

**IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION**

RJ TECHNOLOGY LLC,

Plaintiff,

v.

SAMSUNG ELECTRONICS CO., LTD. and
SAMSUNG ELECTRONICS AMERICA, INC.,

Defendants.

Civil Action No. 2:22-cv-00401-JRG-RSP

JURY TRIAL DEMANDED

**DECLARATION OF THOMAS F. FULLER, PH.D.
IN SUPPORT OF SAMSUNG'S PROPOSED CLAIM CONSTRUCTIONS**

Table of Contents

I.	Introduction.....	1
II.	Summary of Opinions.....	1
III.	Personal Background	3
IV.	Overview of Materials Considered	5
V.	Legal Principles	5
VI.	Level of Ordinary Skill in the Art.....	7
VII.	Background on Lithium-Ion Battery Technology.....	9
	A. Background on Lithium-Ion Batteries	9
	B. Background on Capacity Balancing for Lithium-Ion Batteries	12
	C. Background on Cycling Lithium-Ion Batteries.....	18
VIII.	The '641 Patent.....	19
IX.	File History of the '641 Patent.....	29
X.	The Claim Terms In Dispute.....	34
	A. “Ratio of positive electrode material to negative electrode material . . . is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2V” (Claims 5-14)	34
	a. The Scope of the Phrase “Calculated by a Theoretic Capacity with a Charge Cut-Off Voltage Set as 4.2V” is Undefined in Scope and Indefinite	34
	b. The Claims Are Indefinite Even Under RJ Tech’s Construction.	38
	i. Capacity Must Be Determined Over A Voltage Range And Providing Only The Upper Limit (e.g., 4.2 V) Does Not Tell a POSITA What Lower Value Is For The Capacity Determination.	44
	ii. Determination of Capacity Requires Knowledge Of the Discharge Rate, And Merely Telling the POSITA To Use Parameters “Commonly Used In the Art” Is Insufficient Because There Was Variability in Charge and Discharge Rates.....	50
	iii. Determination of Capacity Requires Knowledge Of The Charging Protocol, And Merely Telling the POSITA To Use Parameters “Commonly Used In the Art” Is Insufficient Because There Was Variability In Charging Protocols.....	54
	iv. Simply Identifying a Charge Cut-Off Voltage At Which To Determine Electrode Capacity is Insufficient to Provide a Clear Scope for the Capacity Ratio Limitation; Additional Considerations	56

B.	“Maintains at least []% of capacity after 400 cycles” (Claims 11-14)	60
a.	When The Initial Discharge Capacity Is Measured Is Material To Evaluating The Percentage of Remaining Capacity After 400 Cycles.....	60
b.	Details Of The Charging And Discharging Protocols As Well As Environmental Conditions, Including Temperature, Are Material To Evaluating The Percentage of Remaining Capacity After 400 Cycles.	62
i.	Temperature is Material to Capacity Retention.....	65
ii.	Charge/Discharge Rates.....	68
iii.	Charging and Discharging Protocol, Including Depth of Discharge and Rest in Between Cycles.....	71
XI.	Additional Statements	73

I. INTRODUCTION

1. I, Thomas F. Fuller, Ph.D. have been retained by Greenberg Traurig, LLP on behalf of Defendants Samsung Electronics America, Inc. and Samsung Electronics Co., Ltd. (collectively, “Samsung”) as a technical expert in this matter. I understand that Plaintiff RJ Technology LLC (“RJ Tech” or “Plaintiff”) has accused Samsung of infringing claims 5-14 of U.S. Patent No. 7,749,641 (the “’641 patent”).
2. I have been asked to explain certain aspects of the ’641 patent and to provide a technical background into some aspects of lithium-ion batteries. Specifically, I have been asked to consider and render opinions on certain phrases used in the claims of the ’641 patent. The opinions expressed in this Declaration are my own. Unless otherwise stated, I have personal knowledge of the facts stated in this Declaration. This Declaration is subject to amendment and/or supplementation on the basis of information that may be made available to me in the future. I reserve the right to submit additional materials related to my opinions about the constructions of the claim terms at issue in this case, including without limitation, a declaration in support of any subsequent claim construction brief filed by Samsung and/or a declaration responding to any expert testimony submitted by Plaintiff. I also reserve the right to submit additional expert reports in this matter in accordance with the case schedule.

II. SUMMARY OF OPINIONS

3. By providing this summary of opinions I in no way intend to limit the complete opinions or bases for those opinions as set forth in this declaration.
4. It is my opinion that a person having ordinary skill in the art (“POSITA”) as of September 28, 2001 would have had a master’s degree in material science, chemical engineering, chemistry, or similar field with four years of experience designing, testing, and building secondary lithium batteries. This person would have been familiar with various ways to characterize the capacity of electrodes used in secondary lithium-ion cells or batteries and the variables that must be set to make such a characterization.
5. Based on my analysis of the ’641 patent and the prosecution history of the ’641 patent, the phrase “a ratio of positive to negative electrode material of the secondary lithium-ion cell or battery is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off

voltage set at 4.2 V” is indefinite because a POSITA would not have been informed of the claim scope with reasonable certainty by the specification or prosecution history of the ’641 patent. There are several reasons for my conclusion.

- First, the specification and prosecution history fail to convey to the POSITA what it means to calculate the claimed ratio of materials “by a theoretic capacity with a charge cut-off voltage set at 4.2 V,” because the concept of a theoretic capacity, which is calculated using stoichiometry of the material is not based on voltage and the patent and prosecution history use the phrases “theoretic capacity” and “specific capacity” inconsistently.
- Second, there is no source in the literature that a POSITA could consult to get a value for capacity at a specific voltage range for a specific material that is universally applicable to all electrodes made of that material (for instance, different preparations of LiCoO₂ published in the literature have different capacities). This is confirmed in the literature.
- Third, even if a “capacity” of the active electrode materials is all that is needed to determine the claimed ratio, a hypothetical electrode made of a specific lithium-containing electrode material, prepared the exact same way, in the exact same amount (e.g., mass), can have different capacity depending on various parameters that are not specified in the ’641 patent, but are commonly used by those skilled in the art when providing capacity information about electrode materials. These include:
 - not only the upper voltage (e.g., the “cut-off voltage”) but also the lower voltage limit;
 - the charge and discharge rate; and
 - the charging protocol.
- Fourth, the concept of the capacity of the negative electrode “as calculated . . . with a charge cutoff voltage set at 4.2 V” is nonsensical because a cut-off voltage of 4.2 V has no meaning when it comes to negative electrode materials that typically have maximum voltages of, at times, considerably less than 1 V (depending on the material used).

- Fifth, the '641 patent and its prosecution history fail to indicate what the reference value is for determining the capacity using a charge cut-off voltage of 4.2 V, and known reference materials lead to significant changes in resulting capacities depending on the reference material selected for determining capacity.
6. Additionally, the phrase “where the secondary lithium ion cell or battery maintains at least [X]% of capacity after 400 cycles” is indefinite because the '641 patent fails to specify essential details needed to ascertain the capacity drop over 400 cycles including: 1) when the initial discharge capacity is measured; and 2) details of the charging and discharging protocols as well as environmental conditions, including temperature.

III. PERSONAL BACKGROUND

7. I received a Bachelor of Science degree in Chemical Engineering from the University of Utah in 1982. I thereafter received a Doctor of Philosophy degree in Chemical Engineering from the University of California at Berkeley. I am a professor in the School of Chemical & Biomolecular Engineering at the Georgia Institute of Technology, where I conduct research in batteries and fuel cells, as well as teach graduate and undergraduate courses in thermodynamics, transport, process control, and electrochemical engineering.
8. From 1981-2001, I served in the United States Navy, and I retired with the rank of Commander. I served six years of active duty and have 14 years of reserve experience for supervising the operation, maintenance, and repair of a reactor plant aboard a nuclear-powered submarine. More specifically, I was responsible for the propulsion systems as well as chemical and radiological controls.
9. From 1987-1997, I was engaged in several assignments in the Naval Reserve on the East and West Coasts. From 1998-2001, I was one of four Officers in Charge for Fleet Support Teams for SPAWAR (Space and Naval Warfare Systems Commands). I coordinated reserve support activities for the Roosevelt Battle Group, and I was awarded a Navy Commendation in 2001 for my leadership role in developing the Fleet support organization.
10. During my postdoctoral fellowship in 1992-1993, I worked for the Lawrence Berkeley National Laboratory, which is a multi-program lab where research in advanced materials, life sciences, energy efficiency, detectors, and accelerators serves the country's various needs in technology and environment. I developed thin film lithium/polymer solid-state

batteries for U.S. Advanced Battery Consortium. This required mathematical modeling of polymer electrolytes and the design and scale-up of polymer batteries.

11. From 1994-2004, I worked for UTC Fuel Cells, a division of United Technologies Corp. UTC Fuel Cells designed, manufactured, and serviced fuel cells for space, transportation, and stationary applications. From 1994-1997, I was a Senior Engineer in Advanced Technology and the Principal Investigator of Independent Research & Development (IR&D), the Department of Energy (DOE), and Defense Advanced Research Projects Agency (DARPA) sponsored fuel cell programs. As part of these programs, I authored more than 25 publications and am an inventor for six issued patents in proton-exchange membrane (PEM) fuel cell, direct methanol fuel cell (DMFC), and phosphoric acid fuel cell (PAFC) technologies. I was responsible for managing joint research programs with major universities and small businesses, and I conducted mathematical modeling of advanced reformers and fuel-cell stacks, including thermal balance, current distributions, and electrolyte transport.
12. From 1998-2002, I was the Manager of Power Section Development, leading Integrated Product Development (IPD) teams for cell stacks. I developed strategies and led initiatives to reduce costs and increase the reliability of cell stacks, including with regard to power density. From 2001-2004, I was the Director of Power Section Development. I led the effort to transfer technology to automotive OEMs, and I was a key member of the Patent Committee.
13. I have been the recipient of numerous awards, including being named a Fellow of the American Institute of Chemical Engineers in 2018, receiving the AIChE Outstanding Faculty Award in 2012, being named Fellow of the Electrochemical Society in 2009, receiving the Research Award of the Energy Technology Division from the Electrochemical Society in 2008, and being named Fellow of Georgia Tech Research Institute in 2006.
14. I have authored or co-authored a number of published works, including *Electrochemical Engineering*, Wiley, 2018 ISBN 978-1119004257 and a series of five papers on modeling of lithium-ion batteries, which has received more than 7,400 citations. The lithium-ion battery model described in this series of papers has been widely adopted and is now the

industry standard. I have authored more than 150 publications and patents (see curriculum vitae, a copy of which is provided as Exhibit A). These publications have been cited more than 19,429 (Google Scholar, November 3, 2023).

15. I am also a named inventor on 11 issued patents, as well as one patent application.
16. I have been a member of the Electrochemical Society, the leading society for solid-state and electrochemical science and technology, since 1989. Over the last 30 years, I have held a number of leadership positions within the Electrochemical Society. Most recently, I served as an Associate Editor for the Journal of the Electrochemical Society from July 2009-2011, and I have served as the Technical Editor for the Journal of the Electrochemical Society and ECS Electrochemistry Letters, specifically with regard to fuel cells, electrolyzers, and energy conversion from 2012 to 2019.
17. I am also a member and Fellow of the American Institute of Chemical Engineers. AIChE is the world's leading organization for chemical engineering professionals.
18. In summary, I have over 35 years of experience related to the field of batteries, including lithium/polymer solid-state battery design. A detailed description of my professional qualifications, including a listing of my specialties/expertise and professional activities, is contained in my curriculum vitae, a copy of which is attached as Exhibit A. My curriculum vitae also includes a list of publications that I have authored or co-authored.
19. I am being compensated at a rate of \$400 per hour for my time spent working on this case. My compensation is not affected by the outcome of this case.

IV. OVERVIEW OF MATERIALS CONSIDERED

20. In reaching the opinions expressed in this Declaration, I have reviewed and considered the materials cited in this Declaration, including the '641 patent and its file history.

V. LEGAL PRINCIPLES

21. In formulating my opinions, I have been instructed to apply certain legal standards. I am not a lawyer. I do not expect to offer any testimony regarding what the law is. Instead, the following paragraphs summarize the law as I have been instructed to apply it in formulating and rendering my opinions found later in this declaration.

22. I understand that in assessing how a POSITA would understand a claim term, one must consider the claim language, the patent's specification, and the patent's prosecution history,¹ which are collectively called the "intrinsic evidence."
23. I understand that, based on the intrinsic evidence (i.e., the claim language, specification, and file history of the patent), one should try to come to a conclusion about how a POSITA would understand the term in the context of the patent as of the effective filing date, i.e., priority date, of the patent application. I also understand that the context provided by the intrinsic evidence is very important, and that considering how a POSITA would understand a term outside of that context is improper.
24. I understand that in assessing how a POSITA would understand a claim term, it is permissible, and sometimes helpful, to consult other evidence that is not part of the "intrinsic evidence," such as expert and inventor testimony, dictionary definitions and technical treatises. I understand that this type of evidence is called "extrinsic evidence." However, I understand that this should be done only when the meaning is unclear from the intrinsic evidence.
25. I understand that the plain and ordinary meaning of a claim term is the meaning that the term would have to a POSITA as of the effective filing date, i.e., priority date, of the patent application.
26. I understand that a patent applicant may serve as his or her own lexicographer. In doing so, the applicant may rebut the presumption that the plain and ordinary meaning applies to claim terms if the applicant explicitly provides his or her own unique definition separate and apart from the plain and ordinary meaning. If the applicant explicitly defines a claim term, the applicant's definition will be controlling for that term. I also understand that, when a patent applicant chooses to act as his or her own lexicographer, the use of that claim term in the larger context of the specification may further inform the meaning of the term.
27. I understand that a patent claim is invalid as indefinite if the claim does not particularly point out and distinctly claim the subject matter that the applicant regards as his invention. I have been informed that a patent claim is indefinite if the claim, read in light of the

¹ I understand that the "prosecution history" of a patent is also called the "file history."

specification delineating the patent and the prosecution history, fails to inform with reasonable certainty those of ordinary skill in the art about the scope of the invention.

28. I understand that invalidity for indefiniteness (failure to meet the definiteness requirement) must be shown by clear and convincing evidence.

VI. LEVEL OF ORDINARY SKILL IN THE ART

29. I understand that, to determine the appropriate level of skill of a POSITA, the following four factors may be considered: (a) the types of problems encountered by those working in the field and prior art solutions thereto; (b) the sophistication of the technology in question, and the speed with which innovations occur in the field; (c) the educational level of active workers in the field; and (d) the educational level of the inventor. I have been instructed that the level of ordinary skill in the art should be determined at the time of the invention. I have been asked to presume that the relevant date for my evaluation is September 28, 2001.
30. The field of the '641 patent relates to "secondary" lithium-ion cells or batteries. ('641 patent, 1:8-15). Based on my review and analysis of the '641 patent and applying the considerations identified above as best they are known to me today, a POSITA in the field of the '641 patent as of September 28, 2001 would have had a master's degree in material science, chemical engineering, chemistry, or similar field with four years of experience designing, testing, and building secondary lithium batteries.
31. The POSITA would have had certain knowledge about the state of the art of lithium-ion batteries. For example, the '641 patent describes certain background about the field of lithium-ion batteries, including the development of a commercial cell by Sony in the early 1990s. (*See, e.g.*, '641 patent at 1:6-2:67 (describing that the "Technical Field" and providing "Background Art," including Sony lithium-ion batteries). Those of ordinary skill were also aware of components used in batteries such as positive and negative electrodes, electrolytes, and separators, among other things. ('641 patent at 8:4-9:23 (indicating that "components in the positive electrode active material can be those well known in the art," "[t]he separator used in the present invention is a separator well known in the art," "[t]he mesophase asphalt based carbon fiber or mesophase asphalt based spherical carbon [for the negative electrode] can be obtained according to the conventional method," "non-aqueous

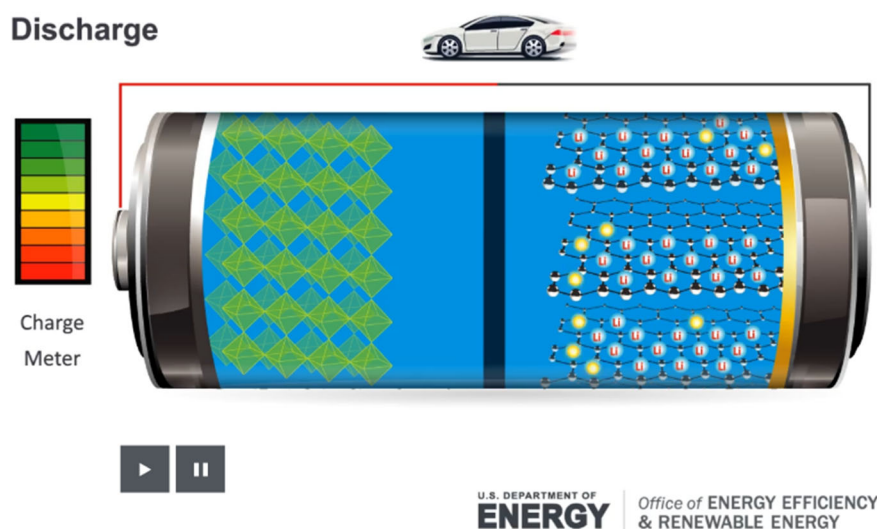
electrolytes . . . well known in the art can be used,” and “the structure of cell is not limited to a certain shape.”).

32. As I explain in further detail below, a POSITA would have also been knowledgeable about charge-discharge testing, capacity balancing, protection circuits, and battery failure modes, such as plating and the formation of dendrites. A POSITA would have been aware that the capacity of an electrode material and battery, i.e., the amount of lithium ions that can be extracted, is dependent on numerous factors, including at least, the upper and lower potential limits applied; the charge and discharge rates applied; temperature; manufacturing information such as particular size, current collectors, electrolyte, and synthesis process; the charging and discharging protocol used; the size and shape of the electrodes. A POSITA would have also been aware that the capacity retention of a battery over repeated cycling is dependent on numerous factors, including at least, the formation of a solid electrolyte interface layer; temperature; charge and discharge rates; the charging and discharging protocol, including depth of discharge, and rest time between cycles.
33. It is my opinion that a POSITA would have had a master’s degree in material science, chemical engineering, chemistry, or similar field with four years of experience designing, testing, and building secondary lithium batteries. In reaching this opinion, I have relied upon my education, experience, and interactions with others in the field of the ’641 patent including in academic and research environments, as well as the literature and other materials cited herein. Further based on my experience and the materials I discuss in this declaration, a person with less relevant practical experience but with additional education can also qualify as a POSITA in the field of the ’641 patent provided the additional education focused on lithium batteries. When I refer to the understanding of a POSITA, I am referring to the understanding of such a person as of September 28, 2001.
34. As of September 28, 2001, I had more than ordinary skill in the art. I am, however, familiar with the skills and knowledge possessed by those I would have considered to be of ordinary skill in the art as of that date.

VII. BACKGROUND ON LITHIUM-ION BATTERY TECHNOLOGY

A. Background on Lithium-Ion Batteries

35. A lithium-ion battery is generally made up of a negative electrode (anode, shown below on the right), a separator (the black bar in the center), a positive electrode (cathode, shown as a green matrix of material on the left), an electrolyte (blue), and two current collectors (positive and negative at the left and right ends of the battery). These elements are shown below:



(See <https://www.energy.gov/energysaver/articles/how-lithium-ion-batteries-work>).

36. The active material for the electrodes is a “host” material that can store lithium. Lithium is found in unoccupied sites of the host material as illustrated below. When the host material has a layered structure, the insertion is called “intercalation.” In the case of intercalation, the host material retains its essential crystalline structure, and the process can be highly reversible. This process is illustrated by the intercalation of lithium into titanium disulfide and into graphite as illustrated below (top figure where the black dots represent lithium) and in graphite (bottom figure where the green dots represent lithium).

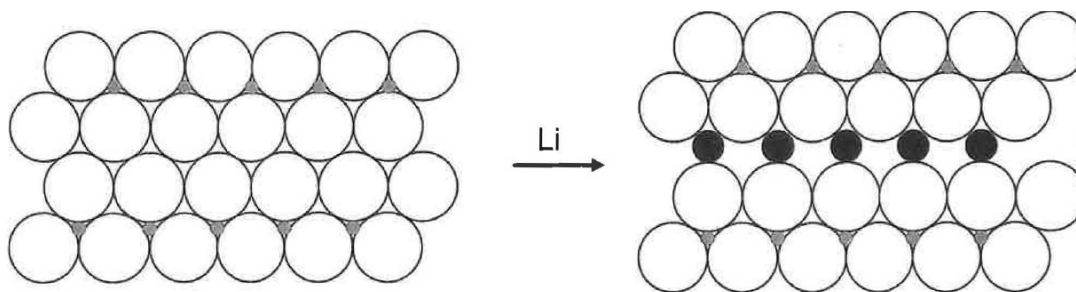


Figure 7.3 Insertion of lithium (solid black circles) into the gallery space of titanium disulfide.

