the range disclosed in Lampe-Onnerud, 0 to 0.2, is within the claimed range of 0.0 to about 0.3.

10. Claim 10

168. Claim 10 depends from claim 9 and also states that the first composition includes nickel in a range of 0.8 to 1. I see that all of the examples in Lampe-Onnerud are within the claimed range. As examples, amounts of nickel within this range and in the core (including primary particles) are disclosed in Examples 1 and 2 ($\text{Ni}_{0.8}$), Examples 3, 6, 7, 8, 9, 10, 11, 12, 13 ($\text{Ni}_{0.87}$), and Example 15 ($\text{Ni}_{0.90}$). Ex_1007, 9:60 - 16:1.

11. Claim 11

169. Claim 11 depends from claim 1 and further states that the first and second compositions include Mn in an amount of about 0.01 to about 0.6 mole.

170. Lampe-Onnerud's empirical formula for the core and for the coating can include Mn in an amount that can range from 0.0 to 0.2. Ex_1007, 4:45-60 ("Q' is at least one element selected from the group consisting of ... manganese" and is in an amount z1 which is "greater than about 0.0 and equal to less than or

about 0.2.”) Examples 6 and 7 describe synthesis of a base material having 0.05 of manganese in primary particles and the grain boundaries. Ex_1007, 13:1-35.

171. In my opinion, a person of ordinary skill would have understood from Lampe-Onnerud that there will be a relatively uniform distribution of manganese in the primary particles and grain boundaries. Therefore, the wide ranges of manganese described in Lampe-Onnerud apply both to the “first composition” and the “second composition.”

12. Claim 12

172. Claim 12 depends from claims 1 or 7 and further recites that the first composition includes nickel in a range of 0.8 to 1. In my opinion, this limitation is met for at least the same reasons discussed above for dependent claim 10.

13. Claim 13

173. Claim 13 is dependent from claim 12 and recites that the first composition comprises nickel at a concentration of 0.92 moles.

174. As I discussed above, Lampe-Onnerud’s empirical formula provides a range of 0.6 - 1 moles of nickel in the core, and the examples are for 0.8, 0.87, and 0.90 moles of nickel. In my opinion, a person of ordinary skill would have understood that these ranges reflect average compositions in primary particles and that there will naturally be some variation. It was well-understood that if one were to perform the example in which a base material is synthesized with 0.90 mole of

Ni (Example 15), at least some primary particles will be characterized as having slightly more or less amounts of nickel, and so if each were characterized, at least one would have an amount of 0.92.

14. Claim 14

175. Claim 14 depends from claims 1 or 7 and recites wide ranges of lithium, nickel, and cobalt in the “first composition.”

176. Lampe-Onnerud discloses that the core can have the empirical formula $\text{Li}_x\text{A}_{x2}\text{Ni}_{1-y1-z1}\text{Co}_{y1}\text{Q}_z\text{O}_a$. This formula includes lithium (Li_{x1} , where “x1” is 0.1 to 1.3), nickel ($\text{Ni}_{1-y1-z1}$ where “y1” and “z1” are between 0 and 0.2), cobalt (where “y1” is between 0 and 0.2). In a chart comparing these amounts with the ranges in claim 14, this is represented as follows:

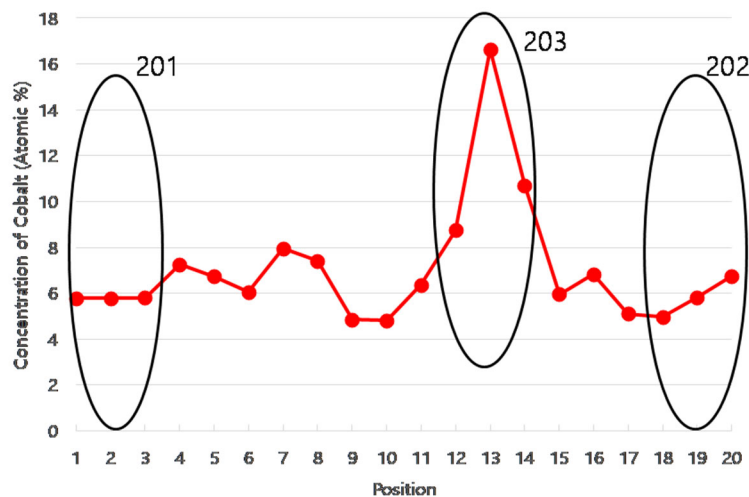
	Claim 14 ranges	Lampe-Onnerud Core
Lithium	0.1 - 1.3	Li_{x1} , where “x1” is 0.1 to 1.3 (Example 1 is 1)
Nickel	0.1 - 1	Core is 0.6-1.0 ($\text{Ni}_{1-y1-z1}$ where “y1” and “z1” are between 0 - 0.2)
Cobalt	0 - 0.5	Core is 0 - 0.2 (Co_{y1} , where “y1” is between 0 - 0.2) (Example 1 is 0.2)

Ex_1007, 4:45-60. These values are within the claimed range.

15. Claim 15

177. Claim 15 is dependent from claims 1 or 7 and further recites very wide cobalt concentrations by atomic percentage.

178. As I explained above, because the process in Example 1 of Lampe-Onnerud is substantially the same as the process described the '317 patent, the resulting material necessarily will have the same claimed characteristics. This is confirmed by the graph prepared in Dr. Noh's declaration. It illustrates the change by atomic percentage at various locations along a line that spans between two adjacent primary particles with a grain boundary there-between.



Ex_1003, ¶20, Figure D(1). This graph illustrates cobalt concentrations in a primary particle (201 and 202) of approximately 6-8% (within the claimed range of 0.25 to 17%) and a concentration in the grain boundary (203) of approximately 10-18% (within the claimed range of 0.5 to 32%).

16. Claim 16

179. Claim 16 depends from claim 1 and further recites a layer on the surface of the particle. Lampe-Onnerud discloses applying an LiCoO_2 -based coating, which is an oxide, as recited in the claim. The coating also can include Al,

B, or Zr, as claimed. Ex_1007, 1: 57-67 (“... the coating on the core has ... at least one element selected from the group consisting of ... boron, aluminum ... and zirconium.”) Ex_1007, 11:38-40.

17. Claim 17

180. Claim 17 recites a method of manufacturing the particle of claim 1.

a) “... combining a lithium compound, a cobalt compound, and a nickel compound to form a mixture;”

181. Example 1 of Lampe-Onnerud discloses steps for mixing quantities of a lithium compound, cobalt compound, and nickel compound. In particular, Example 1 discloses mixing LiNO_3 (lithium compound), $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (cobalt compound), and $\text{LiNi}_{0.6}\text{Co}_{0.2}\text{O}_2$ (nickel compound) in an aqueous solution. Ex_1007, 9:64-66. (Again, as I described above, there is a typographical error. A person of ordinary skill would understand that the molar values of nickel and cobalt will add to 1, and so this should be $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$.)

b) “heating the mixture at about 30 to about 200° C. to form a dried mixture;”

182. Lampe-Onnerud discloses that after the compounds are mixed as described above, they are then heated on a hot plate while stirring to evaporate the excess water. In my opinion, a person of ordinary skill would have understood that the “hot plate” for drying the mixture would be in a temperature range of about 30° to about 200° C. Ex_1007, 9:66-67.

- c) **“heat treating the dried mixture at about 200 to about 500 °C. for about 0.1 to about 5 hours;”**

183. Continuing with Example 1, Lampe-Onnerud discloses that after evaporation, the dried mixture is sintered in a heat ramp at 5 °C/minute to 450 °C and held for 1 hour. Ex_1007, 10:2-3. This is within the claimed temperature range and timing for the second heating step.

- d) **“heat treating at 600 to about 900 °C. for about 0.1 to about 10 hours to manufacture the particle”**

184. Example 1 also discloses another heating step, this time ramping by 2 °C/minute to 750 °C and holding for 1 hour, which is also within the claimed temperature range and timing. Ex_1007, 10:3-4, 13: 30-31.

- e) **“wherein the particle comprises ...”**

185. Claim 17 then recites the product of the process, which repeats the limitations for the particle in claim 1. In Dr. Noh’s replication of Example 1, the base material was synthesized based on the mixing processes disclosed in the other examples in Lampe-Onnerud (to mix lithium, cobalt, and nickel compounds), and then the rest of steps have the same temperatures and timing within the claimed range, as I explained with reference to claim 1.

C. Park

186. Park discloses that enriching the grain boundaries of a lithium nickel oxide-based cathode material can improve the material’s stability. In my opinion, it would have been obvious to a person of ordinary skill in the art in the 2011

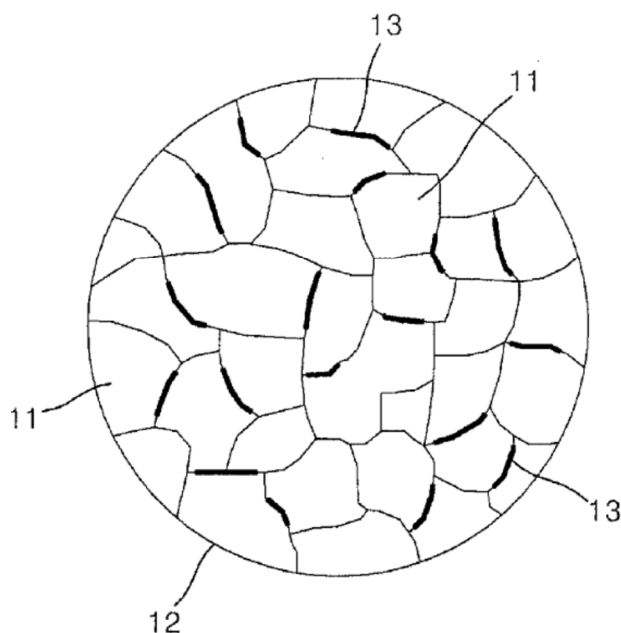
timeframe to combine the teachings of Park with Lampe-Onnerud's disclosures about creating a cobalt concentration gradient to stabilize cathode materials.

187. Park was published on June 16, 2011 as US 2011/0143209, from an application filed December 1, 2010. The reference also claims priority to a Provisional application filed December 11, 2009. I reviewed Park's provisional application and determined that it provides the same disclosure as in the published application, with the exception of patent claims.

188. Just like in Lampe-Onnerud, Park noted that using lithium cobalt oxide as a cathode material is expensive and also remarked that lithium nickel oxide was not an adequate alternative because it created instability and other problems. Ex_1008, ¶¶7-8. Park discloses enriching the grain boundaries in the material with a second composition, a lithium-based ionic material, to improve its stability and capacity.

189. As I mentioned above, FIG. 1 of Park illustrates a secondary particle (element 12) having a plurality of primary particles (element 11) of various shapes and orientations, just like in FIG. 1 of the '317 patent.

FIG. 1



Ex_1008, FIG. 1. Park notes that “‘primary particles’ refers to particles that agglomerate together to form a secondary particle, and may take various shapes such as rods or squares.” *Id.*, ¶23. The lines at the edges of adjacent primary particles are the grain boundaries. Along these grain boundaries “at the surface of the secondary particle,” there is an amorphous material such as a lithium salt (element 13, in darker lines) for stabilizing the material. *Id.*, ¶29. Park specifically notes that “[t]he amorphous material may be a lithium salt, but is not limited to.” *Id.*, ¶24.

190. Park describes coating grain boundaries by dry mixing/stirring a lithium composite oxide with a lithium salt and then heat treating. As Park notes, the resulting material “includes an agglomeration of at least two primary particles”

with “amorphous material” among the grain boundaries. *Id.*, ¶12. The Park reference includes examples of preparing the cathode material at various temperatures and then verifying that it formed secondary particles using TEM analysis. *Id.*, ¶72; Figs. 3-5. Park also confirmed that a cathode material having enriched grain boundaries emitted less heat and had improved thermal stability. *Id.*, ¶78.

191. In my opinion, a person of ordinary skill in the art would have found it obvious to modify Park’s process of coating the grain boundaries with lithium salts for improved battery performance to include the addition of cobalt oxide salts. The benefit of adding lithium at the edges of the primary particle as described in Park serves to effectively create a buffer-like zone for protection of the bulk lithium nickel oxide layered crystal structure in the primary particles, while still providing Li ions for the charging/discharging process. A POSITA would understand that, while the lithium salt described in Park as the coating in the grain boundaries provides a benefit of protecting and preserving the active mass during cycling, the absence of a layered metal oxide framework (i.e. LiCoO_2) that could provide heightened structural and capacitative stability would still somewhat limit the overall benefit of Park. A POSITA would therefore be motivated to use another coating, as even suggested by Park, to obtain further advantages of enriching the grain boundary. Lampe-Onnerud teaches that coating lithium nickel oxides or

composite materials with lithium cobalt oxide to create a cobalt concentration gradient at the surface of the particles effectively provides the enhanced structural and thermal stability benefits of LiCoO_2 cathodes but without the cost. It would therefore have been obvious for a POSITA to modify the Park approach and add a cobalt salt in addition to the lithium salt as in Lampe-Onnerud to add a protective layer to the surfaces of the primary particles, i.e. at the grain boundaries, in addition to coating the primary particles at the surface of the secondary particle. As a POSITA would expect, the buffer layer of Park between the active mass and electrolyte, which protectively extends the diameters of the primary particles, would be improved by the Lampe-Onnerud lithium cobalt oxide gradients which additionally provide a layered lattice structure which also enhances capacity while shielding the active mass as described above. The approximate ratio of Lithium to Metal to Oxygen atoms would be preserved for the coating (relative to the core values) and therefore the capacity preservation would be achieved without sacrificing any structural stability (i.e. the nickel atoms would predominantly still not be located at the surface/edge of the primary particles, where their presence contributes to cracking). The addition of cobalt salt to the dry mixture of lithium salt in Park before mixing and sintering would be obvious for coating the primary particles before sintering when forming agglomerated secondary particles. It would also have been obvious to a POSITA from Lampe-Onnerud to improve on the Park

process by carrying out the LiCoO_2 coating using a wetting and subsequent evaporation/sintering technique to ensure that the second composition is as evenly distributed throughout the grain boundaries of the primary particles as possible. It is known in the art that liquid/solvent phase transfer of salts is a highly efficient method of distributing ionic materials throughout a solid-phase structure, due to its dynamic nature.

D. Applying Park in view of Lampe-Onnerud to Claims 1-17

1. Claim 1

- a) **“A particle, comprising: a plurality of crystallites comprising a first composition having a layered $\alpha\text{-NaFeO}_2$ -type structure and comprising: lithium, nickel, and oxygen”**

192. Park discloses a lithium nickel oxide-based material according to the empirical formula $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$. The ranges for x, y, z, and a result in a crystallite composition which has nearly the same ranges of lithium, nickel, cobalt, and oxygen as in the '317 patent and in Lampe Onnerud. For example, Park discloses a base material having a composition of $\text{LiNi}_{0.6}\text{CO}_{0.2}\text{Mn}_{0.2}\text{O}_2$. Ex_1008, *Id.*, ¶28. Park also discloses that the cathode material has a plurality of agglomerated primary particles (or crystallites). *Id.*, ¶21

193. As I mentioned above, it was known to those in the art that lithium nickel oxide-based particles have a layered $\alpha\text{-NaFeO}_2$ -type structure. This is

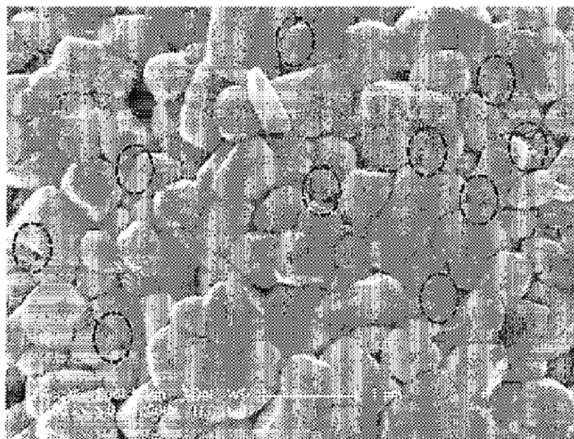
shown, for example, in Fergus and Kalyani. Ex_1012, p.940; Ex_1013, p.691, Figure 1.

194. As I described above, Lampe-Onnerud also discloses generating a polycrystalline lithium nickel oxide-based material, which has a layered α -NaFeO₂-type structure. Ex_1007, 3:46-49, 6:30-52. When combining Park with Lampe-Onnerud by adding the cobalt salt along with the lithium salt in the grain boundary, the resulting material is still polycrystalline as described by Park and will have the same structure in the primary particles.

b) “a grain boundary between adjacent crystallites of the plurality of crystallites and comprising a second composition having the layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof,”

195. Park discloses that the cathode material has grain boundaries, which are located at the edges of adjacent primary particles. This is illustrated explicitly in FIG. 1. Ex_1008, FIG. 1, ¶29. This is also disclosed in FIG. 3 of Park, which illustrates a scanning electron microscope (SEM) image of a cathode material prepared according to Preparation Example 1. The image has “a Li₂SO₄ amorphous layer formed along a grain boundary of adjacent particles.” Ex_1008, FIG. 3, ¶64.

FIG. 3



Ex_1008, FIG. 3. The ovals show locations of grain boundaries having the amorphous layer. *Id.*, ¶74. The amorphous layer, in this case having Li_2SO_4 , is part of the “second composition” in the grain boundary of the secondary particle as compared with the “first composition” in the primary particles.

196. The grain boundaries formed by the agglomeration of the primary lithium composite oxide particles in Park have a layered $\alpha\text{-NaFeO}_2$ -type structure or other cubic structure. As I described above, it was well known in the art (for example, in Zheng) that lithium nickel oxide-based particles have a layered $\alpha\text{-NaFeO}_2$ -type and transition to a more disordered structure which includes regions of cubic and layered crystal structures at their grain boundaries. Ex_1011, Abstract.

197. As I described above, Lampe-Onnerud also describes a process that produces a polycrystalline material with grain boundaries at the interface of

adjacent crystallites having a second composition and a layered α -NaFeO₂-type structure or other cubic structure. Ex_1007, 3:46-49, 6:30-52. By combining Park with Lampe-Onnerud's disclosure of using a cobalt coating, the resulting grain boundaries will have a layered α -NaFeO₂-type structure or cubic structure as described in the previous section where I address Lampe-Onnerud.

c) “wherein a concentration of cobalt in the grain boundary is greater than a concentration of cobalt in the crystallites.”