2

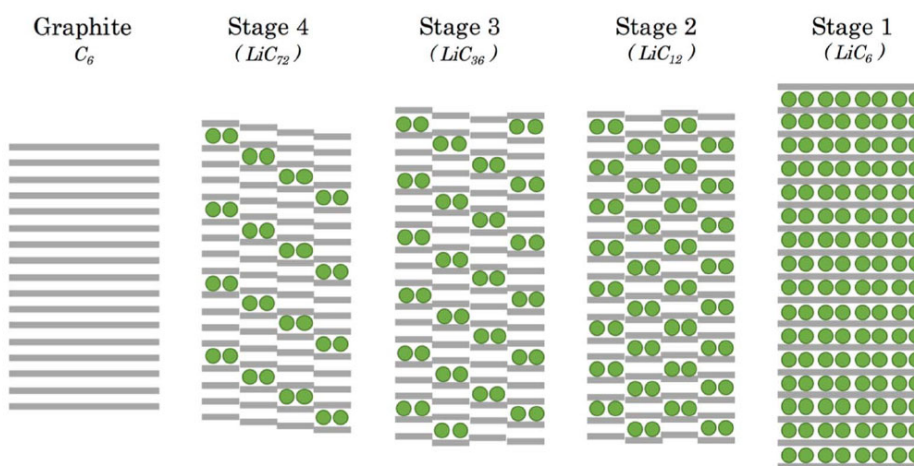


Figure 1. Classical representation of Li insertion stages into graphite and based on the Daumas-Hérol model.⁹

3

37. The amount of lithium contained in the host material can be quantified with a formula such as Li_xCoO_2 for cobalt oxide. During charging the value of x decreases as more and more lithium is removed. x is related to the state of charge (SOC) of the battery.
38. When the cell or battery is being discharged, lithium atoms move from the negative electrode (the anode on discharge) across the separator through the electrolyte and then to positive electrode (the cathode on discharge). See <https://www.energy.gov/energysaver/articles/how-lithium-ion-batteries-work>). A cell is the basic electrochemical device that stores energy.

² Harb and Fuller, *Electrochemical Engineering*, Wiley 2018 (“Harb and Fuller”), at 156.

³ Allart et al., *J. Electrochem. Soc.*, 165, A380 (2018) (“Allart 2018”).

39. When the cell or battery is being charged, the flow is reversed: lithium ions move from the positive electrode to the negative electrode through the electrolyte. Thus, during charging and discharging lithium ions are shuttled between electrodes. (*See id.*).
40. Lithium-ion batteries can vary greatly in size and in application. In order to normalize the rate of charge or discharge a “C-rate” is used. The C-rate is a multiple of the rated capacity. A rate of 1C draws a current that is equal to the magnitude of the capacity of the battery in Ah. At a rate of 1C the battery could supply power for an hour. At a rate of 10C, the battery would be limited to about 6 minutes. At a rate of C/5, the battery could supply power for 5 hours. A wide range of C-rates are commonly used for charging and discharging lithium-ion batteries.
41. The potential of the cell, commonly called voltage, is the difference in potential between the positive and negative electrodes. Only potential differences are measurable. As the cell is discharged, the potential of the positive electrode decreases (e.g., $\text{Li}_x\text{Mn}_2\text{O}_4$ in the figure below), and the potential of the negative electrode increases (e.g., $\text{Li}_{1-x}\text{C}_6$ in the figure below).

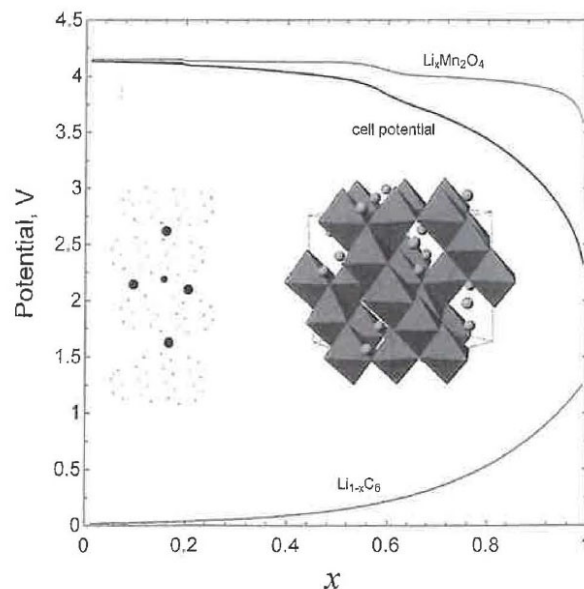


Figure 7.6 Potential versus the fraction discharged for a lithium-ion cell. Also shown are the structural aspects of the negative electrode (a) and positive electrode (b).

4

⁴ Harb and Fuller at 159.

42. The equilibrium potential of each electrode, which is usually reported relative to a lithium reference electrode, can be expressed in terms of the amount of lithium contained in the host material. For a negative electrode material, such as graphite, the potential decreases as the amount of lithium held increases. For positive electrode materials, the effect is reversed—as the potential increases the amount of lithium held by the host, CoO_2 for instance, decreases.
43. To prevent permanent damage to a cell, e.g., structural changes in the materials or decomposition of electrolyte, the upper and lower potential of the cell is limited on charging and discharging. These limits are referred to as an upper and lower cutoff potential.
44. The capacity of the cell or battery refers to the amount of lithium that can be reversibly shuttled between the two electrodes (i.e., the amount of lithium that is inserted into and de-inserted from the host material). This capacity is usually expressed in ampere-hours (Ah). Ah is another means of representing electrical charge.

B. Background on Capacity Balancing for Lithium-Ion Batteries

45. Part of designing a commercial cell requires setting a capacity balance ratio between the capacity of negative electrode material to the capacity of the positive electrode, commonly called a N/P ratio. Throughout this document the N/P ratio is used, and it is appropriate to connect this to the language of the '641 patent. The patent (claim 5, for example) states "...ratio of positive electrode material to negative electrode material of the secondary lithium ion cell or battery is from 1:1.0 to 1:2.5." The quotient N/P, which is further described in paragraph 49, represents the number to the right of the colon found in the patent. A N/P ratio of 1 to 1.5 is commonly used as a balanced ratio of anode/cathode capacity (i.e., 1/1) is typically desired, but due to safety and efficacy concerns, cells are typically designed with additional capacity in the anode compared to the cathode to address the possibility that the cell becomes overcharged. *See, e.g.*, U.S. Patent Application Publication No. US 2002/0012830 to Uemura ("Uemura") at [0033] and Fig. 3; JP10189052 to Abe ("Abe")) at [0093]-[0094], [0103]; U.S. Patent No. 5,260,148 at 3:14-19; U.S. Patent Application Publication No. US2003/0113613 to Takeuchi ("Takeuchi")

at [0031]-[0035]. Specifically, as a larger potential is applied to a cell, more lithium is extracted from the positive electrode.

46. If the N/P ratio is below 1 (i.e., there is more positive capacity than negative capacity), there will be insufficient holding sites on the negative electrode material and dendrites (depositions of lithium on the surface of the electrode) can occur, which negatively affects battery performance. (*See, e.g., Uemura at [0033]*).
47. If the N/P ratio is too high, then there can be negative electrode holding sites that do not contribute to the charge-discharge and results in waste of materials. (*Id.*)
48. Thus, the N/P ratio is typically somewhere above 1 but below 1.5 so that there is no plating in the case of an overcharge and no wasteful extra materials. (*See id.*)
49. The negative to positive capacity ratio can be shown as illustrated below:

$$\frac{N}{P} = \frac{\text{capacity of the negative electrode [Ah]}}{\text{capacity of the positive electrode [Ah]}}.$$

50. Alternatively, the capacity can be decomposed into the product of the loading of active material and the specific capacity.

$$\text{capacity} = \text{loading} \times \text{specific capacity}$$

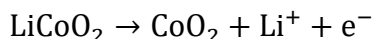
or

$$\text{capacity[Ah]} = \text{g active material} \times \frac{\text{capacity [Ah]}}{\text{g active material}}$$

For each electrode, two pieces of information are required to determine its capacity using this approach: (1) the loading of active material, and (2) the specific capacity of this active material.

51. There are two unambiguous, but different, means of describing the capacity of the electrodes and calculating the N/P ratio.
52. The first is a theoretical method that uses the stoichiometry of the lithiated host to determine the specific capacity of an electrode material (*See Harb and Fuller at 156-158; see also Handbook of Batteries, Third Ed. 2002 ("Handbook of Batteries") at 1.10 – 1.17*).

For example, based on the stoichiometry for LiCoO_2 , we can calculate a theoretical specific capacity of 274 mAh g^{-1} .



$$1 \text{ g LiCoO}_2 \left| \frac{\text{mol}}{97.87 \text{ g}} \right| \left| \frac{96485 \text{ C}}{\text{mol}} \right| \left| \frac{\text{mAh}}{3.6 \text{ C}} \right| = 274 \text{ mAh}$$

53. The second method of finding the specific capacity is empirical. It is well known that extracting too much lithium from, for example, the CoO_2 host results in structural changes in the lattice and causes permanent damage to the electrode. Rather than using the theoretical value, an alternative is to express the electrode capacity in terms of an acceptable potential range relative to a reference electrode. The specific capacity is obtained by dividing the measured capacity by the loading of active material. This experimental method provides a way to measure *practical specific capacity*. (See, e.g., Handbook of Batteries at 1.12-1.15).
54. The experimental method for measuring practical specific capacity is well known to a POSITA. For example, this method is described in Zhang 2006.⁵ Specifically, the positive electrode and negative electrode are separately assembled into a so-called half-cells which commonly uses lithium for the reference and counter electrode. Sometimes a three-electrode cell with an independent lithium reference electrode is used. See, e.g., Fig. 1 below, which is taken from Zhang 2006:

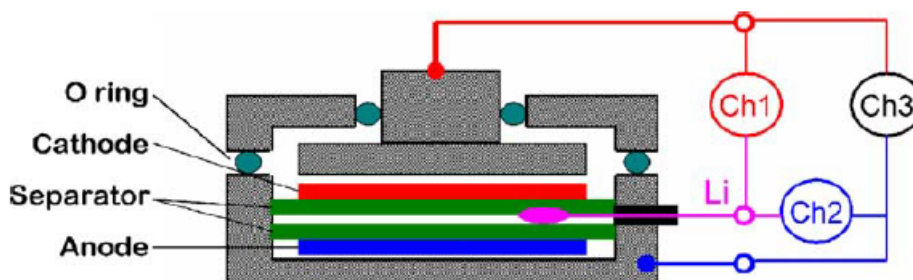


Fig. 1. A schematic of the testing cell and connection circuitry.

This test cell configuration allows the potential of the positive electrode (cathode) relative to lithium to be measured through Channel 1, the potential of the negative electrode (anode)

⁵ Zhang et al., J. Power Sources 160 (2006) 1349–1354 (“Zhang 2006”).

relative to lithium to be measured through channel 2, and the potential of the cell to be measured through Channel 3. By adjusting the potential relative to lithium, charge is inserted into or removed from each electrode. The measured capacity of the positive and electrodes (separate experiments and cells) is divided by the electrode loading to obtain the specific capacity. Rather than the N/P ratio, these authors calculate the inverse, P/N, which they identify as C/A. It is noteworthy for the analysis I present below that the authors provide the details of how they conducted their measurements including specifying the discharge rate, the reference voltage used, and the depth of discharge. These are all required values to determine the practical specific capacity of the positive and negative electrodes. Specifically, the authors state: “the C/A ratio was determined...by cycling a half-cell (three-electrode) at 0.1C between 1.0 and 0.002V versus Li⁺/Li for a Li/MCMB cell [anode] and between 2.7 and 4.2V versus Li⁺/Li for a Li/LiCoO₂ cell [cathode], respectively.” (Zhang 2006 at 1353-54).

55. This method of experimentally measuring specific capacity is also described in Abe. Specifically, Abe teaches:

The design capacity is determined, for example, from the initial charge capacity per unit weight of the active material in a predetermined charging voltage range and the amount of active material coated on the current collector. *The charging capacity can be obtained, for example, by continuously recording a voltage that changes over time by applying a constant current using a three-electrode cell in which both the counter and the reference pole are made of metal lithium. The charge capacity is the amount of charge until a predetermined voltage is reached.* In the triode cell, the starting voltage when using a vapor-phase-grown carbon fiber negative electrode as the working electrode is 3 V, and the charge (applying current from the working electrode to the counter electrode) proceeds and decreases toward 0 V. When a positive electrode is used for the working electrode, the voltage at the start is the potential difference between the metal lithium and the positive electrode material, and the voltage rises with charging (applying current from the counter electrode to the working electrode). The predetermined voltage is 0 V at the vapor-phase-grown carbon fiber negative electrode, and at the positive electrode, the voltage is set to a range in which no electrolyte decomposition occurs, and no irreversible structural breakdown of the positive electrode active material occurs. For example, LiMn₂O₄ is 4.2–4.3 V, preferably 4.2 V, and LiCoO₂ and LiNiO₂ are 4.1–4.2 V, preferably 4.1 V. The design capacity of the negative electrode active material can be the theoretical capacity indicated by the capacity per unit weight of carbon in the negative electrode, or 372 mA/g, if the graphitization of the negative electrode active material is complete; however, if the graphitization of the negative electrode active material is not complete, the design capacity of the negative

electrode is determined by measuring the capacity at a low current of 10 mA/g or less and at a predetermined cut-off voltage.

(Abe, [0078]).

56. This method of measuring electrode capacity is also described in Guyomard 1992.⁶ Specifically, Guyomard 1992 uses two and three electrode Swagelok cells (illustrated in Fig. 1), to cycle LiMn_2O_4 vs. Li (from 3.5V to 4.5 V at a current of 0.4 mA/cm² and from 3.5V to 4.3 V at a current of 0.2 mA/cm²) and to cycle petroleum coke vs. Li (from 0.02V to 1.8V at a current of .5 mA/cm²). (See *id.* at Figs. 3, 6 and p.943).
57. The '641 patent itself refers to two publications that use a half-cell for measuring electrode capacity relative to lithium:

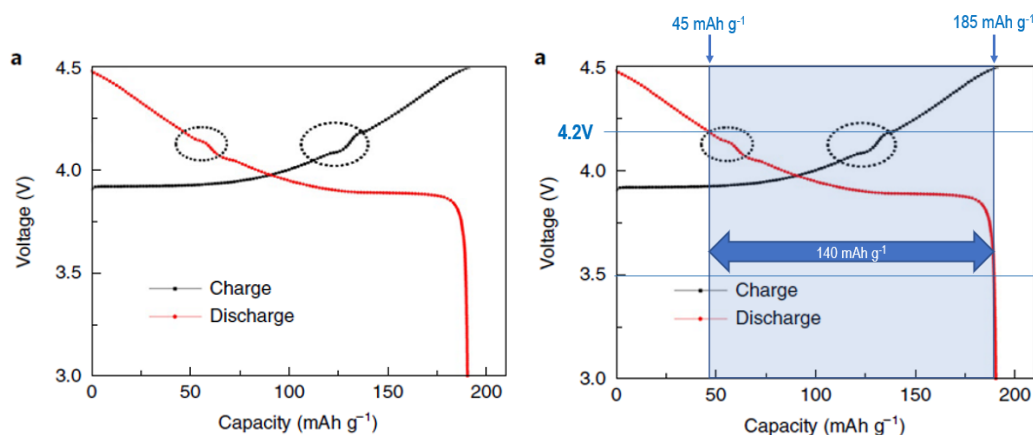
For instance, as to lithium cobalt oxides that is used as positive electrode material in the most commercial lithium ion batteries, the charge cut-off voltage is limited to below 4.2 V and the actual capacity is 120-140 mAh/g, i.e., about 50% of the theoretical capacity, *although many documents indicate that the charge cut-off voltage can be over 4.2 V for a test cell using metallic lithium as counter electrode.* In fact, according to MIZUSHIMAK et al., "A new cathode material for batteries of high energy density", Mater. Res. Bull., 1980, 15:783, the quantity of dedoped lithium ion increases with the increase of charge voltage, and the electrochemical capacity of lithium cobalt oxides increases accordingly. *However, the study deems that the reversible charge-discharge voltage is about 4.3 V when metallic lithium is used as counter electrode, and when said voltage is higher than 4.3 V, the structure of lithium cobalt oxides changes and the lattice parameter C decreases from 4.4 nm to 4.0 nm, and thus the recycle life of cell is affected.*

G. PISTOIA et al., J. Power Source, 56(1995), 37-43, deems that the structure the lithium cobalt oxides changes with the charge voltage, and the coexistence of monoclinic phase and hexagonal phase will appear when the charge voltage is over a certain value, which will spoil the recycle property of cell. *The results of experiments showed that as to a test button cell having metallic lithium as negative electrode, the capacity of lithium cobalt oxides reaches 159 mAh/g when the charge cut-off voltage is 4.35 V, but it drops to 135 mAh/g after several cycles; and the capacity attenuates quickly when the charge cut-off voltage is 4.25 V.* This document takes the opinion that lithium cobalt oxides maintain excellent recycle property and a capacity about 130 mAh/g only when the charge cut-off voltage is 4.15 V, and the corresponding voltages of monoclinic phase and hexagonal phase separately is 4.05 V and 4.17 V, i.e., both of them are below 4.2 V.

('641 patent at 1:64-2:30 (emphases added)).

⁶ Guyomard, J. Electrochem. Soc., Vol. 139, No. 4, April 1992, 937-948 ("Guyomard 1992").

58. Numerous other references similar teach the use of a half cell (or three electrode cell) to measure electrode capacity. *See, e.g., Kim 2000*⁷ at 173 (“Mesocarbon microbeads MCMB2528, Osaka Gas) were used as a negative electrode in the Li-ion half-cell. . . . The cells were discharged at constant current (C/10 rate) to a cut-off voltage of 10 mV vs. Li/Li⁺. Charging was performed at the same rate up to 1.5 V vs. Li/Li⁺.”), Tzerdis 2000⁸ at 298-299 (“Electrochemical measurements were conducted galvanostatically using an Arbin battery testing system and two- and three-electrode cells The cells were cycled galvanostatically at C/8 rate between 1.5 and 0.005 V for C/Li cells or between 4.3 and 2.3 V for the Li-ion cells.”).
59. To illustrate the experimental or practical specific capacity, the data from Liu 2018⁹ for lithium cobalt oxide are analyzed. Both the upper and lower potential limits are required to define a practical capacity. For example, using an upper potential limit of 4.2 V relative to lithium and a lower limit of 3.5 V relative to lithium gives a specific capacity of about 140 mAh g⁻¹. This can be approximated from the plot below where the plot on the left is from Liu 2018 and the plot on the right is annotated to show how the practical capacity can be determined from the measurements.



$$\text{specific capacity} = 185 - 45 = 140 \text{ mAh g}^{-1}$$

⁷ Kim, J. *Power Sources*, 91 (2000), 172-176 (“Kim 2000”).

⁸ Tzerdis, *Solid State Ionics* 135 (2000) 297-304 (“Tzerdis 2000”).

⁹ Liu, “Approaching the capacity limit of lithium cobalt oxide in lithium ion batteries via lanthanum and aluminum doping,” *Nature Energy* (November 2018), 936–943 (“Liu 2018”).

60. The calculated N/P ratio for a cell depends on whether the theoretical capacity or the practical capacity is used. The theoretical capacity will almost always provide a higher capacity than the practical capacity because it reflects the stoichiometric calculation of the total amount of lithium in the active material.

C. Background on Cycling Lithium-Ion Batteries

61. The ability to maintain capacity is an important feature of a commercial cell. Secondary batteries degrade over time (calendar ageing) and with use (cycle life).
62. Capacity retention as a ratio or percentage of remaining capacity in the battery may be expressed as

$$\text{capacity retention} = \frac{\text{discharge capacity}}{\text{initial discharge capacity}} \times 100\%$$

63. It is well-known to a POSITA that various conditions influence cycle life of secondary lithium-ion batteries, including, the charging protocol, including charge and discharge rates, the mode of charge (e.g., constant current (CC), constant voltage (CV), or constant current/constant voltage (CC/CV) charging), the charging voltage; the temperature; voltage regulation; type of discharge (e.g., continuous, intermittent). *See, e.g.,* Zhang 2000¹⁰ at 122 (“[C]apacity fade is caused by various mechanisms, which depend on the electrode materials and also on the charge-discharge protocol.”); Choi 2002¹¹ at Abstract (“Cycle-life is greatly influenced by the charge conditions, but is relatively insensitive to the discharge conditions.”), at 130 (“There are numerous possible factors [that affect the cycle-life of a Li-ion cell], e.g., operation conditions such as temperature and cycle regimes, types of electrode active material, supporting structural materials, cell design variables, and fabrication processes.”); Spotnitz 2003¹² at 74-76 (discussing “Published studies of capacity fade”); Handbook of Batteries at Chapter 3.2 (at 3.3 (“As the current drain of the battery is increased, the IR losses and polarization effects increase, the discharge is at a lower voltage, and the service life of the battery is reduced.”), at 3.5 (“The mode of

¹⁰ Zhang, J. Power Sources 91 (2000) 122-129 (“Zhang 2000”).

¹¹ Choi, J. Power Sources 111 (2002) 130-136 (“Choi 2002”).

¹² Spotnitz, J. Power Sources 113 (2003) 72-80 (“Spotnitz 2003”).

discharge of a battery, among other factors, can have a significant effect on the performance of the battery.”), at 3.10 (“The temperature at which the battery is discharged has a pronounced effect on its service life (capacity) and voltage characteristics.”) and Chapter 35.4 (discussing facts that affect “Li-Ion Battery Performance”); Ning 2003¹³ (“The rate capability losses were proportional with the increase of discharge rates.”); Ramadass 2002 - Part I¹⁴ at Abstract (“The capacity fade of Sony 18650 Li-ion cells increases with increase in temperature.”) and 606 (“[C]apacity fade of the cell depends on the charging rate and on the cut-off potential used to charge the cell”); Ramadass 2002 - Part II¹⁵ at 620 (“The higher capacity fade for the cells cycled at higher temperatures was due to a repeated film formation over the surface of anode which results in increase rate of lithium loss and also a large increase in negative electrode resistance with cycling.”); Sikha 2003.¹⁶

VIII. THE '641 PATENT

64. The '641 patent relates to secondary lithium-ion cells or batteries. Secondary cells or batteries are rechargeable and can be cycled between charged and discharged states. The '641 patent says that it is directed to “a new method for improving capacity, average operating voltage and specific energy of a secondary lithium ion cell or battery.” ('641 patent at 1:7-15). According to the '641 patent, this is “achieved by means of properly adjusting the ratio between a positive material and a negative material, which is calculated by theoretical specific energy, and properly increasing charge cut-off voltage.” (*Id.* at Abstract).
65. The '641 patent explains what the inventors appear to have believed was the state of the art in 2001. For instance, the '641 patent refers to commercialization of a secondary lithium-ion cell by Sony Corporation. (*Id.* at 1:19-21). Also, according to the '641 patent, as of the year 2000, manufactures were seeking ways to improve the capacity of the lithium-ion battery; the patent calls this a “key issue.” (*Id.* at 1:21-24). One way that the

¹³ Ning, J. Power Sources 117 (2003) 160-169 (“Ning 2003”).

¹⁴ Ramadass, J. Power Sources 112 (2002) 606-613 (“Ramadass 2002 – Part I”).

¹⁵ Ramadass, J. Power Sources 112 (2002) 614-620 (“Ramadass 2002 – Part II”).

¹⁶ Sikha, J. Power Sources 122 (2003) 67-76 (“Sikha 2003”).

patent says that battery capacity was increased was to increase “loading quantities of active substances (positive electrode materials and negative electrode materials).” (*Id.* at 1:24-28). In other words, battery capacity is increased by adding more active material such as lithium cobalt oxide (a positive electrode active material) and graphite (a negative electrode active material). The ’641 patent identifies a readily apparent constraint with this approach: there is only so much space to include active materials in a battery having a specific size: “the limitation of the volume of lithium ion battery greatly restricts the increase of battery capacity” (*id.* at 1:24-30). Another technique used by those in the field was to use higher capacity materials. The ’641 patent acknowledges this approach, but says that “so far, there is no notable breakthrough in this aspect for various technical difficulties.” (*Id.* at 1:30-35).

66. Instead of just adding more material or engineering new higher capacity active materials, the ’641 patent instead says the “problem” as being one of “actual utilization rate” of the positive and negative electrode active materials. (*Id.* at 1:36-40.) The ’641 patent explains that the “theoretical capacity” of “the positive electrode materials and negative electrode materials used in the current secondary lithium ion battery” is higher than what is currently utilized. (*Id.* at 1:34-40.) The ’641 patent then says that “lithium cobalt oxides as a positive electrode material of secondary lithium ion cell has a theoretical capacity of 248 mAh/g, while the actually used capacity of it is merely about 140 mAh/g, i.e., about half of said theoretic capacity is not utilized.” (*Id.* at 1:36-44). This statement warrants a brief aside because it is not correct. The “theoretic capacity” for lithium cobalt oxide is a known, calculatable quantity using stoichiometric principles. For example, the Zou reference¹⁷ cited in the prosecution history of the ’641 patent publishes the “theoretic capacity” of lithium cobalt oxide as being 273.8 mAh/g—a nearly 10% difference between the value in the ’641 patent and the known theoretic capacity of lithium cobalt oxide.
67. Setting aside this discrepancy, the ’641 patent attributes this difference between the “actually used capacity” and the “theoretical capacity” to “the limitation of charge cut-off voltage commonly used in the art.” (’641 patent at 1:44-45). The ’641 patent states:

¹⁷ See Zou et al., Chemistry of Materials, Vol. 15, Number 25 (December 16, 2003) at 4699-4702 (RJ00003048-51_Samsung).

At present, the charge cut-off voltage of single secondary lithium ion cell is limited to no more than 4.2 V, and this is well accepted as a technical requirement in the industry of manufacture of secondary lithium ion battery. Further, all lithium ion batteries in the markets around the world are manufactured under this technical requirement. For example, the charge cut-off voltage is limited to below 4.2 V The reasons that the charge cut-off voltage being limited to below 4.2 V lie in the following opinions in the prior research results and documents: although the capacity and average operating voltage are improved by increasing the charge cut-off voltage, the positive electrode materials and the negative electrode materials will undergo structure change, the electrolyte may decompose, and the recycle property of the cell will be adversely affected when the charge cut-off voltage is greater than 4.2 V.

(*Id.* at 1:44-63). I'll observe here that I do not agree with the statement that 4.2 V was universally agreed-upon and used as an upper limit for charging secondary lithium-ion cells or batteries as a general matter because certain lithium-ion batteries were known to be able to be charged to higher voltages such as those using spinel as the positive electrode active material.¹⁸ I'll also observe that the effects of increasing the cut-off voltage stated in the patent are also not universally correct for lithium-ion batteries. For instance, while it is true that at some point, an increase in the cut-off voltage will lead to a structural change in the host material, this change does not occur at 4.2 V for all materials and a well-designed cell can certainly exceed that voltage without being permanently damaged. The '641 patent recognizes this by stating that "the reversible charge-discharge voltage is about 4.3 V" for a metallic lithium metal electrode and a lithium cobalt oxide positive electrode, but "when said voltage is higher than 4.3 V, the structure of lithium cobalt oxide changes" ('641 patent at 2:8-14.) The patent further states that when the charge cut-off voltage of "commercial secondary lithium ion cells and the self made single secondary lithium ion cells" was 4.2 V to 4.30 V, 4.35 V, and 4.40 V the "cells still maintain excellent recycle property," but when the charge cut-off voltage was raised to over 4.45 V, the capacity dropped significantly after only six cycles. (*Id.* at 4:13-26, 5:7-13 ("[W]hen the charge cut-off voltage of the lithium ion cell is greater than 4.45 V, the negative electrode material of the ordinary commercial lithium ion cell is still more deficient, and the excessive lithium

¹⁸ The '641 patent acknowledges this when it says that "many documents indicate that the charge cut-off voltage can be over 4.2 V for a test cell using metallic lithium as counter electrode." ('641 patent at 2:1-3).

ions will deposit on the surface of the negative electrode and form metallic lithium, which jams the channel for passing lithium ions and attenuates the capacity of the cell.”). As another example, electrolytes that were able to withstand voltages of as much as 5 V were known and are even discussed in some of the materials cited during prosecution of the ’641 patent.

68. Setting aside these additional issues, the ’641 patent reiterates that limiting the charge cut-off voltage to 4.2 V “restricts the actual utilization of active electrode materials.” (’641 patent at 2:58-60). “It is urgently needed to provide a method that can improve the efficacy of active substances of lithium ion cell, consequently increase the capacity and average operating voltage, and maintain the better cell performance simultaneously.” (*Id.* at 2:63-67). Thus, the patent explains that it was seeking to improve “efficacy” of active substances, not engineer new ones.

69. The ’641 patent provides the following as the summary of the invention:

the inventor unexpectedly found that the efficacy of electrode active materials is greatly increased by increasing the charge cut-off voltage and property adjusting the ratio of positive electrode material to negative electrode material of single lithium ion cell. Consequently, the specific energy, capacity and average operating voltage of secondary lithium ion cell or battery are improved, while the performance of cell is substantially not changed.

(*Id.* at 3:8-15). Furthermore, the ’641 patent states:

It is one object of the present invention to provide a new method for improving capacity, average operating voltage and energy density of a secondary lithium ion cell or battery, wherein the charge cut-off voltage of the single [sic] cell is greater than 4.2 V and less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, preferably from 1:1.16 to 1:2.5, as calculated by the specific capacity with the charge voltage limited to 4.2 V.

(’641 patent at 3:17-25). The patent also mentions that the present invention provides a “secondary lithium ion cell or battery” with a cut-off voltage and a “ratio of positive electrode material to negative electrode material” is within the ranges recited in the previous paragraph, with the exception that 1:1.16 is changed to 1:1.15. (*Id.* at 3:26-33). This summary of the invention does not discuss the invention in terms of capacity ratios.

Instead, it describes it in terms of ratios of “material” without specifying what characteristic of the material is being used to define the ratio.

70. The '641 patent says that the phrase “theoretical capacities of positive and negative electrode” means the capacities of the positive electrode and negative electrode calculated with an [sic] charge cut-off voltage set at 4.2 V.” ('641 patent at 4:6-9). Notably, this passage tells the POSITA that the ratio is “calculated.” It does not say that the value is measured. This creates certain problems in understanding the scope of what is claimed as I will explain later in this declaration because claim 5 uses the same word “calculated,” but fails to provide any indication of how to calculate the theoretic capacity at the specified voltage. And, as I also explain later, even if the capacity is to be measured and then used in a calculation, critical parameters are missing from the '641 patent and its file history to tell a POSITA how to undertake the calculation.
71. As mentioned above, the '641 patent explains that the cycling performance of the commercial and “self made” lithium-ion cells was good even though the charge cut-off voltage was set at 4.2 V, 4.30 V, 4.35 V, and 4.40 V. ('641 patent at 4:13-26). But, when the cut-off voltage was set to 4.45 V, “the cell exhibits inferior recycle property, e.g., the capacity maintains merely 83.9% after 6 cycles.” (*Id.* at 4:22-26). To achieve better performance, the patent says that the “ratio of positive electrode material to negative electrode material” was “adjusted within the range from 1:1.3 to 1:2.5 calculated according to the theoretical capacity under the charge cut-off voltage of 4.2 V” (*Id.* at 4:27-32). Thus, the patent explains that the cells with the “adjusted ratios” were tested “by charging at an [sic] charge cut-off voltage of 4.45 V, 4.6 V, 4.8 V, 5.0 V, 5.2 V, 5.6 V, and 5.8 V” (*Id.* at 4:32-35). The patent says: “preferably said charging tests were conducted during the formation and test of the cells.” (*Id.* at 4:35-37.) As one would expect, charging at a higher voltage improved “specific energy” and because excess capacity was added to the negative electrode when compared to the negative electrode designed for 4.2 V, the recyclability of the battery was “essentially not affected” (*Id.* at 4:37-42).
72. The patent then uses “theoretical capacity” in the context of describing complete extraction of lithium from the host material (referred to as complete “dedoping” in the patent). For instance, the patent says that “experimental data show that only when the voltage is about

6.20 V” (for certain lithium cobalt oxide and lithium nickel oxide materials) are the “lithium ions completely dedoped,” and for manganese oxides the voltage “is about 6.50 V.” (’641 patent at 6:15-27). The patent uses these examples to explain that “the specific energy of the positive electrode active substance actually used in the present commercialized lithium ion cell is far less than the theoretical capacity thereof, and even if the charge cut-off voltage is elevated up to 5.8 V, the theoretical capacity cannot be achieved under the proviso that suitable formulation is used, thus the cell is not overcharged.” (*Id.* at 6:27-34). Thus, the phrase “theoretical capacity” is referring to the stoichiometric capacity at which all of the lithium is extracted.

73. The ratio range of the patent is described as being important. Using a ratio of less than 1.0 leads to the “recycle life of [the] cell” being “excessively reduced” and if the ratio is greater than 2.5 then the “volume efficiency of the cell is notably reduced.” (*Id.* at 7:43-50).
74. The ’641 patent indicates that the “present method not only can be used to the secondary lithium ion cell or battery of the present invention, but also can be used to the secondary lithium ion cell or battery prepared according to the method of the prior art, such as the present commercialized secondary lithium ion cell or battery.” (*Id.* at 7:51-56).
75. The ’641 patent provides Examples 1-28. With respect to the positive electrode, the ’641 patent explains that the positive electrode material is a “lithium-containing compound.” (’641 patent at 8:11-12). The patent then explains that it is not limited by its examples:

Although the examples use lithium cobalt oxides (lithium cobalt composite oxides), lithium manganese oxides and lithium nickel oxides as positive electrode material, it is understood that the practice of the present invention is not limited to the specific properties of said lithium-containing composite oxides, rather a wide range of positive electrode active substance can be used in the present invention. (*Id.* at 8:11-19).

The present invention can also be used to [sic] lithium ion cells having doped lithium-containing compound [sic] as positive electrode active material, such as various positive electrode active materials containing various oxides and sulfides, such as lithium cobalt composite oxides, lithium manganese composite oxides, lithium nickel composite oxides, lithium nickel cobalt composite oxides, lithium manganese cobalt composite oxides, and vanadium oxides. (*Id.* at 8:24-31).

76. Thus, known materials having lithium can be used and “the present invention can use conventional conducting agent[s] and binder[s],” and have “a mixture ratio for each

component[] in the positive electrode active material can be those well known in the art.” (*Id.* at 8:38-41.) The separator “is a separator well known in the art.” (*Id.* at 8:43-44).

77. With respect to the negative electrode, the '641 patent explains:

The negative electrode active material used in the present invention is a carbonaceous or non-carbonaceous substance capable of doping and dedoping lithium ion, including, such as, lithium alloy (such as $\text{Li}_4\text{Ti}_5\text{O}_{12}$), metal oxide (such as amorphous tin oxide, WO_2 and MoO_2), TiS_2 and carbonaceous substance capable of absorbing and desorbing lithium ions, and especially, the carbonaceous substance is the desired negative electrode active material.

The carbonaceous substance used in the present invention includes: graphite, non-oriented graphite, coke, carbon fiber, spherical carbon, carbon sintered from resin, carbon grown in gas phase, and carbon nanometer tube. Since the negative electrode comprising the aforesaid specific carbon fiber or spherical carbon exhibits high charge efficiency, mesophase asphalt based carbon fiber or mesophase asphalt based spherical carbon is preferably used as the carbonaceous substance. The mesophase asphalt based carbon fiber or mesophase asphalt based spherical carbon can be obtained according to the conventional method.

(‘641 patent at 8:56-9:7).

78. The invention is not limited to any particular electrolyte, shell, or shaped cell: “non-aqueous electrolytes and shells of the type well known in the art can be used in the present invention,” and “the structure of [the] cell is not limited to a certain shape” (*Id.* at 9:8-21). “Except voltage, all process parameters for charge and discharge are commonly used in the art.” (*Id.* at 9:22-23). As I explain below, there were many parameters for charge and discharge, and the patent’s failure to specify those parameters leads the scope of the claimed ratio uncertain.
79. The cell or battery can be used in various devices ranging from computers, PDAs, bicycles, or even automobiles. (*Id.* at 9:45-48).
80. Examples 1-4 relate to lithium-ion cells “of quadrate type 653466” prepared according to the method outlined in columns 9 and 10. (‘641 patent at 9:59-11:6). The positive electrode active material is lithium cobalt oxide and the negative electrode active material is MCMB (mesocarbon microbeads). (*Id.*) The amounts of the active materials are not specified, though the “ratio of positive electrode material to negative electrode material” are given. (*Id.* at 10:29-11:6.) For each stated example, seven (7) cells appear to have been produced

with ratios ranging from 1:1.0 to 1:1.3. (*Id.*). Example 1 applies a cut-off voltage of 4.2 V, Example 2 applies a charge cut-off voltage of 4.3 V, and Example 3 applies a cut-off voltage of 4.35 V. (*Id.*). The patent does not report the results for each individual battery, but instead obscures the results of each ratio increase by publishing a single number that may be an average or mean including for the capacities after 400 cycles. For instance, a POSITA would be interested in seeing results from the 1:1.0 ratio experiment at a charge cutoff voltage of 4.35 V and would have expected that battery to have worse capacity after 400 cycles than the battery with a 1:1.3 ratio in that example.

81. Recalling that the '641 patent explained that cyclability of the cells was “inferior” when the cut-off voltage was set to 4.45 V using commercially available cells, Example 5 sets the cut-off voltage to 4.45 V and has a “ratio of positive electrode material to negative electrode material” of 1:1.45. ('641 patent at 11:10-16). While this example refers to multiple “cells” being produced, some of the figures are reported for “said cell” and it is not clear whether the results are an average or are reported for a single cell. (*Id.*) Examples 6 and 7 are similar, but use even more negative electrode material to positive electrode material and raise the cut-off voltage to 4.60 V (Example 6) and 4.80 V (Example 7). (*Id.* at 11:20-36).
82. Example 8 pushes the cut-off voltage to 5.0 V, but requires the addition of an unidentified “substance A” or “electrolyte solution B” to the cell and the ratio is 1:1.9. Examples 9-12 push the cut-off voltage even higher but add another unidentified composition, “compound C” to the “positive electrode slurry” and are silent on modifications to the electrolyte solution though the electrolyte used for the earlier examples such as Example 1 would likely have decomposed under a charge cut-off voltage of 5.20 V or 5.40 V. ('641 patent at 11:52-12:34). Example 13 raises the charge cut-off voltage to 5.9 V, uses “compound C” as part of the positive electrode, but shows poor cyclability even though the “ratio of positive electrode material to negative electrode material” is 1:2.6. (*Id.* at 12:38-45).
83. Examples 14-18 provide some details about the mass of the materials used to make the positive and negative electrode slurry, such as the use of 4 g of lithium manganese oxide and 2.6 g of MCMB ('641 patent at 12:60-66); however, such information does not necessarily represent the mass of the electrode, e.g., if not all of the slurry is used to coat

the current collector. The patent purports to describe “[t]he data of experiments” in Table 2 (*id.* at 12:66-67):

TABLE 2

Example	Charge cut-off voltage (V)	Processing change	Recycle property	Capacity (mAh)
14	4.20	—	Maintaining 84.23% after 400 recycles	375
15	4.30	—	Maintaining 85.12% after 400 recycles	405
16	4.60	The ratio of positive electrode material to negative electrode material is 1:1.6.	Maintaining 83.45% after 400 recycles	575
17	5.80	The ratio of positive electrode material to negative electrode material is 1:2.5, and substance A is added into the electrolyte solution.	Maintaining 82.83% after 400 recycles	567
18	5.90	The ratio of positive electrode material to negative electrode material is 1:2.7, and substance A is added into the electrolyte solution.	Maintaining 54.23% after 30 cycles	312

(*Id.* at Table 2, column 13).

84. Examples 19-23 indicate that 4 g of lithium nickel oxide was used to make the positive electrode slurry and 3.5 g of MCMB was used to make the negative electrode slurry, and the following results are provided:

TABLE 3

Example	Charge cut-off voltage (V)	Processing change	Recycle property	Capacity (mAh)
19	4.20	—	Maintaining 81.23% after 400 recycles	610
20	4.30	—	Maintaining 80.72% after 400 recycles	675
21	4.60	The ratio of positive electrode material to negative electrode material is 1:1.6.	Maintaining 78.32% after 400 recycles	912
22	5.80	The ratio of positive electrode material to negative electrode material is 1:2.5, and substance A is added into the electrolyte solution.	Maintaining 75.83% after 400 recycles	879
23	5.90	The ratio of positive electrode material to negative electrode material is 1:2.7, and substance A is added into the electrolyte solution.	Maintaining 47.53% after 50 cycles	796

(’641 patent, Table 3, column 14).

85. Examples 24-28 use 4 g of lithium nickel oxide and form a “cobalt-doping lithium nickel oxide” (though the amount of cobalt is not specified) for the positive electrode slurry and use 3.5 [g] of MCMB to make the negative electrode slurry. The following results are provided:

TABLE 4

Example	Charge cut-off voltage (V)	Processing change	Recycle property	Capacity (mAh)
24	4.20	—	Maintaining 81.23% after 400 recycles	623
25	4.30	—	Maintaining 80.72% after 400 recycles	682
26	4.60	The ratio of positive electrode material to negative electrode material is 1:1.6.	Maintaining 78.32% after 400 recycles	934
27	5.80	The ratio of positive electrode material to negative electrode material is 1:2.5, and substance A is added into the electrolyte solution.	Maintaining 75.83% after 400 recycles	919
28	5.90	The ratio of positive electrode material to negative electrode material is 1:2.7, and substance A is added into the electrolyte solution.	Maintaining 39.53% after 50 cycles	697

(’641 patent, Table 4, column 15).

86. While the examples describe and rely upon “a ratio of positive electrode material to negative electrode material,” the examples do not indicate how these ratios are determined; that is, whether a theoretical or practical value of electrode capacity is used. The examples also do not provide information on how that ratio was calculated or measured, including at least 1) any capacity values used for the capacities of the negative or positive electrodes, 2) any electrochemical data or analysis that provides information on the capacity, 3) the cycling range for the negative or the positive electrode, or 4) the current used for cycling.
87. Similarly, while the patent examples provide a percent capacity after “400 recycles” the patent does not provide any test conditions for cycle testing, including the temperature, charge and discharge rates, the charging protocol used, rest time in between cycles, etc.
88. I understand that RJ Tech does not have any documents concerning the patent examples or the testing thereof.
89. The ’641 patent has 18 claims. I understand that claims 1 and 5 are independent claims, which means that they do not refer to any other claims. I also understand that claim 1 is not being asserted in this litigation any longer. Claims 6-14 are dependent claims, which means that they refer to earlier stated claims and thus include the requirements provided in the earlier claim or claims that they refer to. Independent claim 5 states:

5. A secondary lithium ion cell or battery, characterized in that the secondary lithium ion cell or battery has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and a ratio of positive electrode material to negative electrode material

of the secondary lithium ion cell or battery is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2 V.