198. Park discloses adding a second material to or coating grain boundaries to improve their stability and other properties desirable for cathode material. While Park discloses grain boundaries coated with lithium salt, it does not disclose using cobalt salts explicitly together with the lithium salt to enrich the grain boundaries. Park notes however that “[t]he amorphous material may be a lithium salt, but is not limited thereto.” Ex_1008, ¶24.

199. Lampe-Onnerud discloses wetting a base material having lithium nickel oxide with a dissolved solution of lithium nitrate (a lithium salt) and cobalt salt. *See* Ex_1007, Examples. The stated purpose for Lampe-Onnerud's coating is for stabilizing the material to improve its properties as cathode material. *See id.*, 6:53-7:5. Lampe-Onnerud explains that this process results in substituting out less-stable nickel at the edges, which Park had recognized as well to be beneficial. *See id.*

200. In my opinion, it would have been obvious to a POSITA to modify Park's technique by additionally including a cobalt salt as disclosed in Lampe-Onnerud. Further to my discussion above at paragraph 191, the modification would be to enrich the grain boundary with cobalt salt in addition to the lithium salt which creates the coating material of Park. From reviewing Park, a person of ordinary skill in the art would have understood that it is beneficial to enrich grain boundaries to stabilize the material. Combining this with Lampe-Onnerud's disclosure that it is beneficial to have a gradient comprising cobalt to stabilize the secondary particle, it would have been obvious to enrich the grain boundaries with cobalt, as a gradient with a higher concentration of cobalt in the grain boundary than in the crystallite bulk. This would be accomplished by adding cobalt salt along with the lithium salt to dry mix with the base material before heating, or by performing the wetting with the dissolved cobalt salt and lithium salt as disclosed in Lampe-Onnerud.

201. A person of ordinary skill would have been motivated to make such a modification. First, Park specifically noted that cobalt is stabilizing, that LiCoO_2 is widely used for cathode material but is expensive, and that nickel as an alternative is unsatisfactory in terms of stability. Ex_1008, ¶¶7-8. Park also noted that it is beneficial to enrich grain boundaries "at the surface of the secondary particle 12" and that doing so "imparts good thermal stability." Ex_1008, ¶¶14, 29.

Lampe-Onnerud similarly discloses that LiCoO_2 and conventional LiNiO_2 -based materials are not sufficient and that it is advantageous to have a greater ratio of cobalt to nickel near the surface. Ex_1007, 4:55-57. Particularly, Lampe-Onnerud explains that including cobalt in the coating is advantageous because:

Further, the capacity and cyclability is higher due to higher stabilization of the structure than that found in the LiCoO_2 system. This means that more lithium can be removed from the structure without having a structural collapse.

Id., 6:60-63. Lampe-Onnerud concludes that with its cobalt coating, “[c]haracteristics of the cathode materials of the invention relate to capacity, cyclability, and safety.” *Id.*, 7:6-8. “Safety” means “structural stability” even at “elevated temperatures.” *Id.*, 7:19-22.

202. In my opinion, Park and Lampe-Onnerud are directed to solving the same problem, and they do so in substantially the same manner. A person of ordinary skill who was reviewing the Park reference to improve lithium nickel oxide-based cathode material by coating grain boundaries would have been motivated to consider other compounds to include along with the lithium salt. In fact, Park explicitly invites the reader to consider other compounds to include. Lampe-Onnerud’s additional inclusion of cobalt salt with the lithium salt is complementary of what Park already discloses.

203. Park suggests that the lithium salt coating will serve as a buffer zone, protecting the nickel-containing surface from contact with the electrolyte solution

while still allowing good transport of Li ions. In the Park disclosure, the structural cracking issue inherent when LiNiO_2 is predominantly found at the surface of the primary crystal is improved by adding additional particles between the nickel layers and the solvent. This coating on the active mass serves a similar purpose as Lampe-Onnerud's lithium cobalt salt coating which will enrich the grain boundaries with cobalt and consequently reduce the nickel content at the edges/surfaces of the primary particles. Accordingly, it is expected that both coatings will help stabilize the secondary particle but do so in a different way, and therefore they are not duplicative.

204. Accordingly, Park when supplemented with the teaching of Lampe-Onnerud results in a particle in which the concentration of cobalt in the grain boundaries is greater than its concentration in the crystallites.

2. Claim 2

205. Park discloses claim 2, which I understand, depends from claim 1. It further adds “wherein the grain boundary is substantially rectilinear in cross-section.” Park discloses in Figure 1 what the cross-sectional shapes look like, and the grain boundaries are generally rectilinear. Also, Park notes that the shapes of the primary particles can be squares, and so the grain boundaries defined thereby will be rectilinear. *Id.*, ¶23. When viewed as a cross-section, the grain

boundaries will therefore appear rectilinear, i.e. they will be composed of at least some straight lines.

3. Claim 3

206. Park discloses claim 3, which depends from claim 1 and further adds “wherein a direction of a surface of the grain boundary is different than a direction of a tangent of a nearest outer surface of the particle.” Ex_1001, 17:39-41. FIG. 1 of Park is virtually identical to FIG. 1 of the '317 patent, which is relied upon as support for claim 3. Both show a horizontal cross-sectional view of a secondary particle with grain boundaries in various random directions, nearly all of which are different than a tangent at the outer surface. Most of these lines are in different directions than a tangent of the secondary particle's outer surface.

4. Claim 4

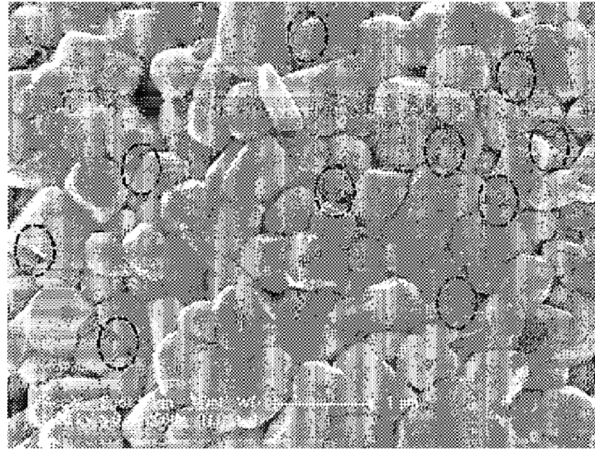
207. Park also discloses claim 4, which depends from claim 1. Referring again to FIG. 1 of Park and FIG. 1 of the '317 patent, there are many instances where two grain boundaries are on the same crystallite and intersect at an angle according to the shape of the crystallite.

5. Claim 5

208. Claim 5 depends from claim 1 and further adds wide ranges for a grain boundary length (“about 50 to about 1000 nanometers”) and thickness (“about 1 to about 200 nanometers”). Park discloses a table (TABLE 1) in which, for Preparation Example 3, the average diameter is 350 nm). Ex_1008, ¶75.

Therefore, the grain boundary lengths will be approximately that length, which is within the claimed range. From Park's FIG. 1 and the disclosure about length in Park, a person of ordinary skill in the art would understand that many, and maybe all, grain boundary lengths are greater than 50 nm and less than 1000 nm (1 μ m).

209. FIG. 3 illustrates that the grain boundaries are at the intersections of the primary particles and their thickness is generally somewhat less than 5% of the width of a primary particle, and so they are within the claimed range.



Ex_1008, Figure 3. Also, from Dr. Noh's replication of Example 1 in Lampe-Onnerud, the grain boundary thicknesses are approximately 100nm thick, which is within the range. Ex_1003, ¶15, Figure B(1) (annotated). The combination of Park with Lampe-Onnerud would include a similar cobalt coating, and so the thickness of the grain boundary would be commensurate.

6. Claim 6

210. Park also discloses claim 6, which depends from claim 1 and further adds that the “second composition” (in a grain boundary) has very wide ranges of possible amounts of lithium, nickel, cobalt, and oxygen.

211. Park discloses a primary particle lithium composite oxide with empirical formula of $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$, where $0.5 \leq x \leq 1$, $0 \leq y \leq 0.5$, $0 < z \leq 0.5$, $0.90 < a \leq 1.15$. This closely approximates and is squarely within the ranges stated in the claim. In my opinion, a person of ordinary skill in the art would have known that enriching with additional lithium salt will provide a coating in the grain boundary but will not disturb the ratios of lithium, nickel, cobalt and oxygen in the bulk material. In combination with Lampe-Onnerud, a coating with cobalt salt along with lithium salt will increase the relative concentration of cobalt and decrease the relative concentration of nickel in the region (with the amount of lithium and oxygen remaining the same), as Lampe-Onnerud discloses. Despite the coating added, the overall amounts of cobalt and nickel will still remain within the wide ranges of the claimed quantities, or else it would have been obvious to a POSITA as part of the normal optimization process of optimizing a material with further improved stability.

7. Claim 7

212. Park discloses claim 7, which further adds that the first and second composition have an additional metal, in a very wide range from 0.01 to about 0.9 moles. In Park's empirical formula $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$, "Me" can include titanium (Ti) or manganese (Mn), as also stated in claim 7. Ex_1008, ¶28. The amounts of the selected transitional metal can range can be, for example, 0.3 moles (when $z=0.3$ and $a=1$), which is squarely in the claimed range.

8. Claim 8

213. Park also discloses claim 8, which depends from claims 1 or 7 and further adds that the "first composition" contains cobalt in a range of 0 to about 0.5 mole.

214. Park's empirical formula for the primary particle can include Co in an amount that can range from $0 \leq y \leq 0.5$ mole, which is the same as what is claimed. Ex_1008, ¶28.

9. Claim 9

215. Park also discloses claim 9, which depends from claim 8 and further recites that the cobalt concentration ranges from 0.0 to about 0.3. As I stated above, the range disclosed in the Park, which is 0 to 0.5, includes the claimed range of 0.0 to about 0.3. In particular, Park discloses example lithium composite oxides having the formula $\text{LiNi}_{0.5}\text{Co}_{0.2}\text{Mn}_{0.2}\text{O}_2$, such that cobalt is 0.2 moles, which is within the range. *Id.*, ¶28.

10. Claim 10

216. Park also discloses claim 10, which depends from claim 9 and further adds that the first composition includes nickel in a range of 0.8 to 1. Park's empirical formula for the primary particle can include Ni in an amount that can range from $0.5 \leq x \leq 1$ mole, which closely overlaps the claimed range. Ex_1008, ¶28.

217. Also, all of the examples in Lampe-Onnerud are within the claimed range. For example, amounts of nickel within this range and in the core (including primary particles) are disclosed in Examples 1 and 2 ($\text{Ni}_{0.8}$), Examples 3 and 6-13 ($\text{Ni}_{0.87}$), and Example 15 ($\text{Ni}_{0.90}$). Ex_1007, 9:60-16:1. In my opinion, it would have been obvious to a POSITA to utilize amounts of nickel at the higher end of Park's range, such as the example compositions in Lampe-Onnerud, because it was well-understood (and recognized in Park itself) that additional nickel tends to reduce cost.

11. Claim 11

218. Park discloses claim 11, which depends from claim 1 and further adds that the first and second compositions include Mn in an amount of about 0.01 to about 0.6 mole.

219. Park discloses an empirical formula of $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$ for the core and the coating, where Me can be Mn in an amount that can range from

$(0 \leq z \leq 0.5)(2 - (0.9 \leq a \leq 1))$). Ex_1008, ¶28. For example, if $z = 0.5$ and $a = 1$, this computes to 0.5 mole of Mn, which is within the range. Similarly, in Lampe-Onnerud, Examples 6 and 7 describe synthesis of a base material having 0.05 of manganese in primary particles and the grain boundaries. Ex_1007, 13:1-35.

220. A POSITA would have understood from Park and Lampe-Onnerud that there will be a uniform distribution of manganese in primary particles and grain boundaries, and so the disclosed ranges of manganese in these references generally applies to the “first composition” and the “second composition.” This is because the base material can be doped with additional metals such as Mn as described in the references, and therefore the concentration of Mn in the grain boundary will be similar to that of the bulk. When the grain boundary coating is enriched with additional cobalt, which substitutes for nickel or other metals in the lattice, the relative quantities of the Ni/M will decrease at the edges. However, they will still remain within the ranges described in this claim.

12. Claim 12

221. Park discloses claim 12, which depends from claims 1 or 7 and adds that the first composition includes nickel in a range of 0.8 to 1. I refer to the discussion that I provided above for dependent claim 10.

13. Claim 13

222. In my opinion, it would have obvious to synthesize a particle having nickel at a concentration of 0.92 moles, based on the discussions in Park and Lampe-Onnerud.

223. As I discussed above, Lampe-Onnerud's empirical formula provides a range of 0.6 - 1 moles of nickel in the core, and the reference provides examples with 0.8, 0.87, and 0.90 moles of nickel. In my opinion, a person of ordinary skill in the art would have understood that these ranges reflect average compositions in primary particles and that there will naturally be some variation. In my opinion, if one were to perform an experiment in which a base material is synthesized with 0.90 mole of Ni, such as in Example 15 of the reference, at least some primary particles will be characterized as having slightly more or less amounts of nickel. If each were characterized, at least one would have an amount of 0.92.

14. Claim 14

224. Park discloses claim 14, which depends from claims 1 or 7 and adds wide ranges of lithium, nickel, and cobalt in the "first composition." Park discloses an empirical formula of $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$, where $0.5 \leq x \leq 1$, $0 \leq y \leq 0.5$, $0 < z \leq 0.5$, $0.90 < a \leq 1.15$, which are as follows:

	Claim 14 ranges	Park
Lithium	0.1 - 1.3	Li_{x1} , where "x1" is 0.9 to 1.15 (Example 1 is 1)

Nickel	0.1 - 1	Core is 0.425-1.1 (0.5 to 1)(2- (.9 to 1.15))
Cobalt	0 - 0.5	Core is 0 - 0.55 (0 to 0.5)(2 - (0.9 to 1.15))

Ex_1008, ¶28. This includes $\text{LiNi}_{0.6}\text{Co}_{0.2}\text{Mn}_{0.2}\text{O}_2$, which is within the range for lithium, nickel, and cobalt as stated in the claim. *Id.*

15. Claim 15

225. Lampe-Onnerud discloses claim 15, which is dependent from claims 1 or 7 and further adds very wide cobalt concentrations by atomic percentage, for the reasons that I explained above for claim 1. In my opinion, it would have been obvious to include the cobalt salt coating in Lampe-Onnerud to enrich Park's grain boundaries for the purpose of increasing its cobalt concentration so as to stabilize. The amounts disclosed in Lampe-Onnerud would cause the concentration to increase by the wide range amounts recited in claim 15.

16. Claim 16

226. Park on its own, or in combination with Lampe-Onnerud discloses claim 16, which depends from claim 1 and further adds a layer on the surface of the particle. Park explains that the amorphous lithium salt can be lithium carbonate. Ex_1008, ¶25, 31. Lampe-Onnerud discloses applying an LiCoO_2 -based coating, which is an oxide. The coating also can include Al, B, or Zr. Ex_1007, 2:57-67 (“... the coating on the core has ... at least one element selected from the group consisting of ... boron, aluminum ... and zirconium.”)

227. In my opinion, a person of ordinary skill in the art would have found it obvious to include the coating from Lampe-Onnerud with Park's particle for purposes of further isolating the particle from the electrolyte, as Park discloses. Ex_1008, ¶14 (describing that it is advantageous "to reduce the specific surface area of the positive electrode active material that is exposed to the electrolyte").

17. Claim 17

228. Claim 17 pertains to the particle of claim 1, synthesized by the process disclosed in Lampe-Onnerud. In my opinion, it would have been obvious to a person of ordinary skill in the art to combine Park's disclosure about enriching grain boundaries with Lampe Onnerud's process, in the manner recited in claim 17.

a) "...combining a lithium compound, a cobalt compound, and a nickel compound to form a mixture;"

229. Park discloses a base material that includes lithium, cobalt, and nickel, $\text{Li}_a(\text{Ni}_x\text{Co}_y\text{Me}_z)_{2-a}\text{O}_2$, which is a nickel compound. Park discloses mixing a lithium compound with this nickel compound.

230. As I explained for claim 1, in my opinion, a person of ordinary skill would have found it obvious to also mix a cobalt compound to enrich the grain boundary, because this would improve the stability of the cathode material. This results in forming a mixture of a lithium compound, a cobalt compound, and a nickel compound (which is the lithium composite oxide).

231. Additionally, it was well understood by a person of ordinary skill in the art that a lithium composite oxide as disclosed in Park, such as the lithium composite oxide mentioned in Preparation Example 1, is formed by mixing a lithium compound, cobalt compound, and nickel compound. That is the typical way that it would be prepared.

b) “heating the mixture at about 30 to about 200° C. to form a dried mixture;”

232. Lampe-Onnerud discloses that once base material is formed, it is dissolved in distilled water with a cobalt-based coating and then the mixture is heated and dried. For example, the base material synthesized in Example 6 is then, in Example 7, dissolved into water with lithium nitrate and cobalt nitrate hydrate, and then heated to be dried. In my opinion, a person of ordinary skill would have understood that the “hot plate” for drying the mixture would be in a temperature range of about 30° to about 200°C. Ex_1007, 13: 20-26.

233. In my opinion, it would have been obvious to synthesize the base particle using the method of Lampe-Onnerud, for the reasons that I set forth in claim 1.

c) “heat treating the dried mixture at about 200 to about 500 °C. for about 0.1 to about 5 hours;”

234. Continuing with Example 7, Lampe-Onnerud discloses that after evaporation, the dried mixture is sintered in a heat ramp at 5 °C/minute to 450 °C

and held for 1 hour. Ex_1007, 13: 26-30. This is within the claimed temperature range and timing.

235. In my opinion, it would have been obvious to perform a first heat treatment step using the method of Lampe-Onnerud, for the reasons that I set forth in claim 1.

d) “heat treating at 600 to about 900 °C. for about 0.1 to about 10 hours to manufacture the particle”

236. Park discloses heating at 800 °C or 900 °C, which are both within the claimed range. Example 7 also discloses another heating step, this time ramping by 2 °C/minute to 750 °C and holding for 2 hours, also within the claimed temperature range and timing. Ex_1007, 13: 30-31. In my opinion, it would have been obvious to perform a second heat treatment step using the method of Lampe-Onnerud, for the reasons that I set forth in claim 1.

e) “wherein the particle comprises”

237. Claim 17 then states the composition of the particle yielded by performing the steps of the process, which repeats the language from claim 1. I already addressed this language regarding claim 1 for Park and for Lampe-Onnerud, and that same explanation applies here.