90. This claim is not limited to a lithium-ion battery for any specific application. And, as mentioned above, the claims are not limited to any particular anode material, cathode material, conducting agent, binder, electrolyte, separator, current collector, geometry, charge and discharge parameters, protection circuits, or anything else other than the cut-off voltage limitation and the capacity ratio limitation.
91. Claims 11-14 recite that the cell or battery of claim 5 “maintains at least” some specified capacity “after 400 cycles.” I understand the parties have agreed that the reference to “7500” in claim 11 means “75%,” and that claims 12-14 refer to 75.83%, 80%, and 80.72%, respectively.

IX. FILE HISTORY OF THE '641 PATENT

92. Below, I discuss aspects of the file history of the '641 patent which are relevant to the “ratio limitation” and the “cycling limitation.” Importantly, as noted throughout the below, RJ Tech’s arguments to the Patent Office indicated that they understood there to be a difference between the “specific capacity” and “theoretic capacity” ratio limitations.
93. U.S. Patent Application No. 10/491,134, the application leading to the '641 patent, was filed on September 28, 2002. The original application contained 6 claims. Two of the original claims included ratio limitations:

CLAIMS:

1. A method for improving the capacity, average operating voltage and specific energy of a secondary lithium ion cell or battery, characterized in that the charge cut-off voltage of the single cell is greater than 4.2 V but less than 5.8 V, preferably within a range from 4.3 V to 5.2 V, and more preferably within a range from 4.3 V to 4.8 V; and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, preferably from 1:1.15 to 1:2.5, as calculated by the specific capacity with the charge voltage limited to 4.2 V.
2. A secondary lithium ion cell or battery, characterized in that the single secondary lithium ion cell has an charge cut-off voltage of greater than 4.2 V but less than 5.8 V, preferably within a range from 4.3 V to 5.2 V, and more preferably within a range from 4.3 V to 4.8 V; and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, preferably from 1:1.15 to 1:2.5, as calculated by theoretic capacity.

(RJ00003189_Samsung (emphasis added)). As shown above, original claim 1 had a ratio “as calculated by the specific capacity with the charge voltage limited to 4.2V” and claim 2 had a ratio “as calculated by theoretic capacity.” None of the original claims had a cycling limitation.

94. RJ Tech filed a preliminary amendment on March 29, 2004, in which it amended the claims, including the ratio limitation directed to “theoretic capacity”:

1. (Amended) A method for improving the capacity, average operating voltage and specific energy of a secondary lithium ion cell or battery, characterized in that the charge cut-off voltage of the single cell is greater than 4.2 V but less than 5.8 V, ~~preferably within a range of 4.3 V to 5.2 V, and more preferably within a range from 4.3 V to 4.8 V;~~ and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, ~~preferably from 1:1.15 to 1:2.5,~~ as calculated by the specific capacity with the charge voltage limited to 4.2 V.

5. (Amended) ~~An electronic device using a secondary lithium ion cell or battery as energy source, characterized in that said electronic device comprises a protecting circuit, wherein the single lithium ion cell has a first overcharging protection voltage of greater than 4.35 V, and an overcharge release voltage of greater than 4.45 V, and an overcharge release voltage of greater than 4.25 V.~~ A secondary lithium ion cell or battery, characterized in that the single secondary lithium ion cell has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2 V.

(RJ00003150-54_Samsung (emphasis added)).

95. In response to an Office Action dated January 16, 2009 that rejected the claims as obvious, the patent applicant amended the claims and provided remarks. Specifically, RJ Tech maintained the “specific capacity” ratio limitation in claim 1 and amended the “theoretic capacity” ratio limitation of claim 5 so that instead of referring to “theoretic capacity” is now referred to “capacities of the positive electrode material and the negative electrode material are calculated with a charge cut-off voltage set at 4.2V.” (RJ00003037-3038_Samsung). Claims having the capacity after 400 cycles were also added. (RJ00003040_Samsung).

96. The applicant argued that “[a]lthough using a charge cut-off voltage greater than 4.2V results in improved capacity and improved operating voltage, negative side effects such as structural changes in the positive and negative electrode materials, decomposing of the electrolyte, and reduced recycle properties have kept the battery industry from using a charge cut-off voltage greater than 4.2V.” (RJ00003041_Samsung). The applicant then asserted that the claims were non-obvious based on unexpected results when the ratio is “calculated by the specific capacity with the charge voltage limited to 4.2V.” (RJ00003042_Samsung (emphasis added)). They called this part of the “inventive methodology.” (*Id.*).
97. The inventors also referred to the Examiner to the Zou publication, which discusses the “theoretical capacity” and “practical capacity” of LiCoO₂ and indicates that doping LiCoO₂ with various materials changes its properties, including its capacity: “the maximum attainable *practical capacity* is only around 137 mA h/g when cycled in the voltage range 3-4.25 V, although the *theoretical capacity* is as high as 273.8 mA h/g. . . . Theoretical studies suggest that doping of LiCoO₂ with a transition metal ion leads to an increase in the capacity whereas on the other hand non-transitional metal ion doping leads to an increase in voltage at the expense of capacity.” (RJ00003043-44_Samsung).
98. The Zou publication also discusses galvanostatic cycling of fabricated cells at a given C-rate (C/5) over a given voltage range (3.5-4.5V) at a given temperature (room temperature). (RJ00003049_Samsung). And Zou discusses a high first cycle capacity value but lower capacity rates after cycling:

The galvanostatic cycling behavior of the synthesized doped cathode materials were evaluated in a lithium rechargeable 2032 type coin cell in the voltage range 3.5–4.5 V at a C/5 rate and are presented in Figure 4a–d. It is observed from the figures that the cells employing Cu and Zn doping (Figure 4a,d) show initial discharge capacities of around 165–170 mA·h/g but fade slowly on cycling and retain a capacity of approximately 130 and 110 mA·h/g, respectively. Such kind of fading has also been observed by other authors in the case of LiCoO₂³ and has been ascribed due to the different phase changes taking place on cycling. It is interesting

(RJ00003051_Samsung (emphasis added)). The prosecution history thus illustrates some of the very issues that render the claim scope uncertain: the absence of C-rate and voltage range, among other things.

99. In response to an Office Action, dated August 14, 2009 rejected the claims as obvious, the applicant amended the “capacity” ratio claim language to reintroduce the concept of theoretic capacity with the phrase “theoretic capacity with a charge cut-off voltage set at 4.2V. (RJ00003001-02_Samsung).
100. The applicant again argued that the claims reflected unexpected properties. (RJ00003005-12_Samsung). The patent examiner allowed the claims and indicated that the claims were allowed, in part, because they recited a ratio “as calculated by a specific capacity with a charge voltage limited to 4.2 V.” (RJ00002983_Samsung).
101. I understand that there is one additional patent application filed based on the application that led to the ’641 patent. This application was given U.S. Patent Application No. 12/817,028 and was filed on June 16, 2010. The application was filed with a claim including the “theoretic capacity” ratio limitation found in claim 5 of the ’641 patent—i.e., a ratio “as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2 V.” (RJ00006193_Samsung).
102. After the Patent Office rejected the claims, the applicant argued that the invention required a ratio “as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2 V,” and explained that the language of the claim “tracks that of the claims allowed in parent application” that issued as the ’641 patent. (RJ00006117-18_Samsung).
103. In response to an Office Action again rejecting the claims as obvious, the applicant again argued to the Patent Office that the claimed invention included a ratio “as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2V.” (RJ00006003-6004_Samaung). Moreover, RJ Tech specifically argued that the prior art—a reference called “Idota”—was “silent on whether its ratio is a weight ratio or a volume ratio,” but in any event was “not based on *capacity*” as claimed. (RJ00006005-06_Samsung). The other prior art references cited by the Patent Office also did not “implicate[] the calculation method of capacity-based ratio.” (*Id.*).

104. The relevant portion of the Idota reference, U.S. Patent No. 5,260,148 (at 3:14-19) is copied below:

It is preferable that the ratio of the equivalent amount of the anode active material to that of the cathode active material be larger than 1 (i.e., the amount of the anode active material is more than equivalent to the cathode active material). The ratio thereof is more preferably from 1.1 to 5, most preferably from 1.1 to 3.5.

It is my opinion that Idota is indicating that the capacity of the anode “is more than equivalent to the cathode active material,” i.e., that the anode has a higher capacity than the cathode. This opinion is support by at least the Examples of Idota. For example, Example 1 indicates that the capacity of the anode is 30 mAh and that the capacity of the cathode is 20 mAH, thus informing a POSITA that the capacity of the anode is 1.5 as large as the cathode. (*Id.* at 9:19-43). Example 2 had the same capacity ratio as Example 1 (*id.* at 10:39-50), while the comparative example had a ratio of 2:1 anode to cathode and 1:1 anode to cathode (*id.* at 10:57-11:5). Thus, the only distinguishing feature is that Idota doesn’t reference the calculation being of “theoretic capacity,” it only discloses a “capacity” ratio. Indeed, Idota’s phrasing is very similar to the phrasing used in many places in the ’641 patent itself when it refers to “the ratio of positive electrode material to negative electrode material,” instead of saying anything about capacity. (*E.g.*, ’641 patent at 3:21-22, 3:29-30, 3:64-65 (“adjusting the ratio of the positive electrode to the negative electrode”), 4:29-30). The applicant repeated these arguments after another rejection was made. (RJ0005974_Samsung).

105. The Patent Office maintained its rejection, indicating that “the applicant did not disclose any relationship in the specification” concerning “theoretic capacity and the charge cut-off voltage”:

Response to Arguments

1. Applicant's arguments filed 2/26/2013 have been fully considered but they are not persuasive. Applicant's argument regarding ratio of the positive electrode material to negative electrode material in connection with theoretic capacity and the charge cut-off voltage is not persuasive because these are not related and also, the applicant did not disclose any relationship in the specification.

(RJ00005965_Samsung (emphasis added)). Thus, the Examiner recognized that there is no connection between theoretic capacity and a charge-cut off voltage, which is consistent with my discussion above and below (see Paragraphs 52, 70, 109-116).

106. In response to the Final Office Action, the applicant filed a "Pre-Appeal Brief Request for Review." (RJ00005953-56_Samsung). The applicant repeated the same arguments concerning Idota. The application was then abandoned.

X. THE CLAIM TERMS IN DISPUTE

A. "Ratio of positive electrode material to negative electrode material . . . is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2V" (Claims 5-14)

107. Samsung asserts that the phrase "ratio of positive electrode material to negative electrode material . . . is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge-cut-off voltage set at 4.2V" is indefinite. I agree with Samsung.

a. The Scope of the Phrase "Calculated by a Theoretic Capacity with a Charge Cut-Off Voltage Set as 4.2V" is Undefined in Scope and Indefinite

108. As an initial matter, the '641 patent does not provide any instruction to a POSITA about how to *calculate* a N/P ratio "by a theoretic capacity with a charge cut-off voltage set at 4.2V."

109. As discussed above, practical electrode capacity is something that is *measured* through experimentation, while theoretical capacity is something that is *calculated* based on the stoichiometry of the lithiated host. Thus, when the claim says that the ratio is "calculated by a theoretic capacity," this would suggest to a POSITA that the calculation based on

stoichiometry is involved. Yet, the phrase “with a charge cut-off voltage set at 4.2 V” renders this phrase indefinite.

110. A POSITA in 2001 (or at any time, for that matter) would not know how to calculate a “theoretic capacity with a *charge cut-off voltage set as 4.2V*,” particularly for the wide range of positive electrode active materials that can be used in the claims. This is because theoretic capacity is independent on the voltage applied. As discussed above, the specification provides no guidance on how this calculation is made, even in the context of the examples. Nor is calculating a theoretic capacity with a certain charge-cut off voltage something that was known to a POSITA in 2001. And, as discussed below even in the context of RJ Tech’s proposed construction (which as I understand it is not based on a stoichiometric approach), because certain testing limits are unspecified, the ratio limitation is undefined in scope and indefinite if its broad enough to include practical capacity.
111. I understand that RJ Tech has asserted that “calculated by a theoretic capacity with a charge cut-off voltage set as 4.2V” simply means that a POSITA would obtain a value for the capacity of a known material from the literature based on practical testing. This approach is not described in the patent.
112. Moreover, simply providing a cut-off voltage doesn’t provide sufficient guidance to a POSITA to select a capacity from the literature for any given material. For example, the literature indicates that there was a range of reported specific capacities for a given material because capacity can change based on current, material synthesis, electrode formulation, and test conditions (as is described in more detail below). A survey of the literature was provided by Koksbang in the 1996 publication *Cathode materials for rocking chair batteries*, Solid State Ionics 84 (1996), pp.1-21 (1996) (“Koksbang 1996”). As the author explains “[t]he intention of this paper is to provide the reader with an overview of the battery related properties of cathode materials, including preparation procedures and electrode characteristics; i.e. the applied aspects of the cathode materials.” Koksbang 1996 at 2. Koksbang 1996 includes a table summarizing properties of cathode materials reported in other publications. Koksbang at 4-12. For instance for lithium cobalt oxide, LiCoO_2 , the reported capacity when the upper voltage limit is 4.2 V range from 148 mAh/g to 118 mAh/g for the first half cycle and cycling capacity ranging from 82 mAh/g to 134 mAh/g.

Table 1
Initial and reversible capacities of cathode materials as function of materials synthesis, electrode formulation, electrolyte and test conditions

#	Compound	V-limits (V versus Li)	Current (mA cm ⁻²)	1st half cycle (mAh g ⁻¹)	Cycle cap. (mAh g ⁻¹) (5)	Electrolyte	Electrode	Counter electrode	Synthesis	Refs.
1	LiCoO ₂	2.5–4.1	0.17	140	125/sev.	1M LiClO ₄ EC/DME 1:1	6 w/o AB + 6 w/o Teflon	Natural graphite	Li ₂ CO ₃ + CoCO ₃ 850°C, air	[24–26]
2	LiCoO ₂	1.5–4.2	0.5/1	240 Wh/kg	110 Wh/kg at 100 cyc.	1M LiCF ₃ SO ₃ NMP	10 w/o EPDM 10 w/o CB Ni strips	Li	Carbonates 900°C, air	[27]
3	LiCoO ₂	3.5–4.5	0.05 mV/s	230	145	LiAlCl ₄ /SO ₂	N/A	Li	N/A	[28–29]
4	LiCoO ₂	3.0–4.2	C/100 (3)	123	93	1M LiClO ₄ PC/EC 1:1	50 µm film of oxide SS 304	Li	Thin film, laser ablation	[30]
5	LiCoO ₂	3.0–4.2	C/100 (3)	118	82	1M LiClO ₄ PC/EC 1:1	10 w/o Super-S Al CC	Li	Spray dried 400°C	[30]
6	LiCoO ₂	3.0–4.2	C/100 (3)	148	129	1M LiClO ₄ PC/EC 1:1	10 w/o Super-S Al CC	Li	LiNO ₃ + Co(NO ₃) ₂ LiOH H ₂ O + CoCO ₃ , 850°C, air	[30]
7	LiCoO ₂	3.0–4.2	1	N/A	126	LiAsF ₆ in propi- etary solvent	7.5 w/o AB 7.5 w/o graphite 5 w/o Teflon Al grid	Li	Co ₂ O ₃ + LiOH 700°C, O ₂	[31,32]
8	LiCoO ₂	3.7–4.3	0.25	145	120/sev.	1M LiPF ₆ PC/DEC 1:4	23 w/o TAB SS screen CC	Li	Co(NO ₃) ₂ + LiOH + organic acid 900°C	[33]
9	LiCoO ₂	N/A	2.3	219	poor	1M LiN(CF ₃ SO ₃) ₂ PC/DME	5 w/o CB, EPDM Ni free SS CC	Petrol. Coke	Johnston Mathey	[34]
10	LiCoO ₂	N/A	2.3	137	poor	1M LiN(CF ₃ SO ₃) ₂ PC/DME	5 w/o CB, EPDM Ni free SS CC	Petrol. Coke	Johnston Mathey	[34]
11	LiCoO ₂	3.3–4.2	0.5	137	131	N/A	9.3 w/o graphite 1.8 w/o Teflon	Li	Li ₂ CO ₃ + CoCO ₃ 900°C, air	[35]
12	LiCoO ₂	3.3–4.2	0.5	148	134	N/A	N/A	Li	N/A	[36]
13	LiCoO ₂	3.9–4.2	0.2	137	110	1M LiBF ₄ /PC	100% oxide SS gauze CC	Li or Li _{0.1} V ₂ O ₅	Li ₂ CO ₃ + CoCO ₃ 800°C, air	[37,38]
14	LiCoO ₂	3.8–4.2	< 0.2	137	N/A	LiClO ₄ /PC	Press. oxide powder	Li	Li ₂ CO ₃ + Co ₃ O ₄ 900°C, Ar	[39,40]
15	LiCoO ₂	3.0–4.3	0.25	150	N/A	N/A	N/A	Li	Li ₂ CO ₃ + CoCO ₃ , 850°C, O ₂	[41]
16	LiCoO ₂	3.5–4.5	0.06	110	90/4	Li ₃ PO ₄ -Li ₂ S-SiS ₂	LiCoO ₂ + glass 2:3	Li	Li ₂ CO ₃ + Co ₃ O ₄ , 900°C	[42]
17	LiCoO ₂	3.3–4.1	1	142	118/100	1M LiPF ₆ PC	1.2 %PEO 1.3 stainless steel	Li	N/A	[43]
18	LiCoO ₂	3.0–4.25	0.05	214	164	10%SB + Hybrid	1M LiAsF ₆	Li	N/A	[44]

Koksbang at 4 (emphasis added). This example alone shows the problem of just picking values for a cathode active material from the literature. First, taking a hypothetical battery with a mass loading of 4 g lithium cobalt oxide for the active positive electrode material and 1.3 g mass loading for a graphite negative electrode material, one could arrive at a ratio of somewhere between 1:0.82 and 1:1.02 for the first half cycle depending on which reported values one considers. And, when differences in the cycle (e.g., first half cycle vs. later cycles of the battery) are taken into account the range broadens from 1:0.82 to 1:1.47.

113. Just consulting values in the literature does not provide a POSITA with an answer about the capacity of any particular cathode active material because a number of factors that affect capacity.

114. Furthermore, I understand that RJ Tech asserts that the claims cover any electrode material, including materials not known to a POSITA in 2001. A POSITA would not be able to find a measured capacity of an unknown material in the literature in 2001 to evaluate whether a product made later was inside or outside the scope of the patent claims because, by definition, the material was unknown in 2001.
115. Moreover, the inclusion of a doping element to LiCoO_2 – or any other electrode material – can significantly alter the relationship between capacity and potential, rendering a theoretical calculation of the capacity impossible. For example, it was known to a POSITA that a small amount of doping could significantly change the measured capacity by about 20 percent. (*See, e.g.*, Bates 2000¹⁹ at 40 (“There is a significant improvement in the capacity above 4.5V compared to the undoped films (Fig. 7a), with the result that, for the same discharge current, the energy delivered by the cell is 20% higher than that supplied by a cell with an undoped LiMn_2O_4 ”); Yang 2018²⁰ at 2 and Fig. 2b (depicting a 20% change for LiCoO_2); Arora 1998²¹ at 3652 (“When the Ni in LiNiO_2 is substituted with Ca, Nb, or In, the structural change observed during the charging process are very small, which leads to better cyclability of these doped materials.”)). Examples 24-28 of the ’641 patent are described as having a doped material. For these doped materials, neither a POSITA nor even a subject matter expert would know a priori what practical capacity to use to calculate the N/P ratio. There is no theory to provide this practical value, and experimentation is needed.
116. Similarly, manufacturing details can also affect the capacity of a given material. For example, Tzerdis 2000 explains how the binder used with graphite can have a significant effect on its capacity. (*Id.* at 299-300 and Table 1 (showing using a different binder with synthetic graphite can vary the reversible capacity from 230 mAh/g to 358 mAh/g); *see also* Koksang 1996 at 4-12 (listing materials made different ways and evaluated under different conditions and showing they have different capacities)). Again, without testing the material—and setting specific conditions for the testing—a POSITA would not know

¹⁹ Bates, *Solid State Ionics* 135 (2000) 33-45 (“Bates 2000”).

²⁰ *Chem. Soc. Rev.*, 2018, 47, 6505 & *Scientific Reports*, (2018) 8:863 (“Yang 2018”).

²¹ Arora, *J. Electrochem. Soc.*, Vol. 145, No. 10, (October 1998) 3647-3667 (“Arora 1998”).

what electrode capacity to use for the anode or the cathode with any degree of certainty and/or accuracy.

117. But, as described below, the patent also does not provide clear direction on how to determine the capacity of the negative and positive electrodes through testing, rendering the scope of the ratio limitation indefinite.

b. The Claims Are Indefinite Even Under RJ Tech’s Construction.

118. I understand that RJ Tech has proposed that “ratio of positive electrode material to negative electrode material . . . is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2V” should be construed as “the ratio calculated as the product of the *capacity* of the cathode active material *per unit measure* (e.g., mass or volume) and the amount of the cathode active material in the same unit measure (e.g., mass or volume) divided by the product of the *capacity* of the anode active material *per unit measure* (e.g., mass or volume) and the amount of the anode active material in the same unit measure (e.g., mass or volume), when the charge cutoff voltage is 4.2 V.” (emphasis added).
119. It is my opinion that this phrase is indefinite even under RJ Tech’s proposed construction for several reasons.
120. The claim language, specification and prosecution history each indicate that the inventors clearly understood that there are two methods of describing the capacity of an electrode: a theoretical value, which is based on stoichiometry and an empirical or practical value that is based on testing, i.e., practical specific capacity.
121. Independent Claim 5 of the ’641 patent, the only asserted independent claim, is directed to a “secondary lithium ion cell or battery characterized in that . . . has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and a ratio of positive electrode material to negative electrode material . . . from 1:1.0 to 1:2.5, as calculated by a *theoretic capacity* with a charge cut-off voltage set at 4.2V.” (’641 patent at 17:5-11 (emphasis added)).
122. The plain language of the claim requires a P/N capacity ratio to be calculated based on “theoretic capacity.”
123. RJ Tech’s proposed construction replaces “theoretic capacity” with “capacity.” But, RJ Tech’s construction is not consistent with the plain language of the claim because “capacity” is broad

enough to cover any kind of capacity, including both “theoretic capacity” and practical “specific capacity” or apparently a mixture thereof (as noted further below).

124. A POSITA also would not understand that claim 5 to be directed to any “capacity” ratio, including “practical capacity,” because, in contrast to the language of claim 5, independent claim 1 is directed to a lithium-ion battery with “a ratio of positive electrode material to negative electrode material of the secondary lithium ion cell or battery is from 1:1.0 to 1:2.5 as calculated by a *specific capacity* with a charge voltage limited to 4.2 V.” Thus, a POSITA would understand that the capacity ratio of claims 1 and 5 are calculated differently based on the difference in language.
125. Furthermore, as discussed above, the patent specification distinguishes between theoretic capacity and specific capacity when the charge cutoff voltage is limited to 4.2V. (See Paragraphs 66-72). Similar to claims 1 and 5, the patent specification also refers to embodiments where the ratio is based on “specific capacity” and embodiments when the ratio is based on “theoretic capacity” when the cut-off voltage is 4.2V:
- “It is one object of the present invention to provide a new method for improving capacity, average operating voltage and energy density of a secondary lithium ion cell or battery, wherein the charge cut-off voltage of the single cell is greater than 4.2 V, and less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, preferably from 1:1.16 to 1:2.5, as calculated by the *specific capacity with the charge voltage limited to 4.2 V.*” (641 patent at 3:17-25);
 - “Another object of the present invention is to provide a secondary lithium ion cell or battery, wherein the single secondary lithium ion cell has an charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, preferably from 1:1.15 to 1:2.5, as calculated by the *specific capacity with the charge voltage limited to 4.2 V.*” (*Id.* at 3:26-33);
 - For achieving the better effect, the charge cutoff voltage used in the present invention is preferably 4.3-5.2 V, and more preferably 4.2-4.8 V. In addition, the ratio of positive electrode material to negative electrode material of cell is 1:1.0 to 1:2.5 calculated by the *theoretical capacity under the charge cut-off voltage of 4.2 V.* The experiments showed that when the process parameters go beyond the aforesaid ranges, the properties of cell are deteriorated and unsuitable for use. *When the ratio of positive electrode material to negative electrode material is less than 1.0 calculated by theoretical capacity, the recycle life of cell is excessively reduced, while when said ratio is greater than 2.5, the volume efficiency of cell is notably reduced.*” (*Id.* 6:53-65);

- “Contrary to the prior art, the charge cut-off voltage of the single cell of said secondary cell or battery is greater than 4.2 V but less than 5.8 V, and the ratio of positive electrode material to negative electrode material calculated by the *theoretical capacity under the charge cut-off voltage of 4.2 V* is 1:1.0 to 1:2.5.” (*Id.* at 7:24-29).

126. Thus, the patent specification supports that a POSITA would understand that there is a difference between the ratio calculations in claims 1 and 5.
127. The prosecution history also indicates that the inventors believed that there was a difference between claiming ratios based on “practical capacity,” and “theoretic capacity” as RJ Tech included claims both.
128. For example, in its “Preliminary Amendment,” dated March 29, 2004, the applicant included claims with ratios based on “specific capacity” and “theoretic capacity” with a charge cut-off voltage of 4.2V:

1. (Amended) A method for improving the capacity, average operating voltage and specific energy of a secondary lithium ion cell or battery, characterized in that the charge cut-off voltage of the single cell is greater than 4.2 V but less than 5.8 V, ~~preferably within a range of 4.3 V to 5.2 V, and more preferably within a range from 4.3 V to 4.8 V;~~ and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, ~~preferably from 1:1.15 to 1:2.5,~~ as calculated by the specific capacity with the charge voltage limited to 4.2 V.

5. (Amended) ~~An electronic device using a secondary lithium ion cell or battery as energy source, characterized in that said electronic device comprises a protecting circuit, wherein the single lithium ion cell has a first overcharging protection voltage of greater than 4.35 V, and an overcharge release voltage of greater than 4.45 V, and an overcharge release voltage of greater than 4.25 V.~~ A secondary lithium ion cell or battery, characterized in that the single secondary lithium ion cell has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2 V.

(RJ00003150-54_Samsung (emphasis added)).

129. At other times, RJ Tech attempted to claim a ratio based on “capacities . . . with a charge cut-off voltage set at 4.2V”:

5. (Currently Amended) A secondary lithium ion ~~cell or battery, characterized in that the single secondary lithium ion cell has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and the ratio of positive electrode material to negative electrode material of the single cell is from 1:1.0 to 1:2.5, as calculated by the theoretic capacity with the charge cut-off voltage set at 4.2 V~~ comprising:

a positive electrode material;

a negative electrode material;

an electrolyte; and

a protection circuit,

wherein the protection circuit is configured such that a charge cut-off voltage is greater than 4.2V and less than 5.8V, and

wherein a ratio of positive electrode material to negative electrode material is between 1:1.0 to 1:1.25 when capacities of the positive electrode material and the negative electrode material are calculated with a charge cut-off voltage set at 4.2V.

(RJ00003037-38_Samsung (emphasis added)).

130. Notably, however, RJ Tech abandoned its claim to a “capacity” ratio in favor of a claim directed to a “theoretic capacity” ratio in response to an office action:

5. (Currently Amended) A secondary lithium ion cell or battery, comprising:
characterized in that the secondary lithium ion cell or battery has a charge cut-off voltage of greater than 4.2 V but less than 5.8 V, and a ratio of positive electrode material to negative electrode material of the secondary lithium ion cell or battery is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2 V.

a positive electrode material;

a negative electrode material;
an electrolyte; and
a protection circuit;
wherein the protection circuit is configured such that a charge cut-off voltage is greater than 4.2V and less than 5.8V, and
wherein a ratio of positive electrode material to negative electrode material is between 1:1.0 to 1:1.25 when capacities of the positive electrode material and the negative electrode material are calculated with a charge cut-off voltage set at 4.2V.

(RJ00003001-02_Samsung (emphasis added)).

131. Additionally, statements made by RJ Tech in its Patent Owner's Preliminary Response to IPR2023-01183 concerning the '641 patent ("POPR")²² also indicate that its construction with just "capacity" cannot be correct. For example, RJ Tech argued that the "design capacity" of the Abe prior art reference is "not" the "same as 'specific capacity' recited in claim 1 and the 'theoretic capacity' recited in claim 5". (POPR at 33). Thus, a construction that includes just "capacity" is broad enough to cover "design capacity" which RJ Tech has told the PTAB is different than "specific capacity" and "theoretic capacity" and cannot be correct be this additional reason.
132. As RJ Tech's construction is broad enough to include any type of "capacity," including, theoretical capacity based on stoichiometry, practical capacity based on experimentation, design capacity, and any other capacity measurement,²³ its scope is undefined and therefore indefinite because each type of capacity is determined in a different manner and will produce different results.
133. As discussed above (at Paragraphs 53-59) practical specific capacity is obtained through testing. However, the specification of the '641 patent does not provide necessary details to allow a determination of the practical specific capacity, which is included in RJ Tech's

²² I understand that RJ Tech's statements in its POPR are intrinsic evidence since they are part of the '641 patent's file history.

²³ RJ Tech also refers to "irreversible capacity" in its POPR (at 12-14)

proposed construction which includes “capacity”. As discussed below, because certain testing limits are unspecified, the ratio limitation is undefined in scope and indefinite.

134. Moreover, as discussed below, RJ Tech has also told the PTAB in its POPR that a half cell or three electrode cell is not used to determine the relative capacity of each electrode to determine the claimed ratio. But, the patent, and RJ Tech provide no other way to determine the capacity of each electrode, rendering the claim indefinite for this additional basis.
135. Furthermore, I note that RJ Tech has altered its proposed construction for this term in this case from the construction it proposed in the related Apple litigation. Specifically, RJ Tech changed its construction as shown below:

RJ Tech Construction – Apple Litigation	RJ Tech Proposed Construction
“the ratio calculated as the product of the capacity of the cathode active material <i>per mass unit</i> and the amount of the cathode active material in the <i>same mass unit</i> divided by the product of the capacity of the anode active material <i>per mass unit</i> and the amount of the anode active material in the <i>same mass unit</i> , when the charge cutoff voltage is 4.2 V.”	“the ratio calculated as the product of the capacity of the cathode active material <i>per unit measure (e.g., mass or volume)</i> and the amount of the cathode active material in the <i>same unit measure (e.g., mass or volume)</i> divided by the product of the capacity of the anode active material <i>per unit measure (e.g., mass or volume)</i> and the amount of the anode active material in the <i>same unit measure (e.g., mass or volume)</i> , when the charge cutoff voltage is 4.2 V”

(all emphasis added)

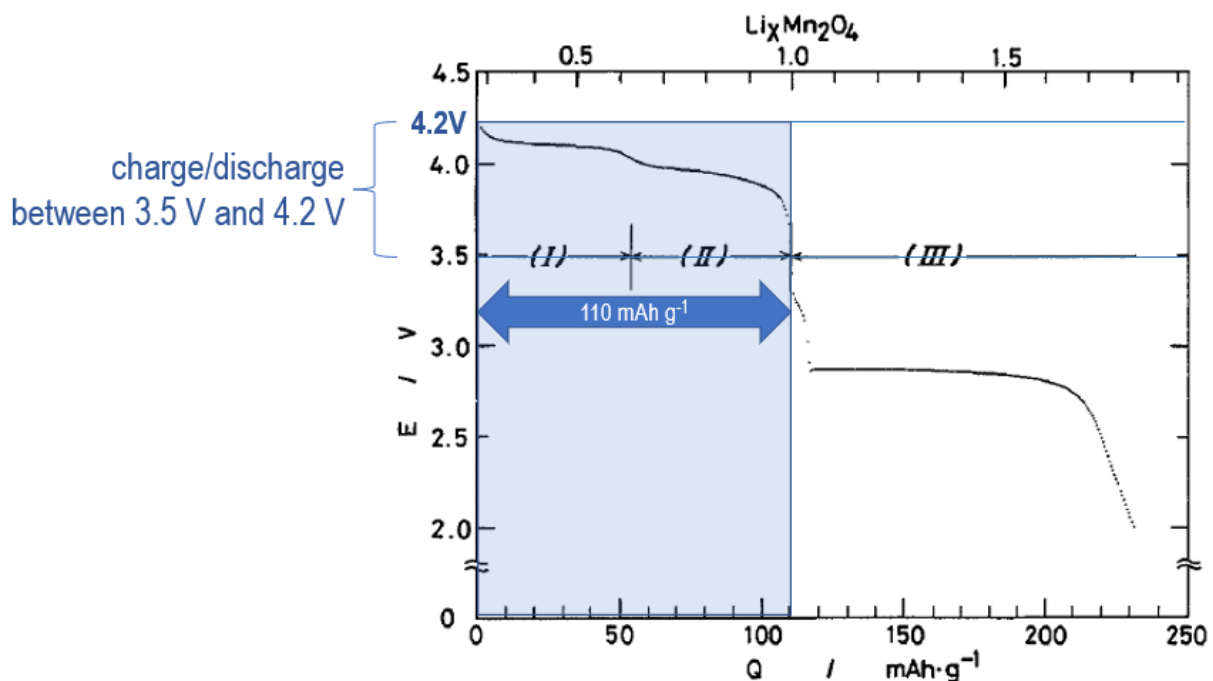
136. RJ Tech’s proposed construction in this case is broader, since it changed from “mass unit” to “unit measure (e.g., mass or volume)”. I do not agree that a POSITA would determine theoretic capacity or practical capacity based on volume. Use of capacity based on volume introduces yet more uncertainty in determining the capacity ratio. Within a cell, it is not possible to measure the volume of the active material. Use of volume would require measurement of mass and then converting this mass to a volume with the density. These active materials are produced

as powders and their densities depend greatly on processing conditions. A POSITA would not attempt to calculate the ratio based on volume.

i. Capacity Must Be Determined Over A Voltage Range And Providing Only The Upper Limit (e.g., 4.2 V) Does Not Tell a POSITA What Lower Value Is For The Capacity Determination.

137. As described above, the potential of each electrode varies with the amount of lithium contained in the host material. Thus, to find the practical specific capacity of the electrode the upper and lower potential limits must be known because the capacity varies depending on the specific cycling range used. In other words if one were to ask for the capacity of a specific material, such as lithium cobalt oxide (LiCoO_2) the capacity of two samples of the exact same material made the exact same way would be different if the electrode is cycled from 4.2 V to 3.5 V and then compared to the same material being cycled 4.2 V to 2.0 V. Because the range of voltages over which the capacity is being determined is larger in the latter example, the capacity will be larger too because more lithium is “rocked” between the electrodes.
138. Further because only potential differences can be measured, these limits need to be relative to a reference electrode as taught by the art. For applications of the technical field of the '641 patent, the most common choice for the reference electrode is lithium. (*See, e.g., '641 patent at 2:8-14 (“the reversible charge-discharge voltage is about 4.3V when metallic lithium is used as counter electrode . . .”)* (emphasis added)). If lithium is used as the reference electrode, then the positive electrode would need to be removed from the cell and assembled into a so-called half-cell (or alternatively into a three-electrode system), which uses lithium for the reference and counter electrode. By adjusting the potential relative to lithium, charge is inserted into or removed from the electrode and a specific capacity of the material can be measured.
139. As I mentioned above, the '641 patent claims do not have any requirements for the cathode material other than the resulting battery must be a lithium-ion cell or battery. ('641 patent at 8:5-41). One of the examples given in the patent is to use manganese oxides. (*Id.*). Therefore, I use that as one of my examples to show why the claim scope is not reasonably certain.

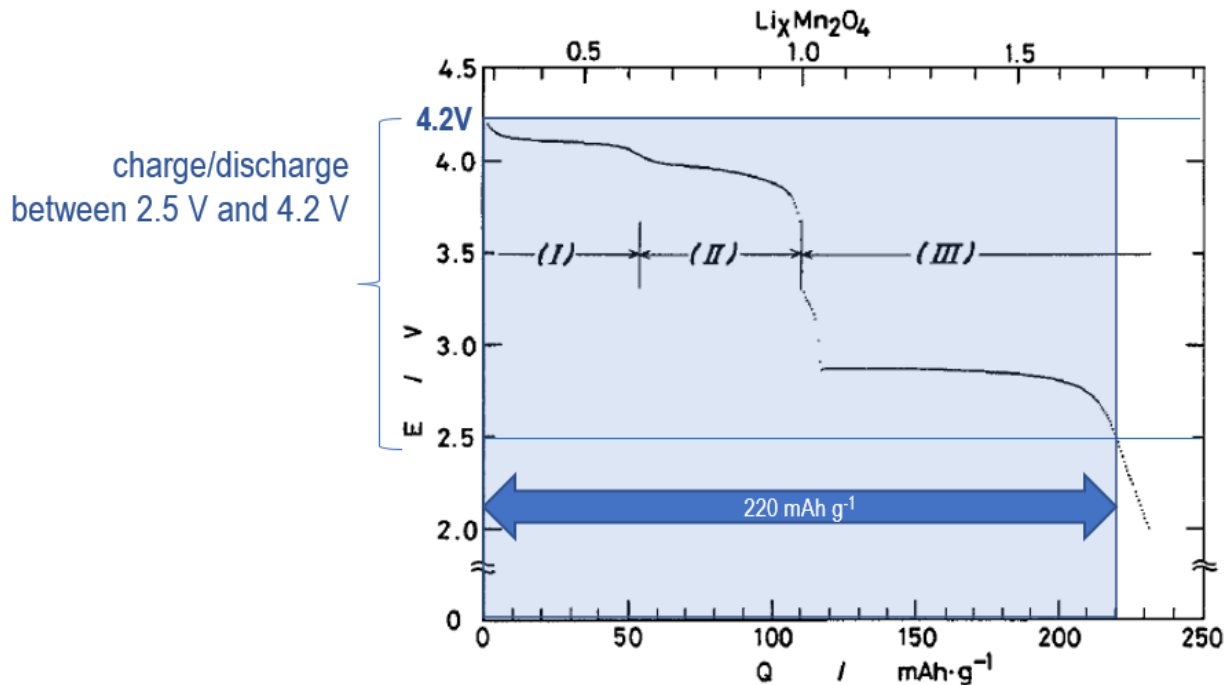
140. I will use a plot from a publication by Ohzhuku et al. from 1990 to illustrate this point using the behavior of a well known material called lithium manganese dioxide or “spinel.”²⁴ For the purposes of this exercise, I have assumed that the cut-off voltage is 4.2 V. It is very apparent from this plot, however, why specifying the lower limit is critical when determining the capacity. In the annotated version of Figure 2 from Ohzhuku that I have provided below, in the top figure I have assumed that the upper voltage limit is 4.2 V and the battery is discharged to 3.5 V. These numbers are consistent with the literature showing that spinel (LiMn_2O_4) was known to be cycled between, for example, 3.3 V and 4.3 V, 3.8 V, and 4.1 V, or even 3.5 V and 4.5 V. *See* Koksang 1996 at 8. When cycling a positive electrode made of Ohzhuku’s spinel at these voltages the capacity is 110 mAh g^{-1} as shown on the graph below.



141. But, this was not the only known range of voltages applicable for spinel. A POSITA would have seen that charging a battery including a spinel positive electrode to, for example, 4.2 V and then discharging to, for example, 2.5 V was also possible because there are examples of spinel being cycled between, for example, 2 V or 2.2 V and 4.25 V or 4.5 V. *See*

²⁴ Ohzuku et al., “Electrochemistry of Manganese Dioxide in Lithium Nonaqueous Cell,” J. Electrochem. Soc., 137 No. 3 (March 1990) 769-775 (“Ohzuku”).

Koksbang 1996 at 8. In this case, and Ohzhku's spinel material has a capacity of 220 mAhg⁻¹ even though the cutoff voltage and material are exactly the same.



142. The impact of this difference in capacity on the claimed ratio is apparent from an example. If the capacity of an arbitrary negative electrode is 10 mAh, and the loading of active material (LiMn₂O₄) for the positive electrode is 0.066 g, below are exemplary N/P calculations for both ranges since the lower limit is undefined:

3.5 V lower limit

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{0.066 \text{ g active material} \times \frac{110 \text{ [Ah]}}{\text{g active material}}} = 1.38$$

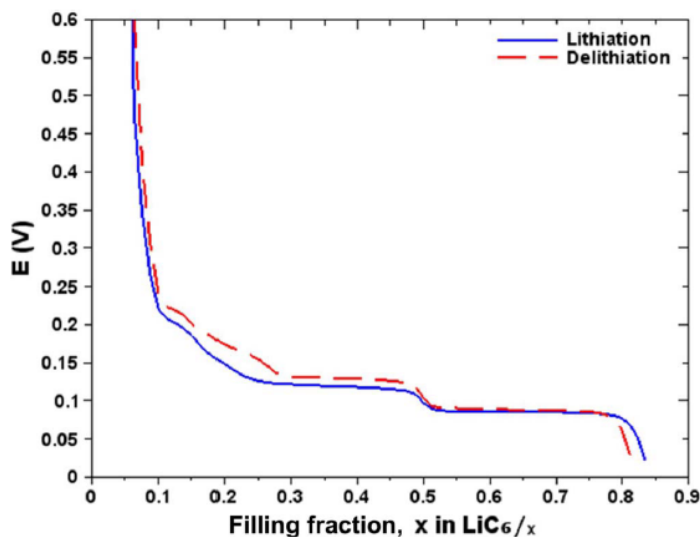
2.5 V lower limit

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{0.066 \text{ g active material} \times \frac{220 \text{ [Ah]}}{\text{g active material}}} = 0.69$$

The battery with a 3.5 V lower limit voltage falls in the ratio range of claim 5, while the same battery with a 2.5 V lower limit voltage is outside of the ratio range of claim 5. Without a clear value for the lower potential limit from the '641 patent claims (or even

specification or prosecution history), a POSITA would have no way to know whether making a battery or cell with, for example, Ohzhku's spinel would fall inside or outside of the claimed ratio. That the same cell can either fall within the claimed range or not depending what the lower voltage limit is when the capacity is determined. This ambiguity in the '641 patent's determination of capacity renders the scope of the claims undefinable and unreasonably uncertain to a POSITA. The ratio limitation could be met or not for the exact same amounts of the exact same materials made the exact same way, charged to the same cut-off voltage (e.g., 4.2 V) depending on the lower voltage limit, which is found nowhere in the '641 patent or its prosecution history.