E. Takagi

238. Takagi is about a battery cathode material that has a stabilized crystal structure to improve performance.

239. In my opinion, Takagi and the '317 patent provide similar explanations about why conventional lithium nickel oxide cathode materials are deficient. Takagi notes that cathodes have “cracking at the bonding interface caused by repeated charge/discharge cycles.” Ex_1010, ¶6. Takagi also acknowledges that lithium cobalt oxide materials are expensive. *Id.*, ¶3. Similar to the '317 patent, Takagi describes an objective to find a material “that is low in cost and has excellent cycle characteristics.” *Id.*, ¶¶7-8.

240. Takagi describes generating cathode materials such that the region that is “near the surface” of the primary particles, or “bonding interface,” has a higher cobalt concentration than the areas inside of the bulk. *Id.*, ¶¶9-10. The primary particles have increased cobalt at their edges/surfaces and so the grain boundaries that form at the interfaces of adjacent primary particles have increased cobalt concentration. This helps to prevent cracking.

241. I note that the technique disclosed in the '317 patent and Lampe-Onnerud is different from that disclosed by Takagi. Instead of wetting the already-formed secondary particle with a lithium cobalt oxide salt solution, Takagi produces secondary particles from primary particles already enriched with cobalt at their edges, which then aggregate after heating to form co-enriched grain boundaries. This is accomplished by creating primary particles in the initial steps in which the cobalt oxides adhere to their edges, as they are initially formed, and

then using careful heating and grinding steps control the ultimate final surface cobalt gradient. Example 5 of Takagi provides particular temperatures and heating times for this process. I understand that Dr. Noh replicated this process and from my review of the results of his experiment, it confirms that the Example 5 process necessarily yields a material that meets the '317 patent claims. In my opinion, Takagi's disclosure addresses the same problem described in '317 patent and Lampe-Onnerud and also causes there to be a greater concentration of cobalt in the grain boundary than in crystallites.

F. Applying Takagi to Claims 1-9, 11, and 14-17

1. Claim 1

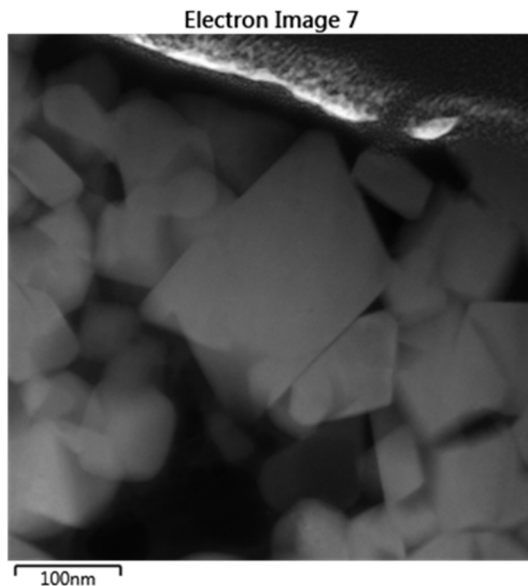
- a) “A particle, comprising: a plurality of crystallites comprising a first composition having a layered α -NaFeO₂-type structure and comprising: lithium, nickel, and oxygen”**

242. Takagi pertains to a cathode material that is “a secondary particle having a plurality of primary particles containing a layered rock salt structure lithium complex oxide containing at least lithium, nickel, and cobalt.” Ex_1010, ¶15.

243. It was well understood that a “layered rock salt structure,” and particularly, a lithium nickel oxide-based cathode material, has a layered α -NaFeO₂-type structure. *See* Ex_1012, 940 (“LiNiO₂, which also forms the α -NaFeO₂ structure ...”); Ex_1019, 707 (explaining that LiCo_{1/3}Ni_{1/3}Mn_{1/3}O₂

“possess[] the ... α -NaFeO₂-type structure ...”). For example, Zheng also has a lithium nickel cobalt aluminum oxide, specifically, LiNi_{0.8}Co_{0.15}Al_{0.05}O₂, that corresponds to the empirical formula in Takagi, which has “an ordered layered (α -NaFeO₂-type) in the grain interior.” Ex_1011, A357-58. This structure is fundamental to the energy storage capabilities of a battery cathode because it enables the material’s two-dimensional lithium-ion conduction through the electrolyte and with the anode. *Id.*, A361.

244. From Takagi’s disclosure of its process, such as for Example 5, I understand that the process will result in a polycrystalline material. From my review of Dr. Noh’s declaration, where he replicates Example 5 of Takagi, I find that his experimentation confirms that there are agglomerated primary particles, or crystallites, similar to those in FIGS. 1 and 10 of the ’317 patent. The image below (Figure L(1)) from Dr. Noh’s declaration shows a polycrystalline material, made up of a plurality of agglomerated crystallites.

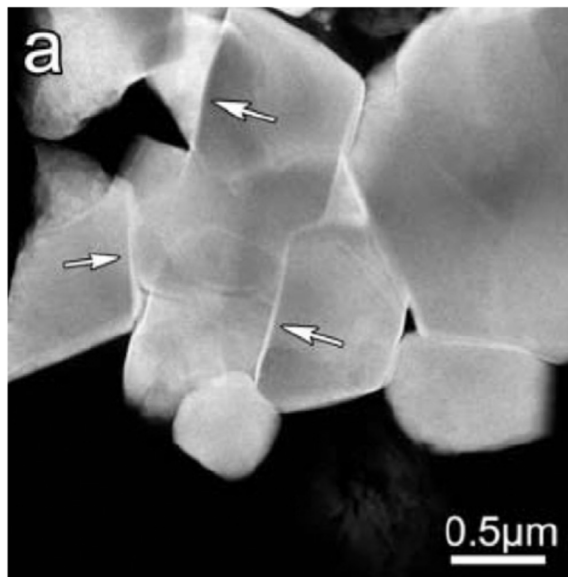


Ex_1003, 42, Figure L(1).

b) “a grain boundary between adjacent crystallites of the plurality of crystallites ...”

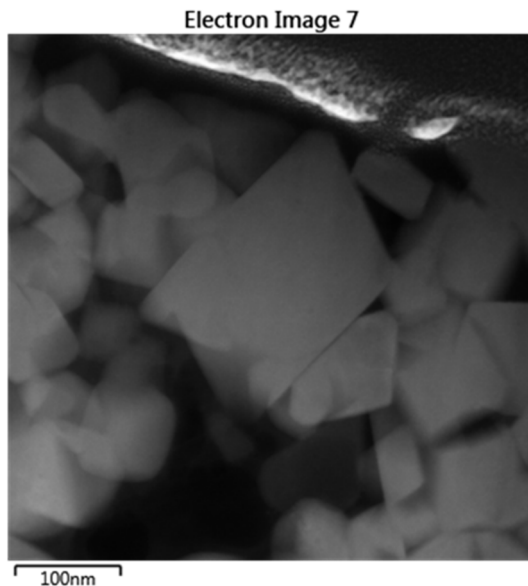
245. As I mentioned above, Takagi discloses a polycrystalline material. The secondary particles in a polycrystalline material have agglomerated primary particles that form grain boundaries at their “bonding interface.” *See, e.g.,* Ex_1010, ¶¶6, 9, 19. When Takagi uses the term “bonding interface,” he is referring to a grain boundary. Earlier in my report I provided my opinion about the meaning of the term grain boundary, and that it is a region located generally at the edges/surfaces of and between adjacent crystallites where they interface with each other. Takagi’s mention of the “bonding interface” corresponds with the proper interpretation of the claim term grain boundary.

246. As an example, Zheng illustrates an image of a secondary particle of a lithium nickel cobalt aluminum oxide cathode material, specifically, $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ which is a composition that fits within Takagi's empirical formula, and the image show the grain boundaries with white arrows.



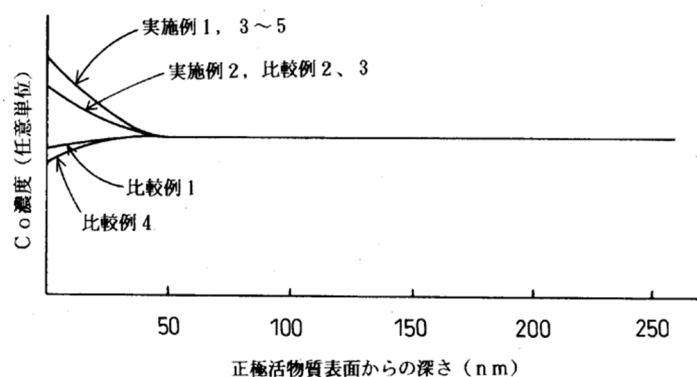
Ex_1011, FIG 5, A359 (grain boundaries annotated with white arrows in original).

247. Again, from Takagi's disclosure of his process, such as for Example 5, and his disclosure about "bonding interface," I understand that the resulting material has secondary particles with grain boundaries. Dr. Noh's experimentation of Example 5 of Takagi confirmed this by producing secondary particles with grain boundaries throughout, analogous to those depicted in '317 patent FIG. 10. Ex_1003, ¶42, Figure L(1). Additionally, I note that Dr. Noh's image obtained from his experiment is very similar to the image of Zheng's agglomerated primary particles.



- c) **“... comprising a second composition having the layered α -NaFeO₂-type structure, a cubic structure, or a combination thereof, wherein a concentration of cobalt in the grain boundary is greater than a concentration of cobalt in the crystallites.”**

248. Takagi synthesizes primary particles such that the portion “near the surface,” which the reference also refers to as the “bonding interface” or grain boundary, has a higher concentration of cobalt relative to the primary particle’s “inside.” Ex_1010, ¶10, 11, 13, 14, 19. This is shown in FIG. 1 of Takagi, particularly, for Example 5, where the concentration of cobalt is highest at the outer surface of the primary particles (at 0 nm at the left of the graph), and decreases toward the inside.



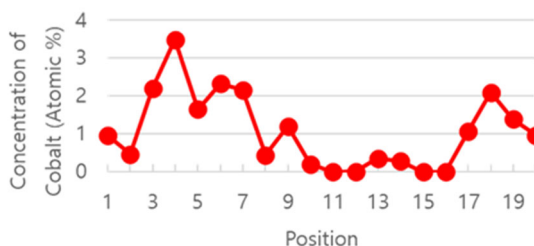
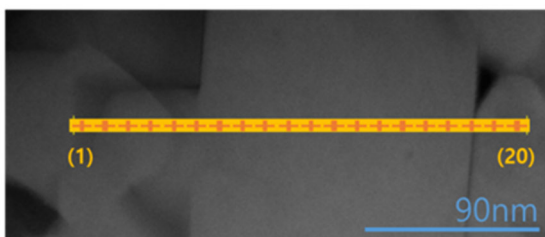
249. Takagi explains that “setting the cobalt concentration in the portion near the surface of the primary particles to be high enables suppression of occurrence of cracking at the bonding interface of the primary particles and thus is preferable.” Ex_1010, ¶19.

250. As such, there are two compositions. A “first composition” corresponds to the inner portion of the primary particle. A different, “second composition” is at the surface portion that forms the grain boundaries, which has a higher concentration of cobalt. *Id.*

251. The structure in the surface layer/grain boundary might be the same or different than the layered α - NaFeO_2 -type structure at the interior, but areas which would not be layered would likely be cubic, which is the structure that results from the reorganization of nickel into the lithium layers and the corresponding loss of oxygen. Just like I described earlier in Zheng, and also with reference to

Lampe-Onnerud, the grain boundary is more disordered than in the bulk interior of the primary particles, but it may still have regions of defined 3-D structure.

252. Dr. Noh's 's experimentation of Example 5 of Takagi confirmed the teaching in the reference that there is a higher concentration of cobalt in the grain boundaries. Ex_1003, ¶45, Figures N(1) and N(2). From these images, I understand that twenty points were measured by Dr. Noh, which span two grain boundaries (near point 4 and near point 17).



253. The regions where the grain boundary is crossed have higher cobalt concentration than the interiors of the adjacent primary particles, or crystallites. At the grain boundaries, there is comparatively more cobalt and less nickel, and so they are a “second composition.”

2. Claim 2

254. Claim 2 is also disclosed in Takagi. Here, I refer back to the same explanation that I provided about claim 2 in my discussion of the Lampe-Onnerud reference. The SEM images provided by the Petitioner reproducing Takagi clearly show that the grain boundaries in a two-dimensional cut through the secondary particles have at least some straight-line structure, thereby confirming that they are

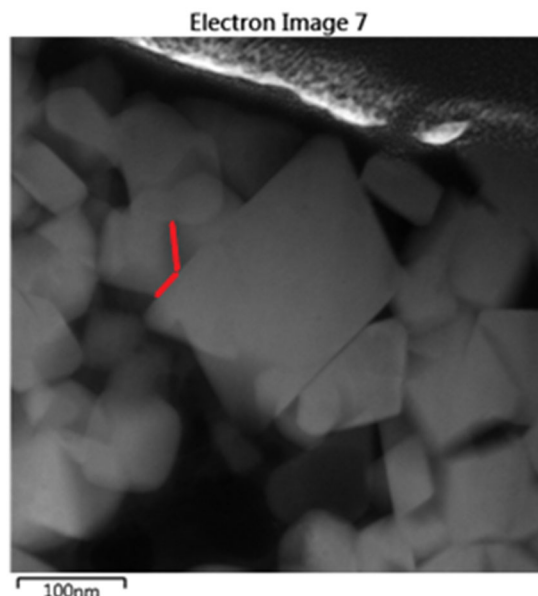
“rectilinear” in shape. In other words, Dr. Noh confirmed that Takagi discloses a process in Example 5 of the reference that will result in have primary particles having geometric shapes, thereby creating rectilinear grain boundaries.

3. Claim 3

255. Takagi discloses the added language in claim 3, at least for the same reasons that I explained for the Lampe Onnerud reference. The '317 patent relies on FIG. 1 as support for this limitation. Dr. Noh's replication of Example 5 of Takagi yielded virtually the same image as '317 patent FIG. 1, indicating that grain boundaries are oriented in various random directions, nearly all of which are different than a tangent at the outer surface.

4. Claim 4

256. In my opinion, Takagi discloses the added language in claim 4 about an angle between grain boundaries on a single crystallite. Referring once again to the STEM image from Petitioner's experiment of Example 5 from Takagi, two grain boundaries are highlighted (in red) that are on the same crystallite. The two highlighted grain boundaries intersect at an angle according to the shape of the crystallite. Ex_1003, ¶42, Figure L(1) (annotated in red).



5. Claim 5

257. Claim 5 defines the length of the grain boundary as being “parallel to a surface of an adjacent crystallite” and requires both the length and the average length of the grain boundary to be from “about 50 to about 1000 nanometers.”

258. Takagi discloses that the primary particles can have an average diameter of “about 500 nm.” Ex_1010, ¶54. A primary particle’s cross-sectional diameter can correspond to the length of its edge or at least approximate that value for regularly shaped crystals. In Petitioner’s experiments, (see for example Fig. L(1)), many cross-sectional lines through the particles have similar lengths as their edges, which themselves comprise the grain boundary lengths. Ex_1003, ¶42, Figure L(1). Thus, Takagi discloses that the length and average length of the grain boundaries are from “about 50 to about 1000 nanometers.”

259. Claim 5 also adds that the thickness of the grain boundary as being “perpendicular to the crystallite surface” and requires both the thickness and average thickness of the grain boundary to be from “about 1 to about 200 nanometers”. Takagi discloses that the “surface” where the cobalt concentration is increased is about 50 nm, which also is within the claimed range. Ex_1010, ¶52.

6. Claim 6

260. I have found that Takagi also discloses a “second composition” that is in ranges in claim 6. Takagi discloses that the general formula for the average composition of layered rock salt structure lithium complex oxides is $\text{LiNi}_{1-X-Y}\text{Co}_X\text{M}_Y\text{O}_2$ where X is preferably 0.01 or more and 0.5 or less, and Y is preferably 0.01 or more and 0.2 or less. Ex_1010, ¶18. From this it can be deduced that there is:

	Claim 6 ranges	Takagi Grain Boundary
Lithium	0.1 - 1.3	1
Nickel	0.1 - 1	0.2-0.98 (Ni_{1-X-Y} where X is preferably 0.01 or more and 0.5 or less, and more preferably 0.3 or less, and Y is preferably 0.01 or more and 0.2 or less) The grain boundary region will have a lower amount of nickel than the average empirical formula amount, which will still be within the range
Cobalt	0.02 - 0.99	On average, 0.01 - 0.5 (Co_X , where X is preferably 0.01 or more and 0.5 or less) The grain boundary region will have a greater amount of

		cobalt than the average empirical formula amount, so the amount is within the range
Oxygen	1.7 - 2.3	2

7. Claim 7

261. Takagi also discloses the added language in claim 7. The reference discloses that the cathode material preferably includes a range of 0.01 to 0.2 of Fe, Mn, or Al. Ex_1010, ¶18. That amount will be evenly distributed in the bulk and at the surface, and so the range corresponds to both the first and second compositions as stated in claim 7.

8. Claims 8 and 9

262. Takagi discloses that the empirical formula includes cobalt that is “preferably 0.01 or more and 0.5 or less,” which within the range recited in claim 8. Ex_1010, ¶18.

263. Takagi also discloses that the range is “more preferably 0.3 or less,” which is in the range recited in claim 9. Ex_1010, ¶18.

9. Claim 11

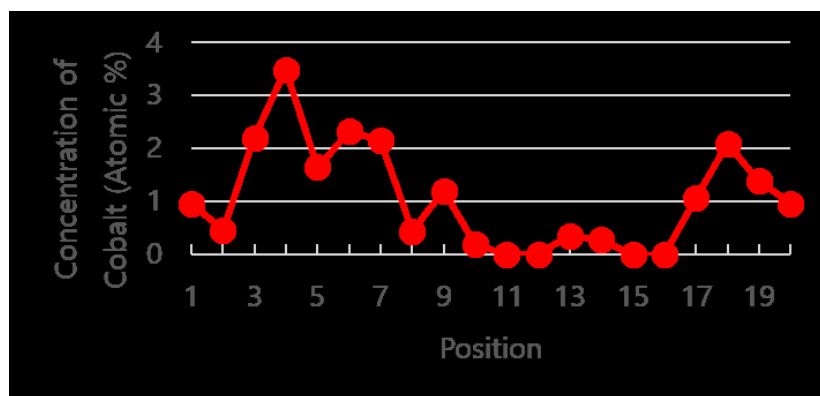
264. Takagi discloses the empirical formula can include Mn in a range “preferably 0.01 to 0.2. Ex_1010, ¶18. That amount will be evenly distributed in the bulk and at the surface, and so the range corresponds to both the first and second compositions as stated in claim 11.

10. Claim 14

265. Takagi discloses the ranges recited in claim 14 for at least the reasons that I set forth for claim 6 in this section of my report.

11. Claim 15

Claim 15 recites that the concentration of cobalt is about 0.25 to 17 atomic percent in the bulk and about 0.5 to about 32 atomic percent in the grain boundary. I have found that this is depicted by Dr. Noh's results of Experiment 5 of Takagi, as shown below:



Ex_1003, ¶45, Figure N(2). At position 8 in the bulk interior, the concentration is about 0.5%, whereas at position 18 in the grain boundary, the concentration is about 2%.

12. Claim 16

266. Takagi teaches that the cathode active material can include a binder having fluorides such as polyvinylidene fluoride. As such, Takagi discloses what

was added for Claim 16. I also refer to my discussion of claim 16 with regard to the Lampe-Onnerud reference.

13. Claim 17

267. Takagi discloses the method of claim 17. Claim 17 pertains to the particle of claim 1, synthesized by the process disclosed in Takagi.

268. First, Takagi combines “raw materials” including a mixture of oxides and hydroxides of “at least lithium nickel and cobalt.” Ex_1010, ¶26.

269. Takagi also discloses three heating steps in the claimed ranges. In Example 5 of Takagi, the materials are heated at 200° C for 3 hours, then 500° C for 5 hours, then 700° C for 5 hours. Ex_1010, ¶¶27-29.

270. The resulting material has the claimed structure and composition, just as I explained above in this section for claim 1.

G. Claims 10, 12, and 13 were obvious over Takagi

271. Takagi discloses that "the general formula for the average composition of layered rock salt structure lithium complex oxides is $\text{LiNi}_{1-X-Y}\text{Co}_X\text{M}_Y\text{O}_2$ ($0 < X < 1$; $Y \geq 0$; M is one or more elements selected from Fe, Mn, and Al). Note that X is preferably 0.01 or more and 0.5 or less, and more preferably 0.3 or less,” and that “Y is preferably 0.01 or more and 0.2 or less.” Ex_1010, ¶18. Therefore, the preferred average for nickel is 0.5 to 0.98, which overlaps the claimed range for claims 10 and 12. In my opinion, a person of

ordinary skill would have understood at the time that for a lithium nickel oxide-based cathode material, it was preferable to have at least 0.8 moles of nickel, for example, to realize cost savings and because of nickel's advantages for increasing capacity. *See* Ex_1011 and Ex_1007. Also, as indicated by several of the other references addressed in this report, it was well known for lithium nickel oxide-based cathodes to have 0.8-1 mole of nickel, including around 0.9 mole of nickel in cathode materials. *See e.g.,* Ex_1011, A357 ($\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$); Ex_1022, ¶100 ($\text{Li}(\text{Ni}_{0.85}\text{Co}_{0.15})_{0.93}\text{Al}_{0.07}\text{O}_2$); Ex_1007, 14:1-3 ($\text{LiMg}_{0.01}\text{Ni}_{0.87}\text{Co}_{0.08}\text{Mn}_{0.05}\text{O}_2$). Because the amount of nickel varies throughout the material, there are at least some areas where there will be 0.92 mole of nickel, or that would have been obvious to synthesize the material such that at least some areas have 0.92 mole of nickel. As such, Takagi renders claims 10, 12, and 13 obvious because it discloses a range that overlaps with the claimed ranges.

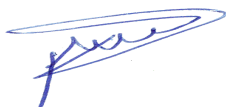
VIII. Conclusion

272. All of the foregoing statements are true and correct to the best of my knowledge, information, and belief. I reflect in this document a knowledge that I gained during 4 decades of extensive research work on a wide variety of compounds, solutions, devices, analytical efforts related to the field of rechargeable batteries, with a special emphasis on Li ion battery systems.

273. 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.

Executed on this date of 29 July 2024.

Doron Aurbach



PROF. DORON AURBACH



Bar-Ilan University
אוניברסיטת בר-אילן

Curriculum vitae



Prof. Doron Aurbach

Prof. Doron Aurbach is a leading electrochemist, materials, and surface scientist, one of Israel's most productive and creative scientists.

Born: Born: September 3, 1952, Israel, seven married children

Military Service: Officer in the IDF (Rav seren, Major rank), combat infantry

Doron Aurbach is a leading electrochemist, materials, surface, and physical chemist who heads a most prolific research group working on frontier topics in electrochemical, surface, material sciences, and physical chemistry, including intercalation processes, passivation phenomena, complex solution chemistry, and development of new analytical avenues: in-situ Spectro-electrochemical tools and hydrodynamic spectroscopy of composite surfaces an electrode. On the practical side, Aurbach and his group work heavily and systematically on R&D of a wide variety of power sources, electronically conducting polymers, and water desalination and purification processes and devices. His group also works on "green" hydrogen production. The scope of his work is vast, keeping an ideal balance between basic and practical science, and it is impressively rigorous. His research work provides novel new technologies while advancing the basic science needed to develop reliable power sources.

SUMMARY

Doron Aurbach became a Professor Emeritus in the Department of Chemistry, the Director of the Energy Center at the Bar-Ilan University Institute of Nanotechnology and Advanced Materials (BINA) in October 2020. He was a full professor at BIU 1996 – 2020. In October 2021 he returned to a position of research (full) professor at BIU, in order to found the center of Energy & Sustainability of Bar-Ilan University. He is the leader of the Israel National Research Center for Electrochemical Propulsion (INREP, since 2012), which includes 28 research groups from the seven leading academic institutions in Israel. He heads the Electrochemistry Research Group at Bar-Ilan. He also served as the chairman of Israel National Labs Accreditation Authority (2010-2016) and is a past Chairperson of the Chemistry Department (2001-2005). **He is the founder and leader of Bar-Ilan university Center of Energy & Sustainability (60 research groups from 8 Faculties), that started working in January 2022.**

He is also the founder and leader of a new energy consortium found during 2022 – INERC = Israel National Energy Research Consortium, working on all aspects of renewable energy – harvesting solar energy, large energy storage, hydrogen economy, batteries recycling, 33 research groups from 7 academic institutions: BIU, TAU, BGU, HUI, Ariel, Technion, Weizmann Institute. He signed in the name of this consortium an MoU with a parallel consortium of energy researchers from Morocco (20 research groups), establishing a broad bi-national collaboration on sustainable energy topics.

Doron Aurbach founded and leads Israel National Institute for Energy Storage (INIES), supported by and affiliated with Israel Ministry of Energy & Infrastructures (100 million NIS for 5 years, starting August 2023).

Prof. Aurbach has mentored > 80 Ph.D. students, 90 MSc students and has supervised > 50 post-doctoral fellows. Many of the graduates of his lab have gone onto successful careers in Israeli academia. Several post-doctoral fellows he guided hold academic positions in their countries (USA, Argentina, India, China, South Korea).

He has published more than **800 peer reviewed research papers** in leading electrochemistry, materials science, and physical chemistry journals. **These papers have been cited more than 10500 citations with h-index 155 (Google Scholar ,March 2024).** The statistics from the WOS (March 2024) are h-index 144, more than 88200 citations. He belongs to the most cited scientists (top 1%) in 2018 – 2023 (including 2023) as published by the Web of Science and Clarivate analytics. In 2022 & 2023 he was ranked among the top 100 leading chemists in the world (number 2 in Israel), in the fields of chemistry & materials Science.

Prof. Doron Aurbach's group collaborates with leading industries in the world related to energy and electro-mobility, including Nichia (Japan), ATL (China, one of the biggest Li batteries manufacturer in the world), BASF (Germany, the biggest chemicals company in the world) during more than 12 years, SAFT (a famous batteries maker in the US) and General Motors (the famous cars maker in the US) during nearly two decades. His research group benefits from annual budgets of millions NIS.

Prof. Aurbach is a fellow of the ECS, MRS, and ISE, a member of the European Academy of Science (since 2015) and serves the electrochemistry and power sources R & R&D Community as a senior editor for the Journal of the Electrochemical Society (since 2003). He also served as a senior editor for the journal of solid-state electrochemistry (2007-2015) and as an advisory board member of the prestigious journal Nature Communication.

Prof. Doron Aurbach has won several prestigious prizes, including the Gold Medal of the Israel Chemical Society ICS (2020), Samson Prime Minister Prize for Innovation in Alternative Fuels for Transportation (2018) A. Frumkin Medal of the international society of Electrochemistry (ISE) in 2018, A.J. Bard Medal of the Electrochemical Society (2017), Ernest B. Yeager Award of the International Battery Association (IBA) for Career-Long achievements in power sources research (2014), the Kolthoff prize of the Technion, Israel Institute of Technology, for excellence in chemical research (2013), the Research Award of the Battery Division of the Electrochemical Society (2013), the Israel Chemical Society Prize of Excellence (2012), the Landau Prize for Green Chemistry (2011), the Edwards Company Prize of the Israel Vacuum Society for Research Excellence (2007), the Technology Award of the Battery Division of the Electrochemical Society (2005) and the Israel Chemical Society prize of excellence in research for young scientists (1992).

EDUCATION

1975 - 1978	B.Sc., Chemistry (<i>Magna cum Laude</i>) Bar Ilan University, Ramat Gan, Israel
1979 - 1981	B.Sc., Chemical Engineering (<i>Summa cum Laude</i>) Israel Institute of Technology, Technion, Haifa, Israel (in parallel to his studies and research for PhD degree at BIU.
1977 - 1979	M.Sc., Physical Organic Chemistry (<i>Summa cum Laude</i>), Bar-Ilan University, Ramat Gan, Israel
1979 - 1983	Ph.D., Physical organic chemistry (with the highest distinction) Bar-Ilan University, Israel Thesis title: Molecular Nucleophilic Reactions with Substituted Bicyclobutanes. Supervisor: Professor S. Hoz
1983 - 1985	Post-Doctoral Research Fellow, "Electrochemistry of lithium and nonaqueous electrochemistry". CWRU, Cleveland, Ohio, USA. Supervisor: Professor E.B. Yeager

POSITIONS

1996 - Present	Full Professor, the Department of Chemistry, Bar-Ilan University. In October 2020 he became a Professor Emeritus but since October 2021 he is again an employee of BIU (full research professor), leading BIU center of Energy and Sustainability.
1993 - 1996	Associate Professor, Department of Chemistry, Bar-Ilan University
1989 - 1993	Senior Lecturer, Department of Chemistry, Bar-Ilan University
1985 - 1989	Lecturer, Department of Chemistry, Bar-Ilan University

BIU, NATIONAL & INTERNATIONAL ACTIVITIES

Appointments and administrative positions

(include administrative positions, advisory boards, chairmanship/membership of committees, incumbent Chairs)

1985 - Present	Head of the electrochemistry group, Department of Chemistry, Bar-Ilan University
1996 - 2018	Senate member, Bar-Ilan University
2001 - 2005	Chairman, Department of Chemistry
2010 - 2016	The chairman of the Israeli Labs Accreditation Authority
2011 - Present	The leader of the Israel National Research center for Electrochemical Propulsion (INREP). 24 research groups from 7 Israeli academic institutions, 2012-2021, working on all kinds of advanced batteries and fuel cells for electric vehicles and large energy storage.
1998 – Present	A member of the international boards of the International Meetings of Li Batteries (IMLB) and Li Batteries Discussion (LIBD).
2003 - 2014	Associate Editor of the "ECS Electrochemistry Letters" journal for fast publications (previously ESL, EEL since 2012).
2007 - 2015	Topical Editor of "J. of Solid-State Electrochemistry".
2010 - 2016	Member of the editorial advisory panel of "Nature Communication" Online journal.
2011 - 2014	Associate Editor of the "Journal of the Electrochemical Society".
2012 – Present	A board member and a director in IMLB LLC, the official organization of the International Li-battery community.
2015 – Present	A senior editor, in charge of batteries & energy storage, J. of the Electrochemical Society.
2017 – present	A member of the international board of the National French Energy Network RS2E.

AWARDS AND FELLOWSHIPS

2020	Recipient of the Gold Medal of the Israel Chemical Society (ICS)
2018	Recipient of the Samson Prime Minister Prize for Innovation in Alternative Fuels for transportation (one of the most prestigious prizes related to energy research and development). Recipient of the Alexander Frumkin Medal of the International Society of Electrochemistry - ISE (one of the most important recognitions in electrochemical sciences). Recipient of an Honorary Doctor degree from the university of Buenos Aires, Argentina.
2017	Recipient of the A.J. Bard Award of the Electrochemical Society - ECS (one of the most important recognitions in electrochemical sciences).
2015	Elected as a member of the international prestigious body: Academia Europaea.
2014	The E.B. Yeager Award of the International Battery Association (IBA) in recognition of life-long remarkable contribution to R&D of power sources.
2013	The research Award of the Electrochemical Society (ECS) battery division.
2012	Nominated a fellow of the MRS, Material Research Society.
2012	The prize of excellence in research of the "Israel Chemical Society" (ICS).
2011	Landau prize for excellence and contribution for "green chemistry". 2010 QUISQUE Became a Fellow of the "International Society of Electrochemistry" (ISE).
2010	Became part of the network of excellence in Energy research, supported by BASF.
2008	Became a Fellow of the "Electrochemical Society" (ECS).
2007	The prize of excellence in research of the "Israel Vacuum Society".
2005	The technology award of the battery division of the "Electrochemical Society".

1995 - 1997	The Israeli Ministry of Industry and Commerce. "Development of anodes based on natural graphite".
1995 - 1998	The Israeli Ministry of Science. "The study of electrochemical Intercalation processes".
1994 - 1997	The Ministry of Energy. "Development of high energy density.
1994 - 1996	The Israeli Ministry of Science. "The study and development of Li-carbon intercalation anodes in liquid nonaqueous electrolytes".
1993 - 1995	The Israeli Ministry of Industry and Commerce. "Development of Li-carbon anodes for rechargeable high energy density batteries".
1992	The Israeli Chemical Society Prize for outstanding young scientists.
1990 - 1992	The Israeli Ministry of Industry and Commerce. "The study and development of electro-coloring processes for aluminum surfaces".
1990 - 1992	The Israeli Ministry of Science. "The development of novel lead-acid batteries".
1989 - 1991	Koret Grant for Young Scientists.
1987 - 1991	The Israeli Ministry of Defense. A grant for the development of methods for surface studies of active metals.
1987 - 1989	The Israeli Ministry of Industry and Commerce. A grant for the development of anodes for rechargeable lithium batteries.
1983 - 1985	Fulbright Fellowship for post-doctoral studies.
1983 - 1984	Rothschild Fellowship for post-doctoral studies.
1976 - 1982	University scholarships for academic excellence.

TEACHING

1. Electrochemistry
2. Basic course in Physical Chemistry (for chemists)
3. Electrochemistry
4. Advanced electrochemistry
5. Advanced laboratory training in Physical Chemistry
6. Power sources

RESEARCH INTERESTS

All aspects of electrochemistry with an emphasis on non-aqueous electrochemistry. High Energy Density Batteries, Super-Capacitors, Energy Storage & Conversion, Power Sources for Electrical Vehicles, Large energy Storage for Sustainable Energy, Load Leveling Applications, Electro-organic Synthesis, Inorganic Synthesis of Intercalation Compounds, Electronically conducting polymers, Sensors, Physical Electrochemistry, Crystallography, General Spectroscopy, Spectroscopic Techniques in Conjunction with Electrochemical Techniques, General Surface and Materials Science, Electrochemistry of Carbonaceous Materials, Separation and Water Desalination Processes, Disinfection (by electrochemical methods) , 'green' hydrogen production, The basic chemistry of cluster compounds.

GRADUATE STUDENTS AND POST-DOCS

Past

80 PhD students that received PhD (until March 2023)
 80 graduate students that received MSc (until March 2023)
 45 post-doctoral fellows were guided and found positions in their countries

Present -
 March 2023

11 Ph.D. scientists (senior researchers), 4 of them with a degree of associate professor
 8 post-doctoral fellows (with PhD)
 5 Ph.D. students
 4 M.Sc. students
 2 engineers and a secretary

SCIENTIFIC COLLABORATIONS

Past

A joint project, Bar-Ilan and Tadiran Inc. "The study of a few selected electrolytes for rechargeable Li batteries, development and commercialization of rechargeable lithium batteries". 1990 - 1995

BSF - Israel-US-Binational Science Foundation. A joint project with

CWRU, Cleveland, Ohio: "The electrochemical behavior of active metal electrodes". 1989 - 1992

Tadiran: "A study of carbon electrodes for Li-ion batteries in Li salt solutions". 1991-1993

A collaboration with Merck KGaA (Darmstadt, Germany) and financed by this company and the German Ministry of Science-BMBF (1996 – 2014).

A collaboration between the Electrochemistry Group at Bar-Ilan University and LG Co., Korea, on the study of Li-ion batteries (1998 – 2012).

Israeli-German DIP project on nano-technological aspects (energy, materials science), 3 BIU groups a group from the Hebrew university and 2 prominent groups from Germany (1998 - 2003).

Leading a consortium of 7 research groups (Israel, USA, Japan) in the framework of NEDO program, Japan, 1998 – 2002.

Israel Science Foundation (ISF), The Israeli Academy of Science "Non- aqueous electrochemistry of iron 6^+ compounds, in collaboration with the group of Prof. Stuart Licht/Technion-Haifa.

Merck KGaA/Germany, Collaboration on R&D of novel systems for Li-ion batteries and ionic liquids. 1997 - 2010

Collaboration with "Mekorot" Israel on R&D of water desalination processes, in the framework of the "NOFAR" Program of the Chief Scientist of the Israeli Ministry of Industry

and Commerce.

Israel-Ukraine bi-national collaboration on material science, Ministry of Science & Technology, Israel.

Collaboration with Pigmentan, Israel, on protection against corrosion of aluminum surfaces.

Collaboration with Mead-West-Vaco, USA, on studies of supercapacitors. 2008 - 2010

Collaboration with Sion Power Ltd., USA, on studies of Li sulfur battery systems. 2005 - 2008

Collaboration with GM USA on new electrolyte solutions for low temperatures. 2007 - 2010

Collaboration with Tadiran-Batteries Division on R&D of new materials for advanced Li-ion batteries, in the framework of "MAGNETON", a program of the Chief Scientist of the Israeli Ministry of Industry and Commerce. 2010 - 2011

Collaboration with BASF on new cathode materials for advanced batteries. Part of a network of excellence in energy research, in collaboration with groups in the UA, Canada, Japan, Germany and Switzerland (14 years collaboration program 2009-2023).