143. Koksang 1996 also highlights that cathode materials will have a wide range of specific capacities depending on "materials synthesis, electrode formulation, electrolyte and test conditions" including voltage limits used for testing. For example, examples 29 and 32 show that lithium nickel oxide (LiNO_2) cycled between 2.5-4.2 V has a higher capacity (190 for first half-cycle and 155 afterward) than LiNO_2 cycled between 3.3-4.2 V (151 for first half-cycle and 126 afterward). Koksang 1996 at 5. As I explain below, the difference in the lower limit voltage is not the only thing that impacts the capacity of the material, so even if the voltage range is the same, the result can be different if, for example, the C-rate is changed.
144. A similar analysis is required to find the specific capacity of the negative electrode. The '641 patent is silent on how this should be done. As an initial matter, the 4.2 V identified in the patent is not relevant for the negative electrode because such a high potential relative to lithium is not observed in any materials used as negative electrodes. (*See, e.g.*, the data in figure from Allart 2018 for example, indicating cycling from about 0.02V to about 0.6V relative to lithium).



Additionally, as is evident from Allart et al.'s 2018 data shown in the plot, the capacity of the anode also changes depending on the potential limits. Determination of the practical specific capacity requires separate specification of the lower and upper potential limits to be well defined. Allart 2018 report the theoretical capacity of commercial graphite (SLP30) as 372 mA g^{-1} , which is based on the stoichiometry for LiC_6 . But, I understand that RJ Tech has said that the capacity recited in the claim is not the theoretical capacity (what RJ Tech has called the "theoretical maximum capacity"). But even if the practical (experimental) capacity is considered, Allart shows that the practical capacity is about 260 mA g^{-1} when the material is cycled between 0.2 and 0.05 V.

145. Similarly, in Kim 2000, mesocarbon microbeads (MCMB, like those disclosed in the '641 patent examples) were cycled between 1.0V to 0.01V relative to lithium. Kim 2000 at 173. Kim 2000 reported that the discharge capacity is 330 mAh/g on the 1st cycle, but 260 and 235 mAh/g on the 2nd and 3rd cycles, respectively. *Id.* This further shows that the range of voltage matters for the capacity of the anode, as well as the time point in which the measurement is made—i.e., during the first cycle or after several cycles. Again, which cycle the capacity is determined at is not specified, but is clearly material for determining whether the ratio limitation is being practiced or not.
146. Thus, essential potential limits for the negative electrode are missing from the '641 patent too.

147. As such, the capacity ratio cannot be calculated, even using the equation expressed by both parties' phrasing with any level of certainty because the voltage range for both electrodes are undefined and that is a critical consideration to determining the capacity at a charge cut-off voltage of 4.2 V. Without a reliable consistent way to determine capacity, the capacity ratio is unspecified and indeterminable with any reasonable degree of certainty.
148. Furthermore, there is no known standard from which to specify the voltage ranges for both electrodes and the intrinsic evidence and prior art points to numerous different ranges that could be used, particularly since the claim is directed to any secondary lithium-ion cell or battery which can be used for any purpose.
149. Notably, I understand that RJ Tech asserted in its Supplemental Response to Interrogatory No. 7 that the capacity used for the materials in Example 1 of the '641 patent was 137 mAh/g for lithium cobalt oxide and 372 mAh/g for MCMB. Notably, while neither of these values are found in the '641 patent specification, the specification indicates that the actual (practical) capacity (i.e., specific capacity) of lithium cobalt oxide is "120-140 mAh/g, i.e., about 50% of the theoretical capacity." ('641 patent at 1:64-2:1). However, 372 mAh/g is the theoretical capacity for graphite, not a practical capacity as indicated above. Thus, RJ Tech appears to be mixing capacity determinations in a manner that cannot be reasonably determined from the specification of the patent. Specifically, nothing tells a POSITA to determine the capacity of the anode using one technique (e.g., a stoichiometric technique) and determine the capacity of the cathode using some other, unspecified methodology.
150. In addition to the capacity changes for MCMB depending on which cycle is considered (*see, e.g.*, Kim 2000 at 173 (discussed above)), there are other unstated considerations that a POSITA would need to evaluate when specifying the capacity of the anode. For example, Terzidis 2000 reported that the reversible capacity of graphite depended on the particular binder used, and similarly that the reversible capacity of graphite was between 230-250, while irreversible capacity was between 85-215. Terzidis 2000 at 299-300. The Handbook of Batteries provides additional different practical experimental specific capacities for various carbons (at 35.20):

TABLE 35.4 Properties and Performance of Various Carbons (Experimental Values). (*From Ref. 67.*)

Carbon	Type	Specific capacity (mAh/g)	Irreversible capacity (mAh/g)	Particle size D ₅₀ (μm)	BET surface area (m ² /g)
KS6	Synthetic graphite	316	60	6	22
KS15	Synthetic graphite	350	190	15	14
KS44	Synthetic graphite	345	45	44	10
MCMB 25-28	Graphite sphere	305	19	26	0.86
MCMB 10-28	Graphite sphere	290	30	10	2.64
Sterling 2700	Graphitized Carbon Black	200	152	.075	30
XP30	Petroleum coke	220	55	45	N/A
Repsol LQNC	Needle coke	234	104	45	6.7
Grasker	Carbon fiber	363	35	23	11
Sugar carbon	Hard carbon	575	215	N/A	40

151. Thus, to the extent RJ Tech is asserting that the proper calculation of the ratio can use practical *capacity* for the positive electrode and a *theoretical capacity* for the negative electrode—which is allowed by their broad construction of just “capacity”—that is nowhere specified by the patent and further renders the claimed ratio indefinite.
152. Moreover, RJ Tech’s unsupported assertion on the capacities used for Example 1 also raises the question of whether the capacity is determined based on the first cycle of a material or after several cycles because as demonstrated, such a distinction has a material difference on the capacity for any given electrode. This further renders the claimed capacity ratio indefinite under any construction of the term.

ii. Determination of Capacity Requires Knowledge Of the Discharge Rate, And Merely Telling the POSITA To Use Parameters “Commonly Used In the Art” Is Insufficient Because There Was Variability in Charge and Discharge Rates.

153. In contrast to the theoretical capacity, which is based on stoichiometry, the rate of charging or discharging also matters when determining the specific capacity experimentally. The only guidance that the ’641 patent provides on the matter is to state that “[e]xcept voltage, all process parameters for charge and discharge *are commonly used in the art.*” (’641 patent at 9:22-23.) The prosecution history provides no guidance. The problem is that there are no universal standards for charging and discharging any particular cell. The literature confirms the wide variability of charge and discharge rates in lithium-ion batteries and the

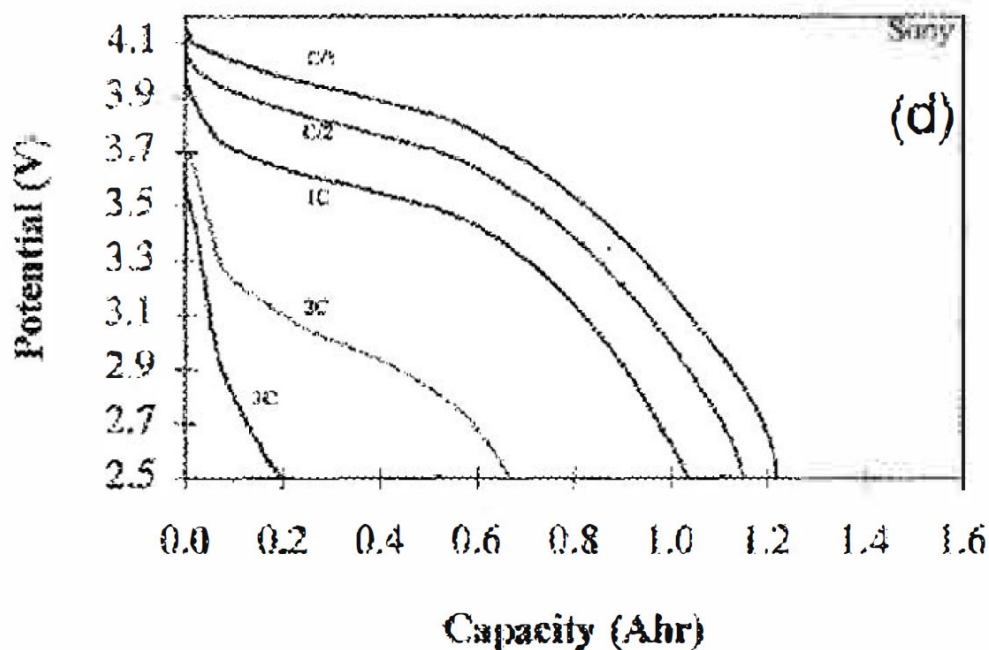
impact that these varying rates have on the capacity of an electrode active material is well-documented. The '641 patent provides no insight into this matter.

154. It was well known to a POSITA in 2001 that the capacity of an electrode changes depending on rate of charging or discharging. I wrote about this in my recent book. (*See, e.g.,* Fuller and Harb, *Electrochemical Engineering*, Wiley 2018 at 161 (“the same cell with a nominal rating of 20 Ah will have a lower useable capacity at higher rates. A correction factor called the capacity offset is frequently applied to the rating of the battery when the cell is discharged at a current other than the one at which it was rated.”); *see also* Mayer 1993 at 7 (“Substantial decreases in capacity and energy are observed at above a 1C discharge rate. The capacity and energy density approach 0.95 Ahr and 83 Whr/kg at very low discharge rates.”) and Fig. 7; Bates 2000 at 36 (“At low currents, the discharge capacity [of LiCoO₂] corresponds to about 0.5 Li per CoO₂ or 137 mAh/g. The shift to lower potentials with increasing current is due to cell resistance.”) and Fig.3; Johnson 1998 at 52-53 (illustrating the effect of discharging cells from C/5 to 3C); Ning 2003 at Fig. 2; Handbook of Batteries at 3.5 (“It is to be noted that the capacity of a battery generally decreases with increasing discharge current.”)).
155. Batteries are typically operated between a lower and upper potential limit of the cell. The cell potential on charging, for example, can be expressed as

$$V_{cell} = U + |\eta_{ohmic}| + |\eta_{neg}| + |\eta_{pos}| + |\eta_{con}|$$

U , the equilibrium potential, depends on the amount of lithium held in the host materials. During charging, the cell potential, V_{cell} , is greater the equilibrium potential. Each of the η terms is a polarization, which are associated with ohmic, kinetic, and mass-transfer phenomena in the cell. Each causes the cell potential to increase from the equilibrium value. Further, each of these polarizations increases as the C-rate for charging increases. This means that the upper cutoff potential will be reached sooner (fewer coulombs passed, and lower capacity) with increasing C-rate. Similarly on discharge, the lower cutoff potential is reached at a lower capacity.

156. There are numerous examples of this phenomena in the literature for lithium-ion batteries. For example, Figure 5.d from Johnson 1998²⁵ show a difference of about 20 percent between a discharge rate of C compared to C/5 for a Sony commercial cell (similar to the one described in the background of the '641 patent) as illustrated in the below graph for C-rates of discharge ranging from C/5 to 3C. Specifically, C/5 results in a capacity of about 1.22 Ahr whereas a rate of C results in a capacity of about 1.02 Ahr. The data shown below are for a full lithium-ion battery and include the effects of both the positive and negative electrodes on rate capability. It is well known that measured capacity is decreased with increasing C-rate for electrodes too, this is further discussed in paragraph 158 below. For transition metal oxides used for the positive electrodes, the impact of rate is much larger on the positive electrode than for a graphite electrode, for example. Thus, it is a reasonable approximation to ascribe the decrease in capacity to the positive electrode.



157. As shown by this data for the capacity of a commercial Sony cell can change whether a battery falls inside or outside of the ratio of claim 5 as illustrated below (using the 20 % change in capacity as the C-rate changes from C to C/5).

Practical specific capacity based on C rate:

²⁵ Johnson, J. Power Sources 70 (1998) 48-54 ("Johnson 1998").

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{9.57 \text{ [mAh]}} = 1.04$$

Practical specific capacity based on C/5 rate:

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{1.2 \times 9.57 \text{ [mAh]}} = 0.87$$

Even larger differences can be found if comparing C/5 to 2C (about 0.66 Ahr) or 3C (about 0.2 Ahr). Thus, again, since there are no charging/discharging conditions provided the same cell can fall inside or outside of the claimed ratio merely on conditions that are not identified and unspecified in scope.

158. Similarly, Bates 2000 also discusses the difference that the rate of discharge can make for capacity. For example, Bates 2000 shows the capacity for LiCoO₂ when discharged at 0.1, 0.4, 1, 2 and 4 (mA):

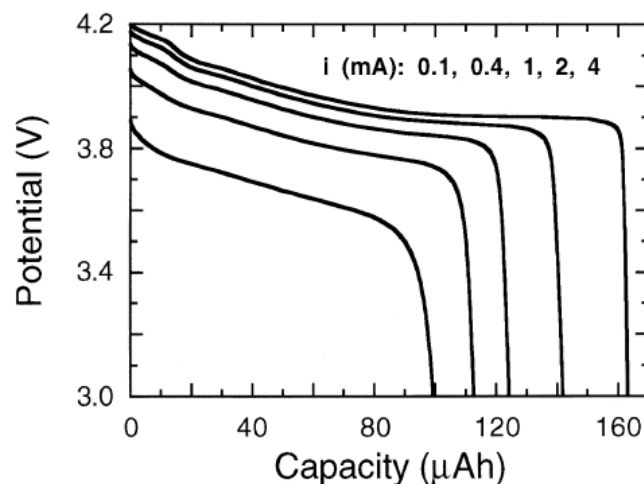


Fig. 3. Discharge of a lithium cell with a 1-cm² × 2.5-μm thick crystalline LiCoO₂ cathode.

This cell used lithium metal as the negative electrode and is equivalent to a half-cell measurement described in paragraph 54. As shown the capacity increases from about 100 mAh (4 mA current) to about 163 mAh (0.1 mA current) depending on the discharge rate. A comparison of 0.1 mA (163 mAh) to 1 mA (123 mAh) is a difference of about 30%. Thus, the discharge current can affect whether a battery falls within or outside of the claimed ratio.

159. Furthermore, there is no known standard from which to specify the charging current and discharge current as the intrinsic evidence and prior art point to numerous different ranges that could be used, particularly since the claim is directed to any secondary lithium-ion cell or battery which can be used for any purpose.
160. Thus, it is my opinion that the failure of the claim to provide any guidance on the charge and discharge rates used to determine capacity of the positive and negative electrode material renders the claim scope undefined and indefinite because the same battery, with the same materials, made the same way, may fall inside or outside of the claimed ratio simply depending on which undefined charge/discharge rates are used.

iii. Determination of Capacity Requires Knowledge Of The Charging Protocol, And Merely Telling the POSITA To Use Parameters “Commonly Used In the Art” Is Insufficient Because There Was Variability In Charging Protocols.

161. Also in contrast to the theoretical specific capacity, which is based on stoichiometry, the charging protocol also matters when determining the specific capacity experimentally. The only guidance that the '641 patent provides on the matter is to state that “[e]xcept voltage, all process parameters for charge and discharge *are commonly used in the art.*” ('641 patent at 9:22-23.) The prosecution history provides no guidance. The problem is that there are no universal charging protocols and those used can vary considerably. The '641 patent thus lacks this additional detail a POSITA would know was critical to determining the capacity of the electrodes of any particular battery or cell.
162. As discussed above, various protocols were known for charging lithium-ion batteries including constant current (CC), constant voltage (CV), and constant current – constant voltage (CC-CV). A POSITA would have recognized from the literature that “[t]he capacity of a Li-ion battery depends on the protocol used to charge the battery.” *See, e.g., Sikha 2003 at 76.*
163. For instance, constant current (CC) charge to the cutoff potential will yield a different capacity than constant current followed by constant voltage (CC/CV) to the cut off potential. For example, Fig. 1 below (which provides a general illustration of charging a lithium-ion battery) shows that for a charging rate of 1C, when the charge cutoff voltage is

reached, the battery has been charged to only about 60% of its practical capacity. Such a large difference can also alter whether a battery falls within the claimed ratio or not.

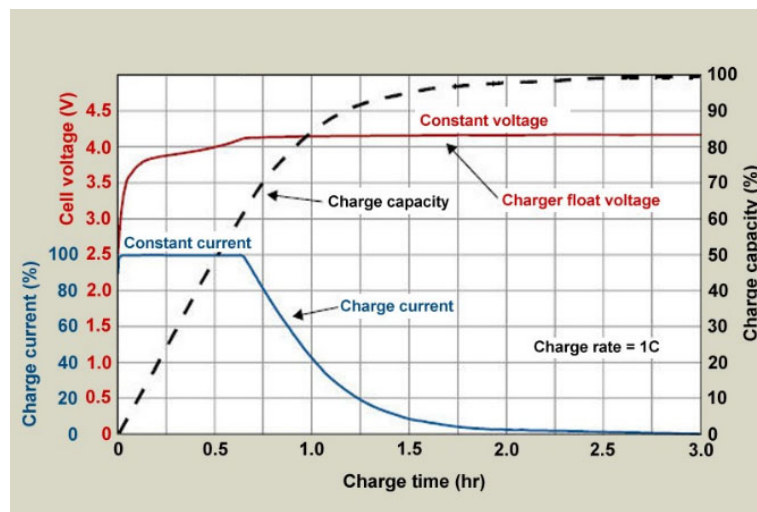


Figure 1 <https://batteryuniversity.com/article/bu-409-charging-lithium-ion>

164. Assuming this charging behavior is present when measuring the capacity of the positive electrode, and 10 mAh for the capacity of the negative electrode, below are exemplary calculations of the capacity ration.

Capacity ratio for full CC/CV charge:

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{10.5 \text{ [mAh]}} = 0.95$$

Capacity ratio for CC charge to cut-off potential:

$$\frac{N}{P} = \frac{10 \text{ [mAh]}}{0.6 \times 10.5 \text{ [mAh]}} = 1.59$$

165. In the first case the cell does not fall within the claimed ratio, however, in the second situation the same cell falls within the claimed ratio. Thus, the charging protocol can have a material effect on whether the same cell falls within or outside of the claimed capacity ratio.
166. In an example of a well-defined method of determining specific capacity, e.g., Zhang 2006 includes the C-rate at which the capacity is measured as well as the charging protocol. The

'641 patent provides no such details even though those details can change whether a battery is falls within the claimed ratio or not based on how they are set. This is demonstrated by numerous prior art references known to the POSITA.

167. The '641 patent does not specify any charging protocol. Furthermore, RJ Tech argued in a related case against Apple that the claims of the '641 patent are not limited to any specific protocol, and I understand that the court accepted that argument. *See RJ Tech v. Apple*, No. 8:22-cv-1874 (C.D. Cal.), Dkt. 82 at 7-11.
168. Because the claim has no limit on what charging protocol is used, and the charging protocol clearly affects the measured capacity of an electrode, including whether the cell or battery including the electrodes falls within or outside the claimed ratio, the claim scope is undefined and indefinite.

iv. Simply Identifying a Charge Cut-Off Voltage At Which To Determine Electrode Capacity is Insufficient to Provide a Clear Scope for the Capacity Ratio Limitation; Additional Considerations

169. The parties agreed to construe the “charge cutoff voltage” as “the maximum voltage to which the battery is configured to be charged.” This means that the upper potential limit is effective during charging (as opposed to discharging) and that there may be current flowing at the point that the cutoff potential is reached. But a charge cut-off voltage of 4.2 V (or any other value) by itself does not provide enough information to determine the capacity ratio of the cell for at least reasons discussed above.
170. First, the starting point of the charging process must be clearly defined. As discussed above in paragraphs 137-152, if a different lower potential limit (starting point) is selected, the measured capacity can be different. Nowhere in the '641 patent is the starting point defined. If the starting point is undefined, the capacity, and therefore, the capacity ratio is indefinite because its scope is not reasonably certain.
171. Second, the rate of charging or discharging affects the potential of the cell due to polarizations in the cell as described in paragraphs 152-160. With faster charging rates, the point at which the upper potential limit is reached occurs sooner (less lithium extracted from the positive electrode). As a result, the measured capacity changes as the rate of

charging is altered. Nowhere in the '641 patent is the rate of charge or discharge defined, thus the specific capacity and therefore the capacity ratio is indefinite.

172. Third, the charging (CC, CV, CC/CV) is not specified in the '641 patent nor can they be discerned from RJ Tech's constructions, which is also material to determining the capacity ratio as discussed above in paragraphs 161-168.
173. Furthermore, the capacity ratio cannot be determined from an experiment at the full cell level as has been asserted by RJ Tech in its POPR and in the related Apple litigation. Specifically, RJ Tech asserted in the Apple litigation that "the 'charge cut-off voltage' as recited in this term [i.e., the ratio limitation] should refer to the full-cell voltage." (Dkt. 74 at 12).
174. Additionally, in its Patent Owner's Preliminary Response to IPR2023-01183 concerning the '641 patent (POPR),²⁶ RJ Tech argued that the "the 'charge cut-off voltage measured for the disclosed full-cell voltage two-electrode system, not an undisclosed three-electrode half-cell voltage system." (At 17-18).
175. RJ Tech further asserted in its POPR that the "design capacity" of the Abe prior art reference is "not" the "same as 'specific capacity' recited in claim 1 and the 'theoretic capacity' recited in claim 5". (POPR at 33). This adds further confusion—and not clarity—to how to determine the capacity ratio as recited in the claim. As discussed above (in Paragraph 55), the Abe reference determines a practical specific capacity for each electrode through testing using a three electrode system, which is the commonly known way to determine practical specific capacity. RJ Tech pointed this out in its POPR: "The charging capacity can be obtained, for example, by continuously recording a voltage that changes over time by applying a constant current *using a three-electrode cell* in which both the counter and the reference pole are made of metal lithium" (POPR at 23). RJ Tech then asserted that "[i]n contrast to the disclosure in Abe, the '641 Patent describes the 'charge cut-off voltage' as the full cell voltage between the negative electrode and the positive electrode." (*Id.*) Thus, RJ Tech has told the PTAB that "as calculated by a theoretic capacity with a charge cut-off voltage set at 4.2V" is not using 4.2V

²⁶ I understand that RJ Tech's statements in its POPR are intrinsic evidence since they are treated as if they are part of the '641 patent's file history.

relative to a lithium reference electrode. Thus, a POSITA in view of that statement would understand that RJ Tech has asserted that, contrary to the known technique for determining specific capacity, a three electrode cell (or half cell) is not used to determine the capacity ratio of the patent claims.

176. But, a POSITA cannot determine a capacity ratio from a battery level (full-cell) test. Unquestionably, the capacity of the battery in Ah can be found from full cell tests, and indeed this is an important quantity to measure the capacity retention. In contrast to the half-cell tests on individual electrodes described by Abe, Zhang 2006, Guyomard 1992, the '641 patent and numerous other references (discussed above in Paragraphs 54-58)—which RJ Tech has stated is not how the capacity ratio is obtained—applying limits to a battery or full cell is unsound as a means for determining the capacity ratio. During tests of the assembled battery (full cell test) the magnitude of the charge removed from the positive electrode is identical to the charge put into the negative electrode. Thus, under RJ Tech's own statements to the PTAB, the ratio of capacities (N/P) will be unity (i.e., 1) regardless of the specific capacity of the individual electrodes. Thus, by definition every battery would fall within the claimed ratio which cannot be correct. If that argument were accepted, then claim makes no sense and the claim should just say the ratio is 1.
177. Moreover, the negative electrode in the cell cannot be used as the reference for the potential of the positive electrode for at least two reasons. First, different negative electrodes have different potentials and therefore would produce different results. This renders the 4.2 V found in the '641 patent meaningless. Second, in contrast to lithium metal that has a constant potential irrespective of the amount of lithium deposited, the potential of an insertion material, such as carbon or titanium disulfide, varies with the amount of lithium inserted, rendering its use as a reference electrode negligible.
178. The allowable potential of negative electrode has a practical limit too. *See, e.g.,* Zhang 2006 ("For the MCMB anode, the lowest lithiation capacity peak potential is 0.065V versus Li^+/Li . This means that the maximum over-potential for the charging process must not exceed this value, otherwise, Li plating occurs."). Thus, there is a practical limit for the negative electrode, which is different from the theoretical limit. The inventors cannot adopt a practical capacity for the positive electrode and then use a theoretical capacity (which

they describe as a theoretical maximum capacity) for the negative, particularly based on the plain language of the claim. Second, the acceptable materials for the negative electrode are described broadly, “...a carbonaceous or non-carbonaceous substance capable of doping and dedoping lithium ion” and, as discussed above, various carbons can have different capacities and properties.

179. Moreover, tin oxide is specifically identified as a potential anode material. ('641 patent at 8:56-63). If LTO is used for the negative electrode instead of graphite, the potential relative to lithium for LTO is about 1.5 V relative to graphite. (See, e.g., Chauque et al., J. Electroanal. Chem., 799 (2017) 142-145). Using a charging voltage of 4.2 volts between the two electrodes to find capacity could lead to permanent damage of the cell depending on the materials used. The battery or cell voltage is

$$V_{cell} = 4.2 = \phi_p - \phi_n$$

When graphite is used, the potential of the positive electrode relative to lithium is

$$\phi_p = 4.2 + \phi_{n,graphite} \approx 4.3 \text{ V(Li/Li}^+)$$

When LTO is used, the potential of the positive electrode is

$$\phi_p = 4.2 + \phi_{n,LTO} \approx 5.8 \text{ V(Li/Li}^+)$$

A POSITA would have understood that removing the amount of lithium from LiCoO_2 to achieve a potential of 5.8 V may permanently damage the cell depending on the materials used.

180. Accordingly, for each of the reasons discussed herein, a POSITA at the time of the Asserted Patents would have found the phrase “ratio of positive electrode material to negative electrode material . . . is from 1:1.0 to 1:2.5, as calculated by a theoretic capacity with a charge-cut-off voltage set at 4.2V” to be indefinite because the technique for determining the capacities needed to evaluate whether a lithium-ion cell or battery is inside or outside of the claims is not disclosed or suggested in the '641 patent or the prosecution history, and a number of unspecified and non-standardized factors were known to influence

capacity of positive and negative electrodes in ways that are material to the claims of the '641 patent.

B. “Maintains at least []% of capacity after 400 cycles” (Claims 11-14)

181. Samsung asserts that the phrase “maintains at least []% of capacity after 400 cycles” is indefinite. I agree with Samsung.
182. The meaning of this ratio (percentage) is straightforward and widely used. However, when the percentage of remaining capacity is used to define the patent claims in the '641 patent, there are important, meaningful details that are required to inform a POSITA about the scope of the claims and those details are missing in this case.
183. Specifically, there are at least two aspects of this measurement vital to providing a meaningful and well-defined number for capacity retention: 1) when the initial discharge capacity is measured; and 2) details of the charging and discharging protocols as well as environmental conditions, including temperature. Because the '641 patent provides no guidance on these issues, this phrase is indefinite and lacks a reasonably clear scope.

a. When The Initial Discharge Capacity Is Measured Is Material To Evaluating The Percentage of Remaining Capacity After 400 Cycles.

184. It is well known that lithium-ion batteries “exhibit a sharp decay in capacity during the first few cycles.” (*See, e.g.,* Johnson 1998; *see also* Kim 2000 at 173 (indicating that the discharge capacity for MCMB is 330 mAh/g on the 1st cycle, but 260 and 235 mAh/g on the 2nd and 3rd cycles, respectively)). This degradation is associated principally with the build-up of a solid electrolyte interphase (SEI), which irreversibly consumes lithium, making less available for cycling. Additionally, cells degrade with time even when not in use, i.e., calendar ageing and/or self-discharge. In order for capacity retention to be meaningful, the point where the initial discharge capacity is measured must be defined. Starting points that include the formation of the battery, as shipped battery, and as received battery can yield different percentages of capacity retention.
185. For example, Guyomard 1992 (at 941) reported a 23% or 21% loss in capacity during the first cycle depending on which electrolyte was used when cycled at room temperature and a 27% and 25% loss in capacity during the first cycle for the same batteries when cycled at 55°C. The battery that exhibited the 27% loss would be outside of the claim just upon

the first cycle, even though the batteries stabilized after the first few cycles.

186. Similarly, Guyomard 1994 (at 232-233) indicates a 20% loss for cells using a coke negative electrode and 7% loss for cells using a graphite negative electrode over the initial few cycles:

Fig. 13b shows variation of the reversible capacity as a function of the cycle number. Both materials show an irreversible capacity loss (about 20% for coke and 7% for graphite) which is interpreted as the reductive degradation of the electrolyte. Further cycles are reversible, i.e., discharge and charge cycles correspond to the same capacity, indicating that the electrolyte reduction during the first cycle produces a stable passivating layer. Coke exhibits a capacity corresponding to 0.65 Li per 6 carbon atoms with an average intercalation voltage of 0.4 V, while graphite intercalates 1.1 Li per 6 carbon at about 0.1 V. It is important to note the very low irreversible capacity loss on graphite during the first cycle as compared to the loss reported in other electrolytes [32]. This behavior makes the efficient use of the graphite/electrolyte interface possible in a rocking-chair cell.

187. As another example, Arora 1998 reports that about 14% “excess capacity is a measure of the amount of lithium needed to form a stable film over the electrode surfaces. The loss of cyclable lithium to create this passivation layer *has a profound impact on the capacity balance in the cell* because it can remove a significant portion of the cyclable lithium depending on the type of carbon used.” (*Id.* at 3649 (emphasis added)). Arora 1998 further states:

Lithium-ion cells exhibit a sharp decay in capacity during the first few cycles. This period is known as the formation period during which cells are conditioned prior to use. It is generally desirable for the capacity decay observed after the formation period to be very small compared to the total cell capacity, after which the charge-discharge reactions are nearly 100% efficient. The sharp decay in capacity is due primarily to the solid electrolyte interface layer formation on the negative electrode. Passivation of the carbon electrode during the formation period and subsequent capacity loss are highly dependent on specific properties of the carbon in use, such as degree of crystallinity, surface area, pretreatments, and other synthesis and process details.^{42,44-46, 52} After the first few cycles, the cell stabilizes and exhibits a constant capacity. The formation cycles are one of the critical steps in the manufacture of lithium-ion systems. For graphitic materials such as Osaka Gas mesocarbon microbeads (MCMB), the irreversible capacity is as low as 8 to 15%, whereas for hard carbons it can be as high as 50% of the reversible capacity.

(*Id.* at 3650).

188. Zhang 2000 similarly describes the formation of the SEI over the first few cycles:

It is well known that the irreversible capacity loss in Li-ion batteries is significant during first charge–discharge cycle due to the irreversible capacity loss in the carbon electrode [10]. The SEI on carbonaceous electrode consists of many different materials including LiF, LiCO₃, LiCO-R, Li₂O, lithium alkoxides, nonconductive polymers, and more [11]. Since an optimized SEI can be formed on the surface of carbon electrode during initial cycles [11], the capacity loss due to impedance on carbon electrode is very small during later cycles. In other words, the carbon electrode causes capacity fade of the lithium-ion cells mainly during formation cycles, which were done by the manufacturers [3,10].

(*Id.* at 128).

189. Thus, depending on whether the capacity is first measured at initial discharge or after the first few initial cycles after the SEI is formed is likely to be highly relevant to whether a battery meets the cycling limitation or not. The '641 patent provides no clues about when the first cycle should be counted (or, if instead, any 400 consecutive cycles is acceptable). The '641 patent examples do refer to “[a]fter formation and test” the cells had a specified capacity “after 400 recycles.” ('641 patent at 10:45-49). But, the patent is silent about whether the initial cycling is considered part of “formation” of the battery, and if not, how long both in terms of calendar days and in terms of battery cycles “[a]fter formation” is intended to be.

b. Details Of The Charging And Discharging Protocols As Well As Environmental Conditions, Including Temperature, Are Material To Evaluating The Percentage of Remaining Capacity After 400 Cycles.

190. To measure the discharge capacity loss of the cell, the cell must start in a known state. Typically, the charging protocol would be specified. Even the charge cut-off voltage specified (e.g., a value over 4.2 V and less than 5.8 V), the '641 patent provides no limit upon or guidance about the charging protocol. Instead, the patent states that “[e]xcept voltage, all process parameters for charge and discharge are commonly used in the art.” ('641 patent at 9:22-23). This does not specify whether the protocol might be CC or CV or CC/CV as a few well-known examples. Further, if a constant current (CC) is used, this current must be specified. Once charging is complete, often the battery is allowed to rest for a given amount of time before commencing the discharge. The coulombs passed during discharge are recorded, typically in amp-hours. The rate of discharge (e.g., C/10, C/5, C/2,

C, 2C, 3C, or 5C) is specified along with the discharge cut-off potential. The temperature for the cycling should also be provided. Even though a POSITA would recognize that each of these variables are material to capacity and cyclability and can greatly affect the outcome of a test performed over 400 cycles, the '641 patent does not specify any of these conditions.

191. Moreover, none of these parameters are set forth in the art consistently in a way that would allow a POSITA to choose a set of variables that would yield consistent results. For example, it is incorrect to assume that the battery would simply be charged and discharged at a fixed rate at room temperature. Within the scope of the technical field of the '641 patent (i.e., secondary lithium-ion cells or batteries), a variety of cycling tests and environmental conditions would be encountered depending on the application.
192. For example, the Handbook of Batteries indicates at 35.35 that "Li-ion batteries can be charged from -20°C - 60°C and discharged from -40°C - 65°C." The Handbook of Batteries provides the below table concerning general performance characteristics:

TABLE 35.11 General Performance Characteristics of Li-ion Batteries

Characteristic	Performance range
Operational cell voltage	4.2 to 2.5 V
Specific energy	100 to 158 Wh/kg
Energy density	245 to 430 Wh/L
Continuous rate capability	Typical: 1C High rate: 5C
Pulse rate capability	Up to 25C
Cycle life at 100% DOD	Typically 3000
Cycle life at 20 to 40% DOD	Over 20000
Calendar life	Over 5 years
Self discharge rate	2 to 10%/month
Operable temperature range	-40°C to 65°C
Memory effect	None
Power density	2000 to 3000 W/L
Specific power	700 to 1300 W/Kg

(*Id.*) The C rate can vary from at least 1C – 5C, and, if pulsed, the pulses can have a C rate of up to 25C. Cycles can also be determined by 100% depth of discharge or 20 to 40%

depth of discharge which also makes a significant difference in cycle life. (*Id.*; *see also id.* at 35.35-35.67; Choi 2002).

193. The United States Advanced Battery Consortium (USABC) produced a test manual that identifies cycling that reflects the Federal Urban Driving Schedule (FUDS) as required for electric vehicle batteries, such as those referenced in the '641 patent. (ELECTRIC VEHICLE BATTERY TEST PROCEDURES MANUAL Revision 2 Published January 1996). This test protocol is markedly different from simply charging and discharging the battery at a fixed C-rate between upper and lower potential limits.
194. Life testing for low earth orbit (LEO) satellite applications involve cycling the cells at 0°C. Further, these NASA tests only used a 40% depth of discharge (“Low Temperature Life-Cycle Testing of a Lithium-ion Battery for Low-Earth-Orbiting Spacecraft,” C. Reid NASA Glen Research Center 2004 NASA Aerospace Battery Workshop, Huntsville, AL, November 2004). Thus, the discharge is stopped well before the lower potential limit is reached. The IEC standard 61427 for photovoltaic batteries calls for 50 shallow cycles at a low SOC and 100 cycles at a high SOC. The temperature of the test is maintained at 40°C (104°F).
195. Accordingly, the claimed capacity retention must be evaluated from a fixed set of criteria when it comes to the charge and discharge protocols because those protocols will dictate how rapidly the capacity of the battery deteriorates over a number of cycles. Some protocols are more abusive on batteries than others.
196. RJ Tech has contended that “a POSITA would understand that testing should be conducted under typical operating conditions of the commercial batteries, which is the subject of the '641 Patent. (*RJ Tech v. Apple*, Dkt. 82 at 20–21.) RJ Tech has also stated “a POSITA would understand that the tests should be performed at room temperature, the temperature in which commercial batteries normally operate. (*Id.* at 21–22.)” First, the statement that commercial batteries normally operate at room temperature is not correct, see paragraphs 192-194. Generally, the range of battery temperatures is fairly wide. Just think of your cellphone battery in a car on a hot day or a cold day. These are both normal operating conditions for lithium-ion batteries. Indeed, in one testing protocol specified by the USABC, the manual (1996) dictates the fraction of test time to be spent at various

temperatures, ranging from -8 °C to 38 °C.

Table 14B-1. Percent of test time to be spent at various temperature ranges

Temperature Range	Full Range Batteries	Hot Climates Only	Cold Climates Only
Cold $T \leq -8^{\circ}\text{C}$	10	-	10
Cool $-8^{\circ} < T < 0^{\circ}\text{C}$	15	-	15
Normal $20^{\circ} \pm 10^{\circ}\text{C}$	50	50	60
Warm $30^{\circ} < T < 38^{\circ}\text{C}$	15	40	15
Hot $T \geq 38^{\circ}\text{C}$	10	10	-

197. As described above the Handbook of Batteries further indicates that lithium-ion batteries have a wide range of temperature uses. Thus, it is wrong to conclude that the patent—which says nothing about temperature at all—meant that all cycling of the lithium-ion batteries must be done strictly at 23°C (room temperature). There is nothing in the patent or its prosecution history that would lead a POSITA to that conclusion and the information known to a POSITA about battery testing would suggest otherwise.
198. Second, the boundary of the claim should reasonably clear and not depend on a particular application within the scope of the technical field. The technical field of the '641 patent covers Li-ion batteries broadly. Its scope is not limited to consumer applications, and therefore the pattern of use and environmental conditions varies on application, including for electric vehicles and satellites. (See '641 patent at 9:37-48 and claim 5). It is not limited to consumer applications at room temperature.
199. Third, in addition to temperature, the charge and discharge conditions matter and can be determinative of whether a product falls within the claimed range or not, which renders the scope of the claim indefinite because none of these values are defined.
200. For these reasons, as well as the reasons set forth in more detail below, it is my opinion that the undefined scope of this phrase renders it indefinite.

i. Temperature is Material to Capacity Retention

201. It was well known to a POSITA in 2001 that the temperature used for cycling has a material impact on capacity retention, particularly over 400 cycles. For example, the Handbook of Batteries (at 3.10) teaches “[t]he temperature at which the battery is discharged has *a*

pronounced effect on its service life (capacity) and voltage characteristics.” (emphasis added). Service life is generally equated with capacity retention. Here, the statement is saying that temperature has a profound effect on capacity retention. This behavior is true for many types of batteries, including lithium-ion cells, and would have been understood by a POSITA.

202. Guyomard 1994 cycled cells at 20°C and 55°C and found that “[c]ycle life is expected to be greater than 2000 cycles at room temperature and 500 cycles at 55°C.” See, e.g., Fig. 16 below showing the room temperature cells to have about 80% capacity after 400 cycles (i.e., within the claimed range) whereas the 55°C cells had about 60% capacity after 400 cycles (i.e., outside the claimed range):

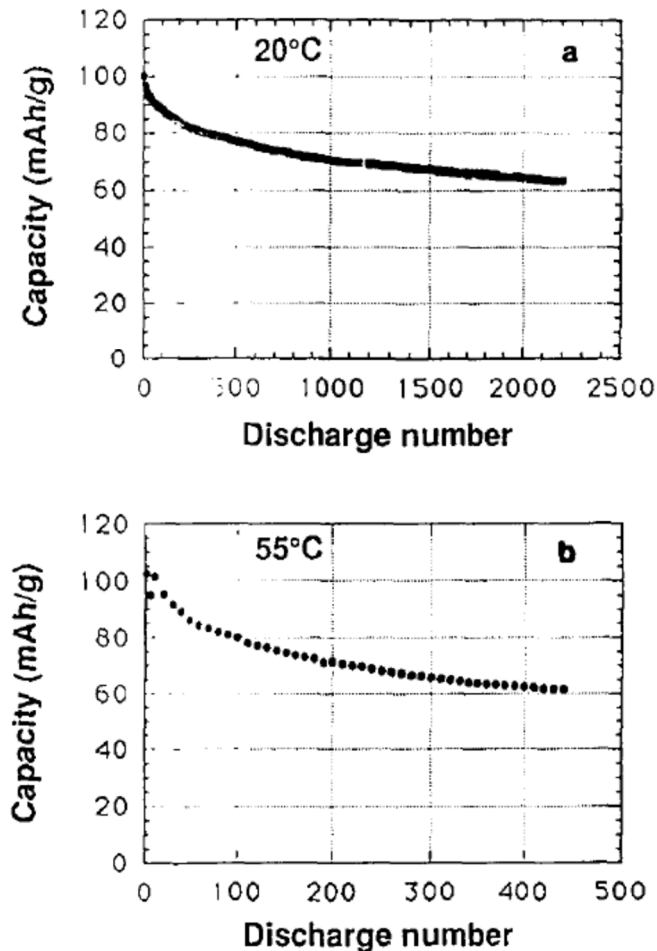


Fig. 16. Variation of the capacity as a function of the cycle number for a coke-based rocking-chair at room temperature (a) and 55°C (b).

Thus, it is clear that merely measuring the cycle capacity at different temperatures can determine whether the cell is either inside or outside of the claimed range. Since the claim provides no guidance on the conditions to use, it is indefinite in scope.

203. Ramadass 2002 shows that merely changing temperature had a significant effect on the cyclability of Sony 18650 cells (like the commercial Sony cells mentioned by the '641 patent) by the time 400 cycles was achieved as shown in Fig. 1 and Table 2:

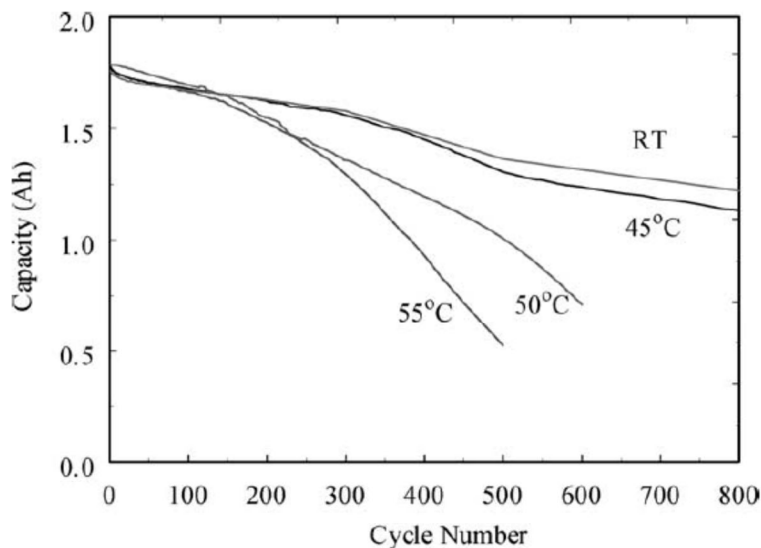


Fig. 1. Discharge capacity of Sony 18650 cells cycled at different temperatures as a function of cycle number.