Collaboration with GM on frontier science related to advanced power sources for electric vehicles. Long term collaboration, started in 2002 – 2023 (expected continuation).

Collaboration with Prof. Yury Gogotsi, Drexel University, USA on novel carbonaceous materials (in the framework of BSF, Israel-USA binational science foundation).

Collaboration with the group of Prof. Volker Presser, Department of Materials Science and Engineering, Saarland University, Saarbrücken, Germany on development of in-situ methodologies for the study of electrodes by AFM and EQCM, EQCA and QCM-D, (in the framework on GIF).

Collaboration with Tadiran-Batteries, Elbit, Electric Fuel and academic groups at Tel Aviv University and the Technion on R&D of new power sources, in the framework of "TEPS" consortium for promoting electro-mobility, supported by the Chief scientist of Ministry of Economy, "MAGNET" program.

Collaboration with Vulcan Ltd, Israel on the development of new lead-acid batteries 2006 - 2010

Collaboration with between 28 research groups from Bar-Ilan, Tel-Aviv, Ariel, Ben Gurion Universities, the Technion, Weizmann Institute, Hebrew University in the framework of INREP – Israel National Research center for Electrochemical Propulsion (supported by the ISF and PMO Israel), led by Doron Aurbach. 2012 – 2022.

Collaboration with the Group of Prof. Yang-Kook Sun, Hanyang University, Seoul, S. Korea, supported by a special program of the Korean Government for international collaborations. Working together on new Li-oxygen, LI-ion batteries, and Mg batteries. 2014 – 2018.

Collaboration with the group of Prof. Jang-Wook Choi, Seoul National University, S. Korea. Working on new intercalation mechanisms and binders 2015 - 2017

Collaboration with the group of Prof. Yan Chiang, School of Space and Environment Beihang University, Beijing, China, in the framework of ISF (Israel) and NSF (China) bi-national project on water desalination purification technologies. 2018 – 2021.

Collaboration with the group of Prof. Martin Winter, MEET institute and Muenster University, Germany on Mg-S batteries, financed by the Israeli & German Ministries of Science. 2018 – 2020.

A Member of the E. Magic consortium, a European Commission project, led by Cidetec, Spain, aims at developing rechargeable Mg batteries technology, collaboration with prominent European research groups from Spain, France, Germany, Denmark and the UK. 4 years project, 2019 – 2023.

Collaboration with Nichia company, Japan on the development of novel Li-S Batteries. A 3-year project, 2019 – 2023.

A new collaboration with GM USA on developing new Si anodes for advanced Li-ion batteries. A 4-year project, 2019 -2023 (in the framework of on-going collaboration during 2 decades, since 2002).

A collaboration with ATL China (the top world Li batteries industry) on high voltage Li ion batteries, 2020-2022.

A collaboration with Kuora, USA, a company which develop fluorinated solvents. Aurbach's group explores the possibility to use fluorinated co-solvents in electrolyte solutions for advanced rechargeable batteries, 2021 – 2023.

Developing rechargeable Na ion batteries for large Energy storage 2022 – 2024, Supported by the Israeli Energy Company Dor-Al.

Collaboration with GAS – Bochemie (Czech Republic) on NiCd batteries for load leveling applications.

GRANTS

Research grants

(last 15 years)

1997 - 2002	A collaboration with Merck KGaA (Darmstadt, Germany) and financed by this company and the German Ministry of Science-BMBF. "The study of advanced battery materials", 50,000 US\$ p.a.
1995 - 2000	The Israeli Ministry of Infrastructure and Energy: R&D of Li Batteries. 40,000 US\$ p.a.
1992 - 2002	Tadiran: "Development of rechargeable Li batteries (Li metal anodes and organic electrolytes". 50,000 US\$ p.a.
1998 - 2001	NEDO Japan. "The science behind Li batteries". 40,000 US\$ p.a.
1999 - 2003	The German Ministry of Science, "DIP" - Israeli-German Science Center of Material Surface and Electrochemical Sciences. "Development of novel microdevices". 50,000 US\$ p.a.
1998 - 2000	Israel Academy of Science, NSF. "Development of novel cathode materials". 38,000 US\$ p.a.
2000 - 2004	A collaboration between the Electrochemistry Group at Bar-Ilan University and LG Co., Korea, on the study of Li-ion batteries. 60,000 US\$ p.a.
2000 - 2004	A European Union-funded collaboration project on 'Solid-State Li Batteries' with Israel, Germany, Switzerland, Austria, England, and the Netherlands. 50,000 US\$ p.a.

2000 - 2003	Israel-US Binational Foundation (BSF): "R&D of Novel Carbonaceous Electrodes". 50,000 US\$ p.a.
2000 - 2002	GM (USA). Development of New Materials for Advanced Batteries.
2000 – 2001	The Israeli Police. Development of Electroanalytical Methods for Identification of Trace Explosives. 60,000 US\$ p.a.
2000 – 2003	ECR (Israel). Development of Super (EDL) Capacitors. 30,000 US\$ p.a.
2001 – 2005	The Israel Science Foundation (ISF), The Israeli Academy of Science, "Magnesium Electrochemistry". US\$ 63,000 p.a.
2001 – 2004	The European Union. The 'Nanobatt' Project for R&D of Novel Materials for Li Batteries. A consortium of Aurbach's group with Tadiran, Israel, and groups from France, Belgium, Germany, and Romania. US\$ 100,000 p.a. Project Coordinator: Prof. D. Aurbach.
1997 – 2006	"ATU" investors in applied science (an Israeli group). "Development of rechargeable magnesium batteries". 300,000 US\$ p.a.
2002 – 2006	Israel Science Foundation (ISF), The Israeli Academy of Science "Non- aqueous electrochemistry of iron 6+ compounds, in collaboration with the group of Prof. Stuart Licht/Technion-Haifa, 33000 US\$ p.a. per group.
2003 – 2005	Merck KGaA/Germany, Collaboration on R&D of novel systems for Li ion batteries and ionic liquids. 60000 Euro p.a.
2003 – 2007	A Knowledge Center on Energy Storage and Conversion, Israel Ministry of Science and Technology, 40000 US\$ p.a.
2005 – 2009	Israel–US Binational Foundation (BSF). Electrochemical and theoretical studies of multivalent cations into inorganic hosts (with Prof. G. Ceder, MIT), 48000 US\$ p.a.
2006 – 2008	A special fund for water desalination research, Wolfson Foundation, 200,000 US\$ (total).
2006	Collaboration with "Mekorot" Israel on R&D of water desalination processes, in the framework of the "NOFAR" Program of the Chief Scientist of the Israeli Ministry of Industry and Commerce. 100000 USD.

2006 – 2009	GIF Israel Germany Binational Foundation, "On the study of transport phenomena", with Prof. J. Maier. 58000 Euros p.a.
2006 – 2008	Israel-Ukraine bi-national collaboration on material science, Ministry of Science & Technology, Israel, 30,000 USD\$
2006 – 2010	ISF, Israel Science Foundation, "R&D of Nano-materials for high rate, high energy density rechargeable batteries. 52,000 US\$ p.a
2007	Collaboration with Pigmentan, Israel, on protection against corrosion of aluminum surfaces, 25000 USD.
2007	Collaboration with Mead-West-Vaco, USA, on studies of supercapacitors, 30000 USD.
2007 – 2009	Collaboration with Merck KGaA, Germany on ionic liquids for battery application, 60000 Euros p.a.
2007 – 2009	Collaboration with Sion Power Ltd., USA, on studies of Li sulfur battery systems, 90000 USD p.a.
2007 – 2009	Collaboration with GM USA on new electrolyte solutions for low temperatures. 130000 USD p.a.
2007 – 2008	Collaboration with Tadiran-Batteries Division on R&D of new materials for advanced Li-ion batteries, in the framework of "MAGNETON", a program of the Chief Scientist of the Israeli Ministry of Industry and Commerce. 60000 USD p.a.
2007 – 2009	A special grant from the "Horowitz Foundation", a foundation for R&D of electrochemical water desalination processes. 42500 USD p.a.
2007 – 2009	A special grant from the "Horowitz Foundation", together with Profs. A. Zaban, A. Gedanken and Dr. J. Frey. Dept. Of Chemistry, Bar-Ilan University, for the development of advanced energy research. 60000 USD per group per year.
2008 – 2010	POW project (an Israeli venture) on R&d of small rechargeable batteries, 100000 USD p.a.
2009 – 2012	A new collaboration with Merck KGaA, Germany on novel materials for Li-ion batteries. 100000 Euro p.a.
2009 – 2012	Collaboration with ETV (an Israeli venture) on R&D of electric Vehicle, 180000 USD p.a. the collaboration is supported by the "Magnetron" program of the chief scientist of the Israeli Ministry of industry & commerce.

2008 – 2010	Collaboration with HPL Switzerland on the study of new olivine compounds for energy storage & conversion. 32000 Euro p.a.
2010 – 2019	Collaboration with BASF on new cathode materials for advanced batteries and advanced Li batteries, Li-S and Li-air batteries, 600,000 Euro p.a.
2009 – 2014	"Magnet" program of the chief scientist of the Israeli Ministry of industry & commerce: "introduction of Nano-tubes as a strategically important component for many uses", collaboration with Vulcan, Elbit, El-mul, 3G-Solar and other Israeli industries on the improvement of devices for energy storage & conversion, 120000 USD p.a.
2010 – 2014	Collaboration with GM on several topics related to advanced Li-ion batteries. 400,000 USD p.a.
2010 – 2013	Collaboration with Prof. C. Thompson & Y. Shao-Horn, MIT, Boston USA, in the framework of BSF – Israel US bi-national science foundation "R&D of novel rechargeable battery systems for load leveling applications", 50000 USD p.a.
2010 – 2014	Collaboration with Pellion USA (based on ARPA-E grant from the US DOE) on rechargeable Mg batteries, 200,000 USD p.a.
2010 – 2012	Collaboration with DOW (USA & Europe) on the study of Li[MnFe]PO ₄ cathode materials for advance Li-ion batteries. 80000 USD p.a.
2011- 2014	I-SAEF Foundation USA on renewable energy, 60000 USA p.a.
2011 -2016	Collaboration with the Israeli company Phinergy, on Aluminum-air batteries for electro-mobility, 50000 USD p.a.
2013-2018	A MAGNET program, a consortium of industries and academic groups, supported by the Chief Scientist of the Ministry of Economy, Israel (together with the Israeli companies ETV, Tadiran, Elbit, Epsilor), elaborating power sources industries in Israel for electrochemical propulsion, 150000 USD p.a.
2012 – 2017	ISF I-core program: Israel National Research Center for Electrochemical Propulsion, leading 12 research groups from BIU, TAU, Technion and AUC, 9,000,000 NIS p.a.
2014-2015	New collaboration with GM on several important problems related to cathode materials for advanced Li ion batteries, 110000 USD p.A.

2014-2015	Collaboration with Vulcan, on advanced lead-acid batteries, supported by the Chief Scientist of the ministry of economy, 40000 USD p.a.
2015 – 2019	Renewal of the 5 years collaboration with BASF, in the framework of the international network of excellence: 650000 Euro p.a.
2014-2017	GIF (Israel-Germany bi-national science foundation). Collaboration with the group of Prof. Volker Presser, department of materials science and engineering, Saarland University Saarbrücken, Germany on the topic “In situ electrochemical methodology for simultaneous tracking of charging and related mechanical processes in batteries and supercapacitors “, 60000 Euro p.a.
2015-2018	BSF (Israel-USA bi-national science foundation). Collaboration with the group of Yury Gogotsi, Drexel University, USA, on “QCM-D characterization of Advanced Electrode Materials “, 40000 Euro p.a.
2015 – 2019	ISF (Israel Science Foundation),” Non-aqueous sodium electrochemistry”, 320000 NIS p.a.
2016 – 2022	Renewal of INREP project, now supported by the Committee for High Education of Israel, D. Aurbach is the leader. 22 research groups, 56.5 million NIS for 5 years.
2017 – 2022	Collaboration between Israeli and German prominent groups in the field of batteries, supported by the ministries of science of Israel (MOST) and Germany (BMBF): Mg-S batteries and then – multivalent metal ions batteries, co-work with the group of Prof. Martin Winter, University of Muenster, Germany: around 2 million NIS for 6 years for the Israeli group.
2017 – 2020	A grant for scientific infrastructure from Israel Ministry of Science and Technology (MOST) for developing new analytical tools in electrochemistry, based on EQCM – D instrumentation: 770000 NIS.
2017 - 2020	A grant of the Israel Science Foundation ISF, a joint program with the Chinese Science foundation, NSFC, collaboration with the group of prof. Yan Xiang Beihang University, (BUAA) Beijing, 310,000 NIS per year.
2019 - 2020	A grant of the Israel Ministry of energy, development of batteries for load leveling applications and large energy storage. 300000 NIS per year.
2019 - 2024	A new project supported by GM, USA – development of Li anodes for advanced Li ion Batteries, 150000 USD per year (in the framework of 2 decades of collaboration)
2019 - 2023	A new 4-year European project, 120,000 Euros annually. A consortium called

y

E-Magic, intending to develop rechargeable Mg batteries. A collaboration with prominent research groups from Spain, France, UK, Denmark & Germany.

2019 - 2024

An Israel – USA project for 5 years on solid state batteries, supported by the American DOE and US – Israel BIRD Foundation. collaboration between 3 research groups from BIU, 2 research group from TAU and 2 start-up companies (the Israeli side) , with research groups from the university of Maryland USA, the big Battery company SAFT and 2 American start-up companies, 85000 USD for each research group per year.

2020 -2025

A collaboration with the big Chemicals Company Nichia, Japan: development of Rechargeable lithium – sulfur batteries, 120,000 USD per year (until 2022), then – developing Rechargeable Zinc -Air Batteries (100,000 USD per year) until 2025

2020-2023

A collaboration with ATL (China), the biggest Li batteries manufacturer in the world, on high voltage/high energy density rechargeable Li ion batteries for mobile electronics, 200,000 USD per year.

2020 -2024

Renewal of collaboration with BASF on high voltage cathodes for Li ion batteries, 200,000 Euros per year.

2022 – 2023

A collaboration with Koura USA, developing new electrolyte solutions for Li & Na batteries, based on fluorinated solvents, 120,000 USD per year.

2022 - 2025

Developing Na ions batteries for large energy storage, 500,000 USD, supported by the Israeli Energy company Dor-Al.

EQUIPMENT GRANTS

1986

A grant for purchasing equipment, The National Council for Higher Education, 100000 USD.

1998

A grant for the purchase of a XPS system ISF 300,000 USD.

2007

A grant from Horovitz foundation, Equipment for water desalination, 200000 USD.

2008

A grant for the purchase of a TEM system, ISF 300,000 USD.

2010

A Grant from BASF for electrochemical equipment, 80000 USD.

2011

A Grant from BASF for ARC system, 60000 Euros.

2012	A Grant for equipment in the framework of the ISF I-core program: Israel National Research Center for Electrochemical Propulsion, 6,500,000 NIS.
2012	A grant for equipment and infrastructure in the framework of INREP project stage 1, supported by the ISF and the Israeli Prime Minister office. 6,000,000 NIS.
2016	A grant for equipment and infrastructure in the framework of INREP project stage 2, supported by the Israel Committee for High Education and the Israel Prime Minister office, 5,000,000 NIS.
2018	A grant from the ISF for the purchase of a new XPS system, 925,000 NIS. The actual cost of the new XPS system was 2,000,000 NIS. We reached appropriate matching funds.
2022	A grant from the ISF for the purchase of a new HRTEM system.

A SUMMARY OF
 ACHIEVEMENTS
 UNTIL MARCH
 2023

1. D. Aurbach contributed significantly to the scientific background that enabled the success of commercial Li ion batteries distribution as safe and reliable rechargeable power sources.
2. He was the first to develop (together with Tadiran-Batteries, Israel) commercial Li metal anode based rechargeable batteries that included internal and intrinsic safety mechanisms, thereby could be distributed as safe commercial products.
3. He systematically mapped the major reactions that limit the electrochemical windows of most important non-aqueous electrolyte solutions and precisely deciphered their mechanisms, thus contributing significantly to basic non-aqueous electrochemistry.
4. He pioneered application of *in-situ* analytical techniques (FTIR, Raman, AFM, STM) for the study of most reactive electrochemical systems (e.g., Li, Mg, Li-C, Li-Si electrodes operating in non-aqueous solutions).
5. He developed the relatively new field of rechargeable Mg batteries, considered as one of the leaders of this area. This included development of a plethora of new electrolyte solutions, Mg ions intercalation cathodes, understanding non-aqueous Mg electrochemistry by theoretical and experimental work, using a large variety of spectro-electrochemical tools.
6. He contributed a lot to the fields of Li-S, Li-oxygen batteries, pioneered development of Si-Li-S battery prototypes and contributed significantly for understanding the limitations of Li-oxygen batteries, namely – intrinsic series of side reactions (including

deciphering reactions paths and mechanisms), that prevent to reach durability of Li-oxygen battery systems.

7. He pioneered the application of EQCM = Electrochemical Quartz Crystal Microbalance (including sophisticated variations like EQCM-D) for operando (*in-situ*) studies of composite electrodes. He demonstrated how to read properly the response obtained, separating properly between gravimetric and viscoelastic effects, applying operando EQCM-D as an important tool for understanding all kind of adsorption and intercalation processes.
8. He has raised a pioneering contribution in development of activated carbon electrodes for capacitive and pseudo-capacitive energy storage. He demonstrated how to control and precisely measure porosity (including pores size and morphology).
9. He has raised a pioneering contribution for understanding ion intercalation processes (e.g. Li, Na, Mg ions into various carbonaceous, transition metal oxides and sulfide hosts) by applying a wide variety of fine electroanalytical tools (PITT, GITT, EIS, slow scanning rate CV simultaneously) in conjunction with spectroscopic, microscopic and EQCM based techniques.
10. He contributed to understanding cluster compounds (some of which, like Chevrel phases can serve as benchmark cathode materials for rechargeable Mg batteries), showing that it is possible to understand the electronic structure of metal-metal bonds in cluster compounds based on analyzing the crystal structure of these compounds.
11. During the last 2 years he has developed a variety of rechargeable aqueous battery prototypes based on both polymeric redox compounds and inorganic intercalation host electrodes' materials that can insert reversibly a variety of cations (protons, Li, Na, Mg, Zn, Ca ions), offering interesting options of large energy storage devices.
12. D.A. leads in recent years the renaissance of using Li metal anodes in rechargeable high energy density batteries, using electrolyte solutions including fluorinated co-solvents. These species are very reactive on Li, Li-C, Li-Si surfaces, their reactions lead to the formation of flexible solid electrolyte interphases (SEI) on these reactive anodes, accommodating very well their morphological changes, allowing a very facile transport of Li ions through them (due to unique composition of elastic polymeric and oligomeric species and ionic Li ion compounds). His group analyzed compositions of these surface films and explained their mechanisms of formation and healing during charge/discharge cycling. The group developed high energy density Li-LNO cells, high energy/high voltage Li-LCO (4.6 V) cells with practical areal loading of electrodes and electrolyte solutions, demonstrating impressive performance thanks to the development of new cathodes coatings and the use of electrolyte solutions containing two types of fluorinated co-solvents.
13. Over the years D.A. group has explored very systematically family of cathode materials with olivine (LiFePO_4 , LiMnPO_4 , $\text{LiFe}_{0.2}\text{Mn}_{0.8}\text{PO}_4$, LiCoPO_4), Spinel (LiMn_2O_4 , $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$) and layered (Ni rich NCM, Li & Mn rich NCM) developed methods for stabilizing them by doping and coating, optimizing their performance (high capacity,

stability, rate capability and safety features). The group has developed active-functional separators that can avoid detrimental transport of transition metal cations from the anodes to the anodes in Li ion batteries. All of these studies can offer now optimal high energy density, durable and stable battery prototypes for electromobility.

14. Aurbach's group is working now on electrochemical devices for large energy storage based on sodium ion batteries and aqueous Na, Mg, Zn and Ca batteries. The group works also toward developing solid-state sodium metal batteries, based on composite polymeric-ceramic solid electrolytes, concentrating on understanding interfacial phenomena in the contact of the active metal anode and the composite solid electrolyte, aiming at developing rechargeable SS batteries that operate well at low external pressures.

D. Aurbach's group works very systematically on a very wide scope of topics related to electrochemical power sources and the field of Energy – Water Nexus: electrodes' materials, a wide variety of liquid and solid electrolyte systems, various types of batteries, super capacitors, water treatment devices, using a very broad scope of *in-situ* & *ex-situ* analytical tools, trying to keep a very careful balance between synthetic and analytical efforts, and between practical and basic science.

PUBLICATIONS

LIST OF PUBLICATIONS

WOS: >88200 CITATIONS, H-INDEX=144; GOOGLE SCHOLAR > 105000
 CITATIONS, H-INDEX = 155, MARCH 2024

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 Chapter 1: Non-aqueous Electrochemistry: An Overview. Doron Aurbach and Idit Weissman.
 Chapter 3: Experimental Considerations Regarding the Use and Study of Nonaqueous Electrochemical Systems.
 Chapter 4: The Electrochemical Window of Nonaqueous Electrolyte Solutions. Doron Aurbach and Yosef Gofer.
 Chapter 6: The Electrochemical Behavior of Active Metal Electrodes in Nonaqueous Solutions. Doron Aurbach.
- Chapter 1 "The Role of Surface Films on Electrodes in Li ion Batteries" in "Advances in Lithium Ion Batteries", W. V. Schalkwijk and B. Scrosati Eds., Kluwer Academic/Plenum Publishers Inc. (2002), pp 7- 77.
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33. Wu, Xiaohan; Garve, Lennart; Karl, Bernhard; Maiti, Sandipan; Sclar, Hadar; Markovsky, Boris; Aurbach, Doron. At least partially coated electrode active material, its manufacture and use. Eur. Pat. Appl. (2022), EP3961763.
34. Wu, Xiaohan; Aurbach, Doron; Maiti, Sandipan; Schreyer, Hannah; Kunkes, Eduard L; Mueller, Imke Britta. Electrochemical cells and electrode active materials suitable for such electrochemical cells. PCT Int. Appl. (2023), WO/2023/280589

INVITED CONFERENCE LECTURES

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(include only lectures within conferences)

- 1) The International Fall meeting of The Electrochemical Society, Phoenix, Arizona, Oct. 1991.
 - a. The electrochemistry of methyl formate solutions.
 - b. The study of electrolyte solutions for secondary Li batteries based on 1-3 dioxolane solutions.
- 2) The 6th International Meeting on Li Batteries, Münster, Germany, May 1992.
 - a. The study of lithium intercalation into carbonaceous materials in a variety of nonaqueous media.
- 3) The University of Austin, Texas (Department of Chemistry), May 1993.
 - a. Lithium electrochemistry.
- 4) Case Western Reserve University, Cleveland, Ohio (Department of Chemistry, May 1993. Lecture related to the behavior of Li electrodes in polar aprotic systems.
- 5) The International Spring Meeting of the Electrochemical Society, Honolulu, Hawaii, May 1993.
 - a. The application of in situ FTIR spectroscopy for the study of electrode reactions in nonaqueous systems.
 - b. The correlation between the surface chemistry and performance of lithium carbon in certain electrodes in selected electrolyte solutions.

- 6) An international symposium on The Science of Advanced Batteries, Case Western Reserve University, November 1993. The development of in situ electrochemical methods for the study of Li electrodes and electrode reactions in nonaqueous systems.
- 7) The 7th International Meeting on Li Batteries, Boston, Mass., May 1994.
 - a. Invited lecture on our recent studies of electrolyte solutions for high energy density rechargeable batteries.
 - b. Presentation of a new rechargeable Li-MnO₂ battery.
- 8) The spring meeting of the Electrochemical Society, San Francisco, May 1994.
 - a. The study of Li electrodes in the electrolyte solutions THF/2Me-THF, Me Furan/LiAsF₆.
 - b. The application of impedance spectroscopy for the study of lithium and non-active electrodes in polar aprotic systems.
- 9) The International Fall Meeting of the Electrochemical Society, Miami Beach, October 1994. An invited lecture on a comparative study of lithium and graphite electrodes in solutions based on mixtures of ethylene and diethyl carbonates.
- 10) Case Western Reserve University (Department of Chemistry), October 1994. Symposium on intercalation of lithium into carbonaceous materials. Mechanisms and the factors which control the electrochemical behavior.
- 11) The 35th Battery Symposium of Japan, Nagoya, November 1994. A keynote lecture on the surface chemistry developed on Li and Li-carbon electrodes, investigation methods and the impact on the electrochemical behavior.
- 12) The 46th International Electrochemical Society meeting, Xiamen, China, 27 Aug. - 1 Sept. 1995. A keynote lecture: The study of active metal electrodes in nonaqueous systems: from fundamental research to practical rechargeable battery systems.
- 13) The 8th International Meeting on Li batteries, Nagoya, Japan, June 1996. An invited lecture on our recent studies of the correlation between surface chemistry, morphology, 3D structure and performance of Li and Li-C electrodes in a variety of important nonaqueous electrolyte solutions, with the emphasis on the application of sophisticated in situ Spectro electrochemical techniques.
- 14) The University of Osaka, Japan (Department of Applied Chemistry), June 1996. An invited lecture on a comparative study of Li and Li-C electrodes for rechargeable high energy density batteries.
- 15) The University of Waseda, Tokyo, Japan, June 1996. An invited lecture on the science behind Li battery systems.
- 16) The University of Hong Kong, Hong Kong, June 1996.
 - a. The correlation between the surface chemistry, morphology, 3D structure and performance of electrodes for rechargeable batteries in nonaqueous systems.
 - b. The application of advanced in situ Spectro electrochemical tools for the study of electrode-solution interactions (FTIR, EQCM, AFM, etc.).
- 17) The International Fall Meeting of the Electrochemical Society, San Antonio, Texas, October 1996.
 - a. The application of EQCM and in situ FTIR spectroscopy for the study of electrode-solution interactions in nonaqueous media.

- b. Discussion on the new Li-LixMnO₂ rechargeable Li-battery technology developed by Tadiran (a collaboration with Bar-Ilan University).
 - c. The study of the mechanisms of intercalation of lithium into graphite. The use of slow-scan C.V, PITT, XRD, and impedance spectroscopy.
 - d. The application of atomic force microscopy (AFM) for the study of Li deposition processes.
 - e. A comparative study of Li and carbon electrodes in nonaqueous electrolyte solutions of importance for high energy density batteries.
- 18) National Renewable Energy Laboratory (NREL), Golden, Colorado and Hughes Laboratories, Malibu, California, October 1996.
 - a. High energy density batteries from fundamental studies to practical working systems.
 - b. The electrochemical behavior of the lithium-carbon intercalation electrode correlation of surface chemistry, 3D structure, morphology, and reversibility.
- 19) The Annual Meeting of the Israeli Chemical Society, Technion, Haifa, February 1997. "The electroanalytical behavior of intercalation processes, lithium and carbon, and transition metal oxides.
- 20) The Joint Symposium of the Electrochemical Society (ECS), the International Society for Electrochemistry (ISE) (the 192nd and 48th meetings, respectively), Paris, August 31 - September 5, 1997.
 - a. Electroanalytical and spectroscopic studies of 4-volt cathodes for Li-ion batteries.
 - b. The study of Li deposition processes by simultaneous in situ EQCM, AFM, STM, FTIR, and impedance spectroscopy.
- 21) The MRS Fall Meeting, Boston, MA, Sept. 1-5, 1997. Symposium on materials for electrochemical energy storage and conversion II (battery, capacitors and fuel cells. "Recent studies of interfacial phenomena which determine the electrochemical behavior of Li and Li carbon anodes (in situ techniques).
- 22) The First Battery Workshop, Taipei, Taiwan, 4-5, 1998. "The correlation among surface chemistry, 3D structure, morphology, interfacial properties and performance of anodes and cathodes for Li-ion batteries".
- 23) The 9th International Meeting on Li Batteries, Edinburgh, Scotland, July 12 - 17, 1998. Plenary lecture on electrolyte systems for Li batteries.
- 24) The fall meeting of the Electrochemical Society, Nov. 1998, Boston, MA. "On the electrochemical behavior of Li insertion cathodes".
- 25) Ibid. "On basic phenomena related to active metal electrodes. New insights".
- 26) Ibid. "In situ studies of Li electrodes by atomic force microscopy – AFM".
- 27) 'Advanced Li Solid State Batteries Workshop' sponsored by the U.S. Department of Energy, Towson, MD, USA, July 13-15, 1999. "Electrode-electrolyte interactions in high energy density non-aqueous batteries and supercapacitors".
- 28) The '99 Meeting of the International Society of Electrochemistry, Padova, Italy, September 1999. Keynote lecture: "Li insertion into host materials: an interesting challenge in material, surface, and electrochemical science".

- 29) The Fall ECS Meeting, Honolulu, Hawaii, October 1999. The electrochemical behavior of magnesium electrodes in polar aprotic systems. Studies by in situ techniques.
- 30) Ibid., The study of non-aqueous supercapacitor systems.
- 31) Ibid., Surface area and pore size at the solid-gas and electrode-solution interfaces of activated carbons.
- 32) Ibid., Phase transition mechanisms of $\text{Li}_x\text{Mn}_2\text{O}_4$ spinel electrodes.
- 33) Ibid., On solution-electrode interactions in Li-ion battery systems.
- 34) Ibid., The study of high surface area graphite as anode material for Li-ion batteries.
- 35) Ibid., What ends the cycle life of rechargeable lithium batteries?
- 36) University of San Sebastian, Spain, Department of Chemistry, November '99. "The science behind Li battery systems".
- 37) University of Paris-Jussieu, France, Department of Chemistry, November '99. "The science behind Li battery systems".
- 38) Jules Verne University, Amiens, France, Department of Material Science. "Electrochemistry of active metals and their application to high energy density, batteries". November 1999.
- 39) The Hong Kong Baptist University, Department of Chemistry, 24 March 2000. "Electrochemical intercalation into host materials".
- 40) Hong Kong University, Department of Chemistry, 6 April 2000. "New trends in R&D of Li batteries".
- 41) The 10th International Meeting on Li Batteries, Como, Italy, May 2000. "Rechargeable magnesium battery technology and comparison with Li-battery systems".
- 42) A lecture at the Technical University, Dnepropetrovsk: "On the science behind rechargeable lithium batteries. From fundamental studies to practical battery systems". July 14, 2000.
- 43) The Annual Meeting of the International Society of Electrochemistry, September 2000, Warsaw, Poland. A keynote lecture: Electrochemistry for a safer and a green environment: "The challenge in the development of safe and environmentally-friendly high energy density batteries".
- 44) A keynote lecture at WEEPF-2000 on "Redox, polymers, electroactive films and related phenomena", sponsored by NATO, Poraj, Poland, Sept. 10-14, 2000. "Li intercalation into mixed-valence oxide films as an example of inorganic electroactive films".
- 45) A keynote lecture at the Frumkin Symposium, Moscow, Russia, Oct. 2000. "Rechargeable nonaqueous batteries and EDL capacitors: from basic studies to practical systems".
- 46) Invited lecture at the Department of Chemistry, Chinese University of Hong Kong, March 16, 2001: "Nonaqueous rechargeable batteries from basic science to practical working systems".
- 47) A lecture at the "Workshop for Advanced Li and Li-ion batteries" (sponsored by NEDO). Keio Plaza Hotel, Tokyo, Japan, February 20, 2001. "Basic studies of novel, high rate Li and Li-ion batteries for application to large scale batteries".
- 48) A lecture at the IBA Meeting, Kwa Maritane, South Africa, March 13, 2001. "On some important electrode-solution interactions in Li-ion batteries".
- 49) A lecture at the IBA Meeting, Kwa Maritane, South Africa, March 13, 2001. "Review on the perspectives and challenges in R&D of rechargeable Li metal batteries and alternative systems".
- 50) Keynote lecture at the Li Battery Discussion Meeting (LIBD), Bordeaux, Arcachon, France, May 27 - June 1, 2001. "The study of electrodes for rechargeable, high energy density batteries (Li, Mg, Li-ion) by in situ scanning probe microscopy (AFM, STM).

- 51) Invited talk at ICMAT 2001, Singapore, July 1-6, 2001. International Symposium on Advanced Materials. "Electrode-solution interactions in Li, Li-ion and Mg rechargeable batteries".
- 52) Invited talk at the Paul Scherer Institute, Zurich, Switzerland: "The science behind Li-ion batteries". August 22, 2001.
- 53) Invited talk at Dalhousie University, Halifax, Canada: "Recent studies on R&D of novel, high energy density, batteries". August 28th, 2001.
- 54) Invited talk at the 6th International Symposium on "Polymers for Advanced Technology", September 2-6, 2001, Eilat, Israel. "Electronically conducting and red-ox polymers for high energy density, rechargeable batteries".
- 55) Invited talk at the ABA3 meeting, June 17-20th 2002, Brno, Czech Republic, "On R&D of rechargeable batteries, an area where practical success depends on rigorous basic research. An example: development of rechargeable magnesium batteries"
- 56) Invited talk at the 11th International Meeting on Li batteries, June 23-28, 2002, Monterey CA, USA, "On electrode-solution interactions in Li and Li-ion batteries: A review and new insights."
- 57) Invited talk at the Faculty of Chemical Engineering, the University of South Carolina USA, 3rd June 2002. "On capacity fading of Li ion batteries".
- 58) Keynote lecture at the 43rd Battery Symposium of Japan, Fukuoka, Japan, October 14th, 2002. "R&D of rechargeable batteries, an area where practical success depends on rigorous basic research. Example: new rechargeable magnesium batteries.
- 59) Invited talk at a Special Seminar on Batteries, The Committee of Battery Technology, ECSJ and The Society of Advanced Battery Technology, OSTEC, Osaka, Japan, October 15th, 2002. "Interface on carbonaceous negative electrodes of rechargeable lithium batteries".
- 60) Keynote lectures at the International Conference: Spectro electrochemistry of Conducting Polymers, October 19-23, 2002, Moscow. D. Aurbach: "On the studies of conducting and red-ox polymers for secondary battery applications." M. D. Levi and D. Aurbach: "New types of diffuse phase transition in graphite electrodes during electrochemical insertion of Li-ions from organic carbonate solutions at elevated temperatures."
- 61) Invited talk at the Indian Institute of Science, Department of Chemistry, Bangalore, India, November 25th, 2002: "Electrode-solution interactions in Li and Li-ion batteries. A review and new insights."
- 62) Keynote (plenary) lecture at the 7th International Symposium on Advances in Electrochemical Science and Technology (ISAEEST-V11), 27-29 November 2002, Chennai, India. "R&D of novel rechargeable batteries, an area where practical success depends on rigorous basic research. Example: new rechargeable magnesium batteries."
- 63) Invited talk at the International Battery Association IBA Conference (IBA-0HBC 2002), Hawaii, January 7-10 (2003). "On the correlation between the 3D structure and the electroanalytical response of host materials for Li and Mg insertion batteries."
- 64) Invited talk at the International Meeting on Polymers for Batteries and Fuel Cells, PBFC-1, June 1-5, Jeju Island, Korea. "Design of novel electrolyte solutions for Li-ion batteries".
- 65) Keynote lecture at the 54th Annual Meeting of the International Electrochemical Society – ISE 2003, San Pedro Brazil, Sept. 1-5, 2003. "On the electrochemical response of active metal (LiMg) insertion electrodes and electronically conducting polymers: New insights and common features".

- 66) The Li battery discussion, LIBD 2003, Arcachon, France, 14-19 Sept. 2003. M. D. Levi and D. Aurbach, "Application of electroanalytical techniques for quantitative studies of self-discharge of graphite anodes at elevated temperatures."
- 67) Invited talk at the 'Advanced Battery Carbon Technology Workshop' sponsored NATO and the DOE-USA, Argonne Nat. Lab, IL, USA, Oct. 19-24, 2003. "The study of graphite electrodes by in situ imaging".
- 68) Invited talk at the International Conference on Electroanalytical Chemistry and Allied Topics, ELAC-2004, Goa, India, 18-23 Jan. 2004, "Understanding the electroanalytical behavior of intercalation reactions red-ox conducting polymers: A challenge in modern electrochemistry".
- 69) Invited talk at the Annual Meeting of the International Battery Association, IBA 2004, Graz, Austria, April 18-22, 2004. "Porous carbon engineering for capacitive energy storage and separation processes".
- 70) An invited lecture at the 12th International Meeting on Li Batteries, 12 IMLB, Nara, Japan, June 27 – July 2, 2004. "New materials and new measurement procedures for Li and Li-ion batteries". 8 posters on various topics.
- 71) Invited talk at the International Conference on Electrochemical Power Systems (ICEPS-2) Hyderabad (India) 20-21 December 2004. "Advances in rechargeable battery research".
- 72) Five oral presentations at the spring ECS meeting, Quebec City, Canada, May 15-20, 2005.
- 73) Keynote lecture at the 3rd Li Batteries Discussion (LIBD), Arcachon, France, May 22-27, 2005: "On the electrochemical response of intercalation electrodes: techniques available, sensitivity, correct response, and significance". 5 posters on various topics.
- 74) Invited talk at the 3rd International Conference on Materials and Advanced Technologies (ICMAT 2005), Singapore, 3-8 July 2005. "Rechargeable batteries: from basic studies to practical systems".
- 75) A talk at a seminar in the Chemistry Department, Monash Univ. Melbourne Australia, 11 July 2005, "On the R&D of Mg batteries, basic science aspects".
- 76) A talk at a seminar of the Chemistry Department, the University of Melbourne Australia. 12, July 2005 "Rechargeable batteries: how practical system development is based on basic electrochemical and materials science studies".
- 77) Invited talk in the IBA-HBC annual meeting, Hawaii, 8-12 Jan. 2006. "On critical cathode-solution interactions".
- 78) Invited talk in the LLIBTA meeting, Baltimore USA, 15-18 May 2006, "Fading mechanisms and life limitations at the anode side of Li-ion batteries".
- 79) An oral presentation at the 13th International meeting on Li batteries, Biarritz France, 18-22 June 2006: "Rechargeable Mg batteries: Status report", and 8 posters on different subjects.
- 80) Invited talk at WEEM 06 (International workshop on the electrochemistry of electro-active materials) St. Petersburg, Russia, 25-30 June 2006. "Understanding electrochemical intercalation reactions: materials, techniques, and applications".
- 81) Two invited talks at the Technological University of Darmstadt, Germany (Inst. of Materials Science), "on the science behind Li-ion batteries" and "On the electro-analytical response of intercalation reactions", 18-19th July 2006.
- 82) Invited talk at MIT, Boston USA, The Institute of Materials Science, 6th Sept. 2006 "Adventures with R7D of new materials for Li and Mg batteries".
- 83) 7 Oral presentations at the ECS (Electrochemical Society) Meeting, Cancun, Mexico, Oct. 2006. Topics: 1- On electrochemical and thermal studies of LiBOB solutions. 2- On the use of ionic liquids for advanced rechargeable Li batteries. 3- Comparison between the

- behavior of micro & Nanomaterials based on layered and spinel $\text{Li}_x[\text{Ni-Mn}]\text{O}_2$ cathode materials for advanced Li-ion batteries. 4- On the electronic conductivity of porous carbon electrodes. 5- On the structural analysis of cathode materials for rechargeable Mg batteries. 6- On the development of new electronically conducting polymers with unique red-ox activity. 7- On the electrochemistry of iron in molten salts at high temperatures.
- 84) Invited talk at the 8th International Symposium on Advances in Electrochemical Science & Technology (ISAEEST-8), Goa, India Nov. 2006. "On the electrochemistry of carbon electrodes".
 - 85) Invited talks at the Institute of General and Inorganic Chemistry, Bulgarian Academy of Sciences, March 12-14th 2007: "New materials and electrolyte solutions for rechargeable Li-ion batteries" and "Major electrode-solution interactions in Li & Li-ion batteries".
 - 86) Invited talk at the 24th International Battery Seminar & Exhibit, Primary & Secondary Batteries, Small Fuel Cells, and Other Technologies", March 19-22nd, 2007, Broward County Convention Center, Fort Lauderdale, Florida: "Electrode-solution interactions in rechargeable Li batteries".
 - 87) Invited talk at the 211th ECS meeting, Chicago, 6-10 May 2007: "Electrochemistry of novel electrode materials for energy storage & conversion".
 - 88) Invited talk at the PBFC 2007 (Polymers for Batteries & Fuel Cells) Meeting, Rome 11-15 June 2007: "Novel electronically conducting polymers".
 - 89) Plenary lecture at the Solid State Ionic (SSI-16) Meeting, Shanghai, China, 1-6 July 2007. "Solid-state ionic of electrochemical intercalation processes, N & P doped electronically conducting polymers: how to interpret the electrochemical response?"
 - 90) Invited talk at the ICE 2007 (International Meeting on Electro-ceramics) Arusha Tanzania, 30th July -3rd Aug. 2007 "Correlation among structure, composition and electrochemical response of Mg and Li insertion materials".
 - 91) Invited talk at the 48th Batteries Symposium in Fukuoka, Japan "Electrodes-solutions interactions in Li-ion batteries: new insights" 13-15th Nov. 2007.
 - 92) Invited talk at the IBA 2007 Meeting, Shenzhen, China, "Nonaqueous magnesium electrochemistry for energy storage & conversion". 18-20th Nov. 2007.
 - 93) Invited talk at the Max Plank Institute Stuttgart, Dec. 3rd, 2007: "On surface chemical aspects of non-aqueous electrochemical systems".
 - 94) Invited talk at the Zing Conference on "Frontiers in Surface Chemistry" Antigua, January 7-10th 2008: "On the surface chemistry of graphite and transition metal oxide electrodes".
 - 95) Invited talk at the Li battery Industry of China, CLTF 2008, Shenzhen China, March 3-5th 2008 "Electrode-solution interactions in Li batteries: the key for good performance".
 - 96) Invited talk in the AABC 08 conference, Tampa FL USA, 12-16 May 2008 "Surface phenomena in super (EDL) capacitor system".
 - 97) 4 invited talks in the ECS meeting, Phoenix AZ USA 18-22 May 2008: "The behavior of graphite electrodes in ionic liquids"; "New rechargeable Mg battery systems"; "On capacity fading phenomena in super (EDL) capacitors"; "On new cathode materials for rechargeable Li-ion batteries".
 - 98) Invited talk in the 14IMLB (International Meeting on Li Batteries 2008), Tianjin, China 22-27 June 2008 "On electrodes-solutions interactions in Li-ion batteries, the key for good performance". In the same meeting, 5 posters were also presented on thermal analysis, magnesium electrochemistry, ionic liquids, super (EDL) capacitors and cathode Nano-materials for Li batteries".

- 99) Talk at PSI, Villigen, Switzerland, 27 Oct. 2008 on "Electrochemistry of porous carbon electrodes for EDLC".
- 100) Talk in EPFL, Lausanne, Switzerland, 28 Oct. 2008 on "The science behind advanced rechargeable batteries".
- 101) Invited talk in "International Workshop on Fundamentals of Li Batteries" organized by MPI Stuttgart, Schloss Ringberg, Tegernsee, Germany, Nov. 23-28, 2009. "on the possible use of ionic liquids in Li-ion and magnesium rechargeable batteries".
- 102) Invited talk in the first annual workshop on electrochemistry: challenges at the electrode/electrolyte interface, the University of Texas at Austin, USA, 7-10 February 2009, "Advances in R&D of rechargeable batteries: Anodes, cathodes, electrolyte solutions".
- 103) Talk at MIT, 11 February 2009: "On the science behind R&D of rechargeable batteries, new insights".
- 104) Invited talk in the Electrochemical Society section of Detroit & Vicinity, 12 February 2009, "On electrochemistry of activated carbon electrodes, EDL (super) capacitors, and separation processes".
- 105) Invited talk in the 26th batteries & 13th recycling seminar, Florida Educational Seminars Inc. Fort Lauderdale FL, USA, 16-20 March 2009, "Advances in R&D of electrolyte solutions for rechargeable batteries".
- 106) Invited talk in the international conference on materials science ICMAT & IUMRS-ICA 2009, Singapore, Symposium: F) Nanostructured Materials for Electrochemical Energy Systems: Lithium Batteries, Supercapacitors and Fuel Cells 28 June- 3 July 2009. "On the Use of Nano-materials and Nano-structures in Rechargeable Batteries and EDL (super) Capacitors"
- 107) Keynote talk in the WEEM 2009 (international workshop on the electrochemistry of electro-active materials), Szczyrk Poland, 14-19 July 2009, Unique transport phenomena related to porous activated carbon electrodes and electronically conducting polymers
- 108) 2 Keynote talks in the ABAF-10, international meeting on power sources, Brno Czech Republic, 30 Aug. – 3 Sept. "Progress in R&D of advanced rechargeable Li-ion batteries" and " On the energy crisis: how to power the world and the contribution of modern electrochemistry".
- 109) A keynote lecture in Ljubljana Slovenia, SLONANO meeting 18-20 October 2009 "On the use of Nanomaterials in rechargeable batteries".
- 110) A keynote lecture in CESEP 09, International meeting on carbonaceous materials, 25-29 October, Malaga Spain " On engineering of carbon electrodes".
- 111) An invited talk in Li-Mobil meeting (organized by Knowledge Foundation USA) Boston MA USA, 12-13 November 2009 " On electrolyte solutions for Li-ion batteries".
- 112) Invited talk in the 50th annual power sources meeting in Japan, 28 November -2 December, Kyoto Japan " On the use of Nano-materials in Li-ion batteries".
- 113) An invited talk in Waseda University, Tokyo Japan, 3 December 2009 " Electrochemistry of carbonaceous materials for energy storage & conversion and for separation processes".
- 114) Invited presentation at a special workshop organized by the British Government on "Battery Technology for a green world", at the London Transport Museum, London, 14-15th January 2010: "On the challenges in R&D of advanced rechargeable batteries for EV applications.
- 115) Plenary talk in the 27th international batteries seminar, Florida Educational Seminars Inc. Fort Lauderdale FL, USA, 15-19 March 2010, " Material Science for advanced Li ion batteries: Electrodes & electrolyte solutions".

- 116) 5 oral presentations in the spring ECS meeting, Vancouver Canada, 30th April – 5th May 2010.
- "Revisiting LiClO₄ as an alternative to LiPF₆ in electrolyte solutions for Li ion batteries".
 - "Application of electrochemical quartz crystal micro-balance (EQCM) to measure adsorption phenomena in micro-porous carbons".
 - "Porous carbon engineering for selective water desalination".
 - "The study of the electrochemical window of ionic liquids by in-situ techniques: Raman & FTIR spectroscopy in conjunction with electrochemical measurements".
 - "On Al current collectors and Li[MnNiCo]O₂ cathodes for Li-ion batteries".
- 117) Invited talk in the symposium on "Next-generation battery materials", Hanse Wissenschaftskolleg, Delmenhorst near Bremen, Germany, 17-19 June 2010: "Electrode-solution interactions in Li batteries: a critical performance determining factor".
- 118) Invited talk in the International Meeting on Li Batteries (IMLB12), Montreal Canada 27 June – 2 July 2010: "Advanced Li-ion batteries: a challenge in R&D of electrolyte solutions".
- 119) Invited talk in the ESF research conference on nanotechnology for sustainable energy, Obergurgl near Innsbruck, Austria, 4-9 July 2010: R&D of rechargeable batteries: a challenge in basic science"
- 120) 4 oral presentations in the fall ECS meeting, Las Vegas 10-15 Oct. 2010.
- "On thermal studies on Li-ion battery materials"
 - "Studies of ionic fluxes in activated carbon electrodes using EQCM".
 - "Electrochemical behavior of Li₂MnO₃*LiMO₂ new cathode materials.
 - "Directions for rechargeable Mg batteries".
- 121) Invited talk in the AVS meeting, Albuquerque USA, 17-21 Oct. 2010: "The use of in-situ electrochemical tools on the way to R&D of rechargeable Li & Mg batteries".
- 122) Invited talk in the "Nano-Israel 2010" conference, Tel Aviv 8&9 Nov. 2010: "The challenges in R&D of novel rechargeable batteries".
- 123) Plenary talk on "Advanced Batteries and Supercapacitors in ISEM 11 CGCRI, Kolkata India, 1 & 2 March 2011.
- 124) An Invited Tutorial Talk "Advanced Materials for Rechargeable Batteries" the 28th international batteries seminar, Florida Educational Seminars Inc. Fort Lauderdale FL, USA, 13-17 March 2011, "Material Science for advanced Li ion batteries: Electrodes & electrolyte solutions".
- 125) Two Invited talks on Rechargeable Batteries and Carbonaceous Materials in the International Conference on Nanoscale Materials and Devices for Energy Storage & Conversion, Storage & Biosensors, Natal Brazil 6-8 April 2011.
- 126) Invited talk on "Water Desalination by Capacitive De-ionization (CDI)" in the International Conference of World Class University of Seoul, Korea, 14 & 15 June 2011.
- 127) Invited talks on "The Science Behind Li-ion Batteries and Related systems" in Giessen Univ. and Technical Univ. Munich Germany, 25 and 27 July 2011.

- 128) Invited talk in the 13th Annual Meeting of China Association for Science & Technology "On the Basic Science Behind R&D of Advanced Rechargeable Batteries", Tianjin China 21-23 September 2011.
- 129) Invited talk on "Advanced materials for high energy density. Li-ion batteries for EV application" in the MRS fall 2011 meeting, special seminar: Materials and Society award forum, Vehicle electrification, Boston, USA.
- 130) Invited talk on "The performance of LiCoPO₄ electrodes and their analytical studies" in ISIPM-7 International symposium on inorganic phosphate materials, 8 – 11 Nov. 2011. Argonne national laboratory, IL USA.
- 131) Invited talk - "A review on frontier challenges in R&D of Li batteries" in ISIPM-7 International symposium on inorganic phosphate materials, 8 – 11 Nov. 2011. Argonne national laboratory, IL USA.
- 132) Invited talk on "Review of materials for advanced EV batteries". International electric mobility conference, Ljubljana, Slovenia. 27, 28 Oct. 2011.
- 133) A Plenary lecture at the 77-annual meeting of the Israel Chemical Society (due to receiving the prize of excellence of the ICS for 2012) on "Rechargeable Batteries: from basic science to practical working systems", Ramat-Gan, Israel, 7 February 2012.
- 134) Invited talk on "Non- aqueous Mg electrochemistry for battery applications". The battery Japan, a technical conference. Tokyo, 28 Feb – 1 March 2012.
- 135) Invited talk on "Advances in Mg batteries, status report." Gordon conference dedicated to advanced batteries. Ventura, California, USA, 4–9 March 2012.
- 136) Invited talk on "Tutorial on Li-ion battery technology." The 29th battery seminar and exhibition, Convention Center, Fort Lauderdale FL USA, 12-16 March 2012. 3 Invited talks on:
 - a. "Electro- adsorption of ion in Nanoporous carbon electrodes,
 - b. studied by quartz crystal micro impedance technique".
 - c. "Enhanced electrochemical performance of Si Nanowires in fluorinated carbonate solutions: a surface chemical investigation".
 - d. "Water desalination by capacitive de ionization: advantages, limitations, and modifications".
- 137) The 221 spring ECS meeting Seattle WA USA. 6-10 May 2012.
- 138) Invited talk on "Electro- adsorption of ion in Nanoporous carbon electrodes, studied by quartz crystal microbalance (EQCM); impedance at the gravimetric response". The workshop on the electrochemistry of electroactive materials, WEEM -2012. Szeged Hodmezovasarhely. 3-8 June 2012.
- 139) Invited talk on "Li Sulfur and Si – Li – Sulfur batteries". In addition, 4 posters were presented on different topics. The international meeting on Li batteries IMLB 2012 in Jeju, Korea. 17-23 June 2012.
- 140) Invited talk on "Water desalination by capacitive deionization (CDI)". The chemistry department Hong Kong University, H.K Island. 15 June 2012.
- 141) Invited talk on "Opinion on challenges in electrolyte solutions for new battery". CEA, Grenoble, France. 9-10 July 2012.
- 142) Invited talk on "Energy challenges that we face today". The first international workshop on Nanomaterials for energy conversion and fuel cells (NMEC – 1). Ho Chi Minh City, Vietnam. 24-23 Aug 2012.
- 143) A full day seminar in electrochemistry for people from American industries, organized by Plugvolt Co. USA, Holiday Inn San Diego CA USA, 4 September 2012.

- 144) Invited talk in Pacific Northwest national laboratory (PNNL), WA USA, "Overview on R&D of advanced battery systems", 6 September 2012.
- 145) 222nd Meeting of the Electrochemical Society Honolulu HI, USA, 7-12 October 2012.
 - a. "Investigation of graphite foils as current collectors for cathodes of Li ion batteries" (paper # 383)
 - b. "Novel electrolytes based on eutectic mixtures of DMMSA with LiFSI and LiTFSI salts: theoretical and experimental studies" (paper # 1227).
- 146) Invited talk on "Advanced Li-ion batteries for EV and load leveling applications: reality vs. dreams". Batteries 2012 Congress. Nice, France. 24-26 October 2012.
- 147) Invited talk in the French Hub (energy consortium) meeting, CEA Grenoble France, 6-7 November 2012 on "From Li to Li-ion, Li-S, Li-air, Mg and Na battery systems, the role of interfaces".
- 148) Invited talk in DGIF 2012, DGIST Global Innovation Festival Daegu Korea, 6 December 2012 on "Beyond Li-ion batteries: Li-sulfur, Li-air, Mg batteries".
- 149) Invited talk in the IBA (International Battery Association) Barcelona Spain 10-15 March 2013 on "What are really the options for developing high energy density rechargeable batteries?".
- 150) Invited talk in the ACS 245th National meeting New Orleans USA, 7-11 April 2013, title: "On the frontier of advanced power sources" (paper # 16773)
- 151) Invited talk in "Workshop on batteries for the future" Como, Italy, 6-7 May 2013 on "Advanced rechargeable batteries".
- 152) Invited talk in the meeting "Beyond Lithium-Ion Batteries". Organized by several USA national laboratories: NREL, ANL, Barkley, Oak Ridge, North Pacific, and IBM. Balder, Colorado USA, 4-6 June 2013 on "Li-sulfur batteries, a review of BIU work".
- 153) Two oral presentations in the ISEECap2013 conference, Taormina, Messina – Italy, 3-7 June 2013. 4 June: The Study of Activated Carbon/CNT/MoO₃ Electrodes for Aqueous Pseudo-Capacitors. S. Okahy, M. Noked, D. Aurbach. 6 June: Introducing Electrochemical Quartz Crystal Admittance for The Characterization of Charging Mechanism in Carbon Electrodes. M.D. Levi, S. Sigalov, G. Salitra, L. Daikhin, D. Aurbach, and a poster: Various CNT/Carbon Composite Electrodes for EDLC. M. Noked, S. Okashy, D. Aurbach.
- 154) Oral presentation and 3 posters in the Li – Battery Discussion (LIBD 2013) Conference, Arcachon France, 16-20 June 2013. Oral presentation: High capacity Li and Mn rich LiMO₂ cathodes for Li ion batteries. Posters on: Li-S cells, Li-O₂ cells, and LiCoPO₄ cathodes.
- 155) Invited talk in the ICMAT 2013 meeting (International Conference on Materials for Advanced Technologies) Singapore 1-6 July 2013 on: "The frontier of advanced Li batteries research".
- 156) Invited talk in the 2nd EuCheMS Inorganic Chemistry Conference, Jerusalem, 11 July 2013 on "Magnesium Electrochemistry for Rechargeable Batteries".
- 157) Invited talk in the research center at General Motors (GM) Warren, MI, USA. 19-20 August 2013 on "Review of frontiers in science for R&D of advanced power sources"
- 158) Invited talk in "The 1st Graz Battery Days" conference, 1 & 2 October 2013, Graz Austria on "The use of in-situ methods for batteries materials characterization".
- 159) Invited talk in Batteries Congress 2013, Nice France, 14-16 October 2013 on "Super Capacitors".
- 160) 8 oral presentations in the 224th ECS meeting, San Francisco, CA, USA 27 Oct.-1 Nov. 2013 on the following topics:

- a. Recent work on super and pseudocapacitors.
 - b. Li-Oxygen systems.
 - c. The use of in situ EQCM measurements of porous carbon electrodes.
 - d. Non-aqueous Mg electrochemistry.
 - e. LiCoPO₄ cathodes.
 - f. Negative electrodes for Li-ion batteries.
 - g. High capacity cathodes for Li-ion batteries.
- 161) Invited course in non-aqueous electrochemistry and batteries at the University of Buenos Aires, Argentina, 11-16 November 2013.
 - 162) Invited lectures on novel power sources, Hanyang University, Seoul, South Korea, 3rd & 4th February 2014.
 - 163) Invited talk on “high capacity cathodes for Li-ion batteries” in the opening ceremony of the BASF new facilities in Amagasaki, Japan, 5th February 2014.
 - 164) The opening plenary lecture in the 16th Israel Materials Engineering Conference (16 IMEC, international), 24th February 2014, Technion Haifa Israel “On challenges of energy storage & conversion technologies that we face today”.
 - 165) The E.B. Yeager Award invited to lecture on “Si anodes for Li-ion batteries”, the annual meeting of the International Batteries Association (IBA), Brisbane Australia 3-7th March 2014.
 - 166) Invited talk: "Tutorial on Advanced Materials for Energy Storage and Conversion" The 31st battery seminar and exhibition, Convention Center, Fort Lauderdale FL USA, 10th March 2014.
 - 167) The 2nd Gordon conference dedicated to advanced batteries. Ventura, California, USA, 11-15 March 2014, served as a discussion moderator.
 - 168) An Electrochemical Society (ECS) supported workshop on electrochemistry and power sources (batteries, super-capacitors, and related basic science aspects), Kodaikanal, India, 12-15th May 2014.
 - 169) “Advanced Materials Science for Energy Storage & Conversion”, a plenary (opening) talk in the 18th international symposium on the reactivity of solids ISRS-18 at “Saint Petersburg Russia, 8th June 2014.
 - 170) Invited talk in the International Meeting on Li Batteries (IMLB 2014), on “The frontier in Li-ion, Li-S and Li-oxygen battery systems”, Como, Italy 9-14th June 2014.
 - 171) A series of invited talks on Li-ion, Li-air, Li-sulfur and magnesium batteries, super-capacitors and the use of surface sensitive analytical tools in electrochemistry, Hanyang University, Seoul, Korea, 18-28th August 2014.
 - 172) Invited talk on “Li-sulfur batteries”, the chemistry department seminar, the University of Texas at Austin, USA, 8th September 2014.
 - 173) A whole day tutorial on basic electrochemistry and electrochemical power sources, Arbin Inc. facilities, College Station, Texas, USA 9th September 2014.
 - 174) Invited seminar on “Li-oxygen & rechargeable Mg batteries, Argonne National Laboratory, USA, 10th September 2014.
 - 175) Invited seminar on “Advanced material science for power sources”, CIDETEC, Sun Sebastian, Spain 3rd November 2014.
 - 176) Invited seminar on “Frontiers in Power Sources development, KIER, Daejeon, Korea, 27th November 2014.
 - 177) Invited seminar on “Materials and electrochemical science for Li-ion batteries” Samsung SDI center in Cheonan, Korea, 3rd December 2014.

- 178) Plenary lecture on “Magic Electrolyte Solutions for Advanced Batteries (Li-ion, Li-S, Li-oxygen, Mg), International Battery Association Conference, Waikoloa Beach, big island, Hawaii, USA, 4-7th January 2015.
- 179) Keynote lecture on “Li-sulfur batteries” in Advanced Automotive Battery Conference (AABC), Mainz, Germany, 26th January 2015.
- 180) Keynote lecture on “Advanced Electrodes Materials for Li and Na ion batteries” in Materials Challenges in Alternative & Renewable Energy 2015 Conference, Jeju, island, Korea, 23-25th February 2015.
- 181) Keynote invited to lecture in the research center of General Motors (GM) Warren, Michigan, USA, 14 April 2015 “Horizons for advanced Li-ion batteries for electromobility”.
- 182) Invited plenary lecture in the workshop on electrochemical electro-active materials (WEEM 2015), Herrenalb, Germany, 1-4 June 2015, “The application of QCM based techniques for electrodes in energy storage & conversion devices”.
- 183) Two invited lectures in Li-Battery Discussion (LIBD), Arcachon, France, 21-25 June 2015: “Li-oxygen battery systems” and “Li&Mn rich cathode materials for advanced Li-ion batteries”.
- 184) Two invited talks in Hanyang University, Seoul, Republic of Korea, 15 July 2015: “New cathode materials for Li-ion batteries”, “Advances in Li-S and Li-O₂ battery systems”.
- 185) Invited talk in KAIST, Daejeon, Republic of Korea, 20 July 2015 “Advanced Materials and Electrochemical Sciences for Energy Storage & Conversion”.
- 186) Two invited talks in Hanyang University, Seoul, Republic of Korea, 21 July 2015: “Non-aqueous sodium electrochemistry”, “Non-aqueous magnesium electrochemistry”.
- 187) Invited talk in Hanyang University, Seoul Republic of Korea, 25 August 2015: “The use of fine electro-analytical tools for the study of intercalation electrodes”.
- 188) Invited talk in Hanyang University, Seoul, Republic of Korea, 2 September 2015: “Power sources for load leveling applications, super, and pseudocapacitors”.
- 189) 4 invited talks in the ECS fall meeting, Phoenix, USA, 11-15 October 2015:
 - a. “The Use of EQCM-D for in-Situ Characterization of Dimensional Changes in Cycled Battery Electrodes”.
 - b. “The Catalytic Behavior of Lithium Nitrate in Li-O₂ Batteries”.
 - c. “Improved Electrochemical Performance of Multi-Phase Layered-Spinel Cathodes for Li-Ion Batteries”.
 - d. “Constraints of the Shuttle Mechanism in Li-S Batteries”.
- 190) Invited plenary talk in the Frumkin Symposium, Moscow, Russia, 21 October 15: “The challenge of high energy density batteries: Where we can go beyond Li ion battery technology?”.
- 191) Invited talk in Waseda University, Tokyo, Japan, 28 October 2015: “Li-sulfur and Li-oxygen battery systems, BIU perspective”.
- 192) Invited plenary talk in the 3rd Dresden Conference on Energy in Future -Materials for Energy, Dresden, Germany, 11 November 2015: Overview on post-Li-ion batteries”.
- 193) Invited talk in the workshop on “Next Generation Energy Storage Technologies: Challenges and Opportunities” 2-3 December 2015, Taormina, Italy: “A review on advanced next-generation electrochemical technologies for energy storage & conversion”.

- 194) Invited talk in Hanyang University, Republic of Korea, 15 December 2015: A tutorial on the application of electrochemical quartz micro and Nano balance techniques for the study of transport phenomena around porous electrodes.
- 195) An invited talk in a Gordon Conference, Ventura CA USA, 21-26 February 2016, "a comprehensive presentation on advance batteries science".
- 196) Invited plenary talk in IBA 2016, Nantes, France, 21-23 March 2015 "on the use of advanced QCM based techniques for the study of composite electrodes in energy storage devices.
- 197) Israel-Germany electrochemistry school on power sources, Munich, Germany 3-6 April 2016. "Description of Li-oxygen battery systems".
- 198) An inviting talk 1-5 May 2016, EMN international conference on advanced materials, Dubrovnik, Croatia "on the use of Nanomaterials in energy storage devices".
- 199) 3 invited talks in the ECS meeting, San Diego, USA, 29 May – 5 June 2016:
 - a. Review on "beyond Li-ion batteries"
 - b. New cathode materials for Li-ion batteries.
 - c. New electrodes for super-capacitors.
- 200) Plenary lecture in the International Meeting on Li batteries, IMLB 2016, Chicago, USA, "On the forefront of advanced batteries", 8 posters on Li-S, Li-oxygen, Na ion batteries, computational work on cathodes design and new cathodes for Li-ion batteries, active separators that trap transition metal ions in Li batteries.
- 201) 2 invited talks in Beihang University, Beijing, China 24-26 July 2016.
 - a. Review on water desalination by capacitive de-ionization.
 - b. Review of advanced batteries: materials science.
- 202) A series of invited talks in Hanyang University, Seoul, S. Korea, 1-12 August 2016.
 - a. Tutorial on non-aqueous electrochemistry.
 - b. Electrochemical impedance spectroscopy (EIS) fundamental aspects and applications.
 - c. A review of progress at BIU in R&D of advanced materials for power sources.
- 203) Invited lecture, Israel-UK workshop in London, sponsored by the two academies of science of Israel and UK, 20 September 2016: advanced Materials Science for Energy Storage & Conversion.
- 204) Invited lectures, Workshop on Energy, 2 November 2016, San-Salvador, Jujuy Argentina.
 - a. The horizon of advanced batteries, from basic science to practical systems.
 - b. Tutorial on non-aqueous electrochemistry.
- 205) Invited lectures, Hanyang University, Seoul, S. Korea 17th January 2017
 - a. Active separators in advance Liion batteries.
 - b. The renaissance of Li metal anodes for rechargeable batteries.
- 206) Invited key-note lecture in the annual meeting of the International Battery Association, IBA, Nara Japan, 5-9 March 2017: Effective Silicon Anodes and Sulfur Cathodes for Advanced High Energy Density Batteries.
- 207) Invited key-note lecture in the topical meeting of the International Society of Electrochemistry, ISE, Buenos Aires, Argentina, 20-23 March 2017: Adventures with Li-Oxygen Batteries.

- 208) Invited lectures in ITRI and National University of Taiwan (NTU), 1-4 May 2017.
 Topics: Scope of advanced Li Ion Batteries; Li-oxygen and Li-sulfur batteries.
- 209) Keynote invited lecture (Alan J. Bard Award lecture) in the Electrochemical Society (ECS) meeting, New Orleans, USA, 29 May 2017. Topic: "Inspired by A.J. Bard: Electroanalytical Techniques Coupled with In-Situ Structural Characterization of Electrodes in Devices for Energy Storage and Conversion".
- 210) 6 Posters on batteries and supercapacitors and an invited short talk on Li & Mn rich NCM cathode materials, Li Battery Discussion (LIBD), Arcachon, France, 11-16 June 2017.
- 211) Keynote invited lecture in the 21st Solid State Ionics (SSI) meeting, Padua, Italy, 19-23 June 2017. Topic: "The true horizon for advanced rechargeable batteries - areas where only good basic science can lead to practical success".
- 212) Invited lecture in Paris, the annual meeting of the Energy Network of France RS2E, "on electrolyte solutions for non-aqueous batteries", 15-17 October 2017.
- 213) Keynote talk in the ABAA-10 (Advanced Li-ion batteries meeting for Automotive Applications) meeting, Chicago USA, "Non-aqueous oxygen electrochemistry", 22-25 October 2017.
- 214) Plenary lecture in the first international conference on Energy storage materials (ICEnSM) 2017, Shenzhen China "Horizons for advanced rechargeable batteries, Li ion systems and beyond them", 19-21 November 2017.
- 215) Invited talk in the research center of Apple, Palo-Alto CA, the USA on the "Frontier in Batteries Research", 2 February 2018.
- 216) Invited talk at the University of California at Berkeley, USA, on "Advanced Material Research for Power Sources.
- 217) Invited talk in the University of Buenos Aires for a ceremony of receiving Honorary Doctor recognition from this university, 21 March 2018.
- 218) 4 invited talks in the Spring ECS meeting, Seattle WA USA on the following topics: Functional Separators for Li-Ion Batteries; True horizons for advanced Li-ion batteries - Ni-rich and Li + Mn-rich NCM cathode materials; Non-Aqueous Mg Electrochemistry; Fluoroethylene Carbonate-Based Electrolyte Solutions for Very Stable and reversible Lithium Metal anodes at High Rates and High Areal Capacity in rechargeable Li Batteries 13 - 17 May 2018.
- 219) Keynote lecture in the IMLB (International Meeting of Li Batteries), Kyoto Japan on "Advanced Batteries Science, New Insights", 16 - 21 June 2018.
- 220) Invited talk at the University of Muenster, Germany on "Frontiers in the Science related to Development of Power Sources" July 2018.
- 221) Invited talk in a Gordon Conference on Ionic Liquids, Newry, Maine USA, 12-18 August 2018. The topic: "The Use of Ionic Liquids in Power Sources".
- 222) Plenary Lecture that opened the annual meeting of the International Society of Electrochemistry (ISE) in Bologna, Italy for my receiving the A. Frumkin Medal of the ISE. The topic: Frontiers in Electro-Analytical Chemistry. 2 September 2018.
- 223) Invited talk in Hong Kong Poly-Technic University on "Li-oxygen and Li-Sulfur Batteries", 12 October 2018.
- 224) Invited talk in the AABA meeting, Huzhou, China on "Reality and Illusions in the Field of Advanced Batteries" 14 October 2018.
- 225) Invited talk in Israel-Italy workshop on Advanced Materials Science, on "Advanced Materials Science Related to Development of Power Sources" Katana, Sicily, Italy, 16 October 2018.

- 226) Plenary talk in the "Smart Mobility Summit" Tel-Aviv, Israel on as a recipient of the prestigious Samson Prime Minister Prize for Innovation in Alternative Fuels for Transportation 30 October 2018.
- 227) A series of lectures in Non-Aqueous Electrochemistry, Supercapacitors, Electrochemical Water Desalination and Capacitive De-Ionization in the university of Beihang, Beijing, China November and December 2018.
- 228) Invited lecture in the Chinese Academy of Science on "The Frontier of Rechargeable Batteries Development", Beijing, China December 2018.
- 229) Plenary talk "On the Frontier of the Science Behind Development of High Energy Density Power Sources" in the Research Center of Nichia Company Ltd, Nichia Headquarters, Tokushima, Shikoku, Japan, 8 & 9 January 2019.
- 230) Invited talk in the International Winter School on 2D materials, Weizmann Institute of Science, Israel, on "The Use of 2D Materials for Electrochemical Energy Storage and Water Desalination Processes", 14 – 16 January 2019.
- 231) Plenary lecture on "Very High Energy Rechargeable Batteries for Propulsion" in the 8th Conference on Propulsion Technologies for Unmanned Aerial Vehicles, Faculty of Mechanical Engineering Technion, Israel, 31 January 2019.
- 232) Invited lecture in Hanyang University, Seoul S. Korea on "Power Sources based on Capacitive Interactions – a Field Review", 13 February 2019.
- 233) Keynote lecture in the IBA meeting San-Diego CA, USA, on "Advances in Non-Aqueous Magnesium Electrochemistry" 3 – 7 March 2019.
- 234) The Israel-Germany binational School for electrochemical power sources (GIBS 4), Berlin, Germany 12 – 15 May 2019, presenting work on Mg-S batteries, lecturing on the challenge of fast charging.
- 235) Invited keynote lecture on "The Use of Novel EQCM-D Techniques for the Operando Analysis of Composite Electrodes", WEEM 2019 (workshop on the electrochemistry of electroactive materials), Borovets Resort Bulgaria, 16 – 21 June 2019.
- 236) Invited keynote lecture in the 70th annual meeting of the International Society of Electrochemistry (ISE) on "The Challenge of Large Energy Storage", Durban, South Africa 4 – 9 August 2019.
- 237) A series of lectures on electrochemical water treatment and electrochemical power sources, Beihang university, Beijing, China, December 2019.
- 238) A lecture in a series of Webinars on electrochemical power sources organized by Stanford university USA (thousands of participants throughout the world), provided on-line in June 2020 on "Basic Science behind Development of High Energy Density Rechargeable Batteries.
- 239) A plenary lecture (online) in the IBA 2020 meeting, Ljubljana Slovenia, November 2020 on "Application of EQCM-D technics for studying transport phenomena in composite electrodes for energy storage devices".
- 240) A key-note lecture in the IBA 2021 meeting Xiamen, China, October 2021 "About the Renaissance of Li Metal Anodes for Rechargeable High Energy Density Batteries, Through Selection and Manipulation of Suitable Electrolyte Solutions".
- 241) On line presentations for universities in Hong-Kong and S. Korea on the frontier of high energy batteries research, March and June 2022.
- 242) A key-note lecture in the IMLB 2022, Sydney Australia, June 2022 on "High Energy Density Li Batteries for Electromobility).
- 243) A Key-note lecture in a binational meeting in Manchester UK on Nano-Technology and Energy Matters, arranged the Israeli National Academy of Science and the Royal UK Academy of Science, 20 September 2022, on "Rechargeable batteries for

electro-mobility, challenges and reality. With an emphasis on high energy density for special needs (drones, unmanned vehicles).

- 244) A key-note lecture in IBA 2022, Bled Slovenia (on-line) , 6 October 2022 on "Resolving Complex Mechanistic Questions Related to Rechargeable Aqueous Batteries, Using Analysis by EQCM -D".
- 245) A Key note lecture in the 13th AABA annual meeting, Marrakesh Morocco, 19th October 2022 on: "The Challenges of Large Energy storage for the Use of Renewable Energy Resources".