Table 2

Percentage capacity fade of Sony 18650 cells cycled at different temperatures

Temperature (°C)	Cycle number					
	50	100	150	300	500	800
RT	3.8	5.11	6.09	10.29	22.5	30.63
45	3.8	5.46	7	11.75	26.46	36.21
50	2.4	5.1	7.9	23.9	43.21 ^a	–
55	4.3	6.4	9.4	27	70.56	–

^a Percentage capacity fade after 490 cycles.

204. Spotnitz 2003 indicates that “capacity loss on storage increases with increasing temperature.” (at 76). Arora 1998 (at 3656) similarly indicates that “self-discharge depends on factors such as cathode and cell preparation, nature and purity of the electrolyte, temperature, and time of storage.”

205. Waldmann et al. (J. Power Sources, 384 (2018) 107-124) note that “the clear trend can be found that the ageing rate is usually higher if Li deposition is involved.” So, it is not surprising that if insufficient capacity of the negative electrode is used, the cycle life will be reduced. More important, the propensity for lithium deposition is highly dependent on the rate of charging and temperature. Both of these values (rate and temperature) are essential to measuring capacity retention and clearly identifying the bounds of the claim.
206. Thus, the temperature used for cycle testing could determine whether a battery meets the cycling limitation or not, and this parameter is not specified by the claim. Moreover, as discussed above, because there is no limitation on the application of the claimed battery, there is no one temperature a POSITA would know to choose. Because this claim limitation is undefined in scope, it is my opinion that this phrase is indefinite.

ii. Charge/Discharge Rates

207. It was well known to a POSITA in 2001 that the charge and discharge rates used for cycling has a material impact on capacity retention, particularly over 400 cycles. For example, the Handbook of Batteries showed that the same battery cycled using different C rates had different capacity fading over a large number of cycles: “The capacity of 18650-type C/LiMn₂O₄ batteries cycled at 21 °C or 45°C at the 1C, 0.5C or 0.2C rates is illustrated in Fig. 35.46. At 21 °C at the 1C rate, after 75 cycles, the fade rate was linear at 0.42%/cycle, and at the 0.5C rate, 0.32%/cycle. After 500 cycles at the 1 C rate, the battery delivered 1.01 Ah, or 70% of the initial capacity. For comparison, the cell cycled at the 0.5C rate at 21 °C delivered 1.16 Ah after 500 cycles, or 80% of its initial capacity. Higher fade rates are observed at 45°C.”

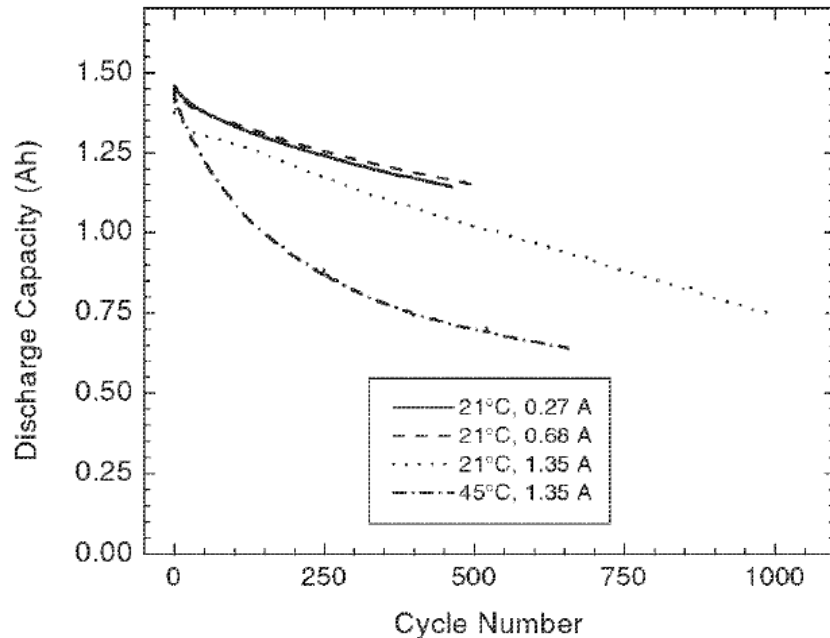


FIGURE 35.46 Capacity fade of 18650-type C/LiMn₂O₄ batteries when cycled at various rates at either 21°C or 45°C between 4.2 V and 2.5 V. (Courtesy of NEC Moli Energy.)

Based solely on the use of a different C-rate, one battery may fall either within or outside the claimed remaining capacity requirements.

208. Similarly, Mayer 1993 found that “cycle life is substantially improved with decreasing charge and discharge rate (below a 1C rate).” (At 11). Mayer also found that decreasing the depth of discharge also has a substantial effect on cycle life:

Table 2
Test Conditions and Cycle Life of
the 20500 Sony Lithium Ion Cell

Depth of Discharge	Discharge Current (Amps)	Cutoff Conditions	Charge Current (Amps)	Const. Voltage Charge Time	Cycle Life ^a
100	0.9	2.75 V	1.4	2 hrs	650 (650) ^b
44	0.9	0.395 A•hr	1.4	2 hrs	3800 (2250) ^c
50	0.36	0.450 A•hr	0.36	2 hrs	14000 (900) ^c
30	0.36	0.270 A•hr	0.9	30 min	40000(4100) ^c

^a The numbers in parenthesis are the actual number of cycles to date.

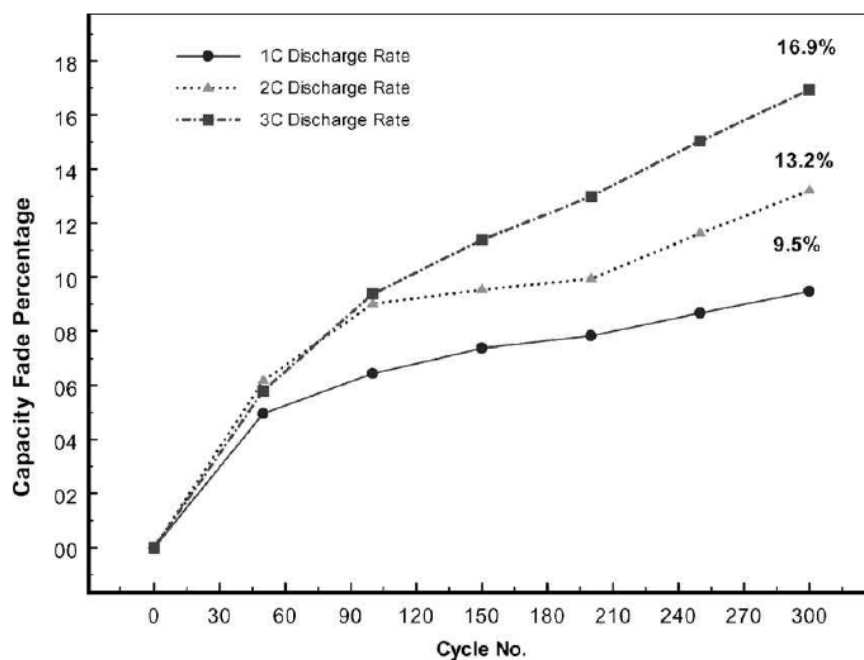
^b To a capacity of 25% of the first cycle capacity at the given rate.

^c Cycle life projections are based on linear interpolations of capacity to a 2.75V EODV.

Thus, testing the battery/cell at different charge/discharge rates, as well as at different depths of discharge can have significant effects on cycle life and neither of these conditions are specified by the patent claims, or anywhere in the patent specification.²⁷

209. Choi 2002 similarly found that “Cycle-life is greatly influenced by the charge conditions.” In particular, they note that long periods at the high potential (CV) can decrease capacity retention.

210. Ning 2003 measured the capacity loss after 300 cycles for the same Sony batteries using three different discharge rates: 1C, 2C, and 3C:



Thus, these results also show that simply changing the discharge rate used can have a material impact on the cycling results, particularly over 400 cycles.

211. U.S. Patent Application Publication No. US2003/0113613 to Takeuchi (“Takeuchi”)²⁸ indicates that “very low current rates (C/50), which is consistent with the discharge rate need for certain medical device applications, such as a cardiac pacemaker in a device monitoring mode and an implantable hearing assist device” decreased capacity fade and

²⁷ The only charge rate mentioned in the specification is “3C5A” at 6:17-26.

²⁸ I understand that Takeuchi is part of the intrinsic record.

increased capacity in comparison to cells discharged at C/5. (at [0029]-[0030]). Thus, a POSITA was well-aware of using very low discharge rates for certain lithium-ion batteries, and as discussed above, the claims are not limited to any specific application.

212. Keil 2016²⁹ shows that cycle life is affected by both charging and discharging rates. They also found that different cell chemistries behave differently. Therefore, to be a meaningful notice of the boundaries of the claim, the charging conditions must be clear.
213. Spotnitz 2003 details some of the available data from early testing of commercial lithium-ion batteries. He notes that “The irreversible capacity loss increases dramatically with increasing state of charge (SOC) and with increasing temperature.” (at 73). Also of note, there are losses that occur with storage in addition to cycling—calendar ageing. Finally, Spotnitz notes that small differences in cells (Sony, which uses hard carbon compared to Toshiba using graphite for the negative electrode) show large differences in storage versus cycling losses.
214. Thus, the charge/discharge rates used for cycle testing could determine whether a battery meets the cycling limitation or not, and this criterion is not specified by the claim. Because this claim limitation is undefined in scope, it is my opinion that this phrase is indefinite.
215. Notably, the patent specification only identifies a charge current of 3C5A (’641 patent at 6:18-24). Thus, using a 3C rate is the only guidance provided by the patent. Further, a POSITA would not be aware any standard charge or discharge rate that would cover the full breadth of the batteries covered by the claims.

iii. Charging and Discharging Protocol, Including Depth of Discharge and Rest in Between Cycles

216. It was well known to a POSITA in 2001 that the charging and discharging protocol, including depth of discharge and rest in between cycles has a material impact on capacity retention, particularly over 400 cycles. For example, the Handbook of Batteries teaches at 3.13 that “[w]hen a battery stands idle after a discharge, certain chemical and physical changes take place which can result in a recovery of the battery voltage. Thus the voltage of a battery, which has dropped during a heavy discharge, will rise after a rest period, giving

²⁹ J. Energy Storage, 6 (2016) 125–141 (“Keil 2016”).

a sawtooth-shaped discharge, as illustrated in Fig. 3.12. This can result in an increase in service life. However, on lengthy discharges, capacity losses may occur due to self-discharge (see Sec. 3.2.12). This improvement, resulting from the intermittent discharge, is generally greater after the higher current drains (as the battery has the opportunity to recover from polarization effects that are more pronounced at the heavier loads). In addition to current drain, the extent of recovery is dependent on many other factors such as the particular battery system and constructional features, discharge temperature, end voltage, and length of recovery period.”

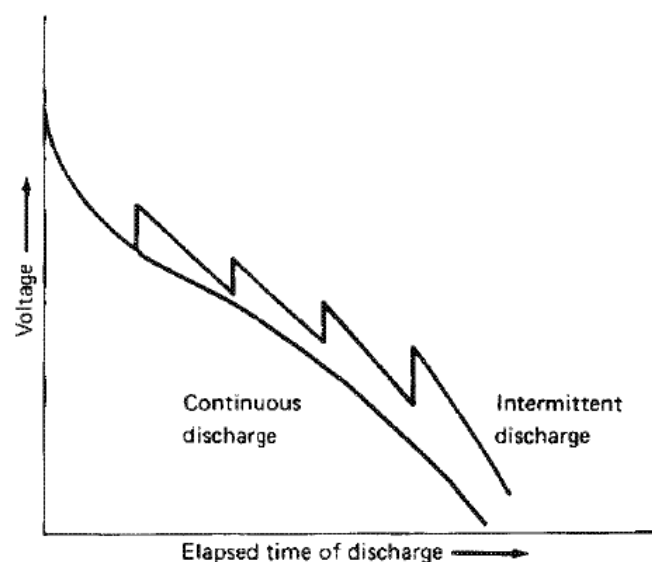


FIGURE 3.12 Effect of intermittent discharge on battery capacity.

The Handbook of Batteries further teaches (at 3.23), “[t]he self-discharge characteristics of a battery that has been or is being discharged can be different from one that has been stored without having been discharged. This is due to a number of factors, such as the discharge rate and temperature, the accumulation of discharge products, the depth of discharge, or the partial destruction or reformation of the protective film.”

217. Zhang 2000 indicates that “capacity fade is caused by various mechanisms, which depend on electrode materials and also on the charge-discharge protocol.” (at 122).
218. Another study, Sikha 2003, concluded “[t]he capacity of a Li-ion battery depends on the protocol used to charge the battery.”

219. As described above (at Paragraph 208), Mayer 1993 also taught that the depth of discharge has a material effect on cycle life.
220. Based on this information it is demonstrated that specifying a charging cutoff voltage is not sufficient to define the degree of charge retention with cycling. Even a small change in the charge retention can mean that a cell falls inside or outside of the claimed values of the '641 patent.
221. Moreover, RJ Tech has specifically argued that the claim is not limited to any charging/discharging protocol. See, e.g., *RJ Tech v. Apple*, Dkt. 82 at 7-11. Nor would a POSITA be aware of one charging/discharging protocol that would cover the full breadth of the batteries covered by the claims.
222. Because this claim limitation is undefined in scope as to charge and discharge protocols, including depth of discharge and rest in between cycles, and because these conditions are material to capacity retention with cycling, it is my opinion that this phrase is indefinite.

XI. ADDITIONAL STATEMENTS

223. It is my understanding that discovery in this action is still ongoing. As such, I reserve the right to revise and/or supplement the opinions expressed in this Declaration in light of new information or allegations disclosed by, or on behalf of, Plaintiff. I further reserve the right to rely on and utilize visual aids, demonstratives, and the like to illustrate and support my opinions.
224. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 28 U.S.C. § 1001.

Dated: November 16, 2023

Thomas F. Fuller

Thomas F. Fuller, Ph.D.

Exhibit A

Thomas F. Fuller

I. Earned Degrees

University of California, Berkeley
Nuclear Power School, Orlando, Florida
University of Utah

Ph. D. Chemical Engineering, 1992
1983
B. S. Chemical Engineering 1982

II. Employment History

Title	Organization	Years
Professor	Georgia Institute of Technology	7/04 – present
Director of Engineering	United Technologies Corp.	2001 – 2004
Manager	United Technologies Corp.	1998 – 2001
Senior Engineer	United Technologies Corp.	1994 – 1997
Post-Doctoral Fellow	Lawrence Berkeley Lab	1992 – 1993
Research Assistant	Los Alamos National Lab	Summer 1990
Research Assistant	UC Berkeley	1987-1992
Naval Reserve Officer	U.S. Navy Reserve	1987-2001
Submarine Nuclear Officer	U.S. Navy	1981-1987

School of Chemical & Biomolecular Engineering, Georgia Tech (2004-present).

Faculty advisor for EcoCAR (2009-2011) and (2014-2022): A collegiate vehicle engineering competition. EcoCAR challenges university engineering students across North America to reengineer a production vehicle to achieve improved fuel economy and reduced green-house gas emissions, while retaining the vehicle's performance and consumer appeal.

Faculty advisor HyTech Racing Student Organization (2011-2014): Team is focused on developing and competing in Formula Hybrid Competition.

Undergraduate Curriculum Committee, School of Chemical & Biomolecular Engineering. 2009-present, Chair of committee 2011-2014, 2020-present.

Representative to the Academic Senate (AS) and General Faculty Assembly (GFA) for the School of Chemical & Biomolecular Engineering 2010-2013.

Google Scholar, 19,175 citations, *h*-index 50

Fellow of American Institute of Chemical Engineering (AIChE), 2018

AIChE Outstanding Faculty Award, Georgia Tech student chapter, 2012

Fellow of the Electrochemical Society, 2009.

Research Award of the Energy Technology Division, the Electrochemical Society, 2008.

Fellow of Georgia Tech Research Institute, 2006

UTC Fuel Cells, South Windsor, CT (1994-2004).

A Division of United Technologies Corp., UTC was Fortune 50 company that provided high technology products to the aerospace and building systems industries throughout the world. UTC Fuel Cells designs, manufactures, and services fuel cells for space, transportation, and stationary applications. UTC Fuel Cells has experience in all types of fuel cells and its products have accumulated over 5 million hours in the field.

2001-2004 Director, Power Section Engineering

- Defined Product Releases and Overall strategy for the cell stack assembly, which is the key component in a fuel-cell system. Based on competitive landscape, identified core and non-core activities. One of the results of this was out-sourcing in some areas that were historically considered core. Developed supply base to support this strategy. This approach has positioned the company to realize a near order-of-magnitude reduction in component costs and established a path to costs that would support introduction of fuel cells into the automotive market.
- Created platform strategy that minimizes the number of products in the development phase and coordinates the insertion of key technologies. Set targets for cost reduction, laid out overall approach and execution.
- Led effort to transfer technology to automotive OEM with whom UTC Fuel cell has established a long-term relationship. Responsible for establishing processes and guidelines to manage intellectual property in support of work with this OEM, but also allowing UTC Fuel Cells to pursue other OEMs, which is part of the company's strategic objectives. Led team for UTC Fuel Cells to complete assessment of the technology as part of the "due diligence" phase of the negotiations.
- Managing Technology Development and Insertion. Coordinate technological development work with United Technologies Research Center and joint venture with Toshiba IFC.
- Key member of Patent Committee. Led effort to revise internal processes to manage patent portfolio. The result was greater input from and responsibility on the technical staff to direct research efforts toward strengthening portfolio.
- UTC Fuel Cells representative on corporate wide effort to reduce cost by \$500 million. Focus has been on outsourcing, consolidation of functions across the divisions, and reducing development costs.
- Put a strong management team in place. Grew the organization from about 50 engineers, scientist, and technicians, to over 120 in two years.

1998-2002 Manager, Power Section Development, Led Integrated Product Development (IPD) teams for cell stack. Responsible for meeting schedule, technical requirements, and budget for all aspects of cell-stack development.

- Doubled power density of cell stack; see press release March 6, 2000, "IFC Boosts Power, Efficiency for Automotive Fuel Cells"

- Change leader, directed company-wide changeover to metric and adoption of global standards; including rationalization and standardization of parts and defining engineering design process for complete fuel-cell power plant
- Developed strategy and led initiatives to reduce cost and increase reliability of cell stacks. Directed joint development with key component suppliers and Toshiba-UTC Fuel Cells joint venture.
- 27 direct reports; excel at finding and developing talent.

1994-1997 Senior Engineer, Advanced Technology, Principal Investigator for IR&D, DOE, and DARPA sponsored fuel cell programs.

- More than 25 publications and six patents issued in PEM, DMFC, and PAFC fuel-cell technologies.
- Managed joint research programs with major universities and small businesses.
- Mathematical modeling of advanced reformers and fuel cell stacks, including thermal balance, current distributions, and electrolyte transport.

Lawrence Berkeley National Laboratory, Berkeley, CA (1992-1993).

Lawrence Berkeley National Laboratory is a multi-program lab where research in advanced materials, life sciences, energy efficiency, detectors and accelerators serve the countries needs in technology and the environment.

Postdoctoral Fellow Development of thin film lithium/polymer solid-state batteries for U.S. Advanced Battery Consortium. Mathematical modeling of polymer electrolytes. Design and scale-up of polymer batteries.

Los Alamos National Laboratory, Los Alamos, NM (Summer 1990).

Research Assistant in Electronics Group. Experimental measurement of transport properties of membranes and modeling of fuel cells.

U. S. Navy, (1981-2001).

Twenty years Naval experience, retired with the rank of Commander. 6 years of active duty and 14 years of reserve experience.

1998-2001 One of four OIC's (Officer in Charge) for Fleet Support Teams for SPAWAR (Space and Naval Warfare Systems Command), San Diego, CA. Coordinated reserve support activities for Roosevelt Battle Group. Awarded Navy Commendation in 2001 for leadership role in developing Fleet support organization.

1987-1997 Several assignments in Naval Reserve on East and West Coasts

- completed Engineering Duty Officer Qualification 1996
- twice selected by national boards for command of Naval Reserve Units
- experience with new construction and repair of ships

1984-1987 Submarine Nuclear Officer, USS Woodrow Wilson (SSBN 624), Charleston, South Carolina. Supervised the operation, maintenance, and repair of reactor plant aboard nuclear-powered submarine. Responsible for chemistry and radiological controls.

III. Honors and Awards

Fellow of the American Institute of Chemical Engineers, 2018

AICHE Outstanding Faculty Award, Georgia Tech student chapter, 2012

Fellow of the Electrochemical Society, 2009.

Research Award of the Energy Technology Division, the Electrochemical Society, 2008.

Fellow of Georgia Tech Research Institute, 2006

Awarded Navy Commendation Medal in 2001 for leadership role in developing Fleet support organization. Coordinated reserve support activities for Roosevelt Battle Group. One of four OIC's (Officer in Charge) for Fleet Support Teams for SPAWAR (Space and Naval Warfare Systems Command), San Diego, CA.

IV. Research, Scholarship, and Creative Activities

Electrochemical Engineering, Wiley, 2018, ISBN 978-1119004257. Merging theoretical concepts with widespread application, this book is designed to provide critical knowledge in a real-world context. Beginning with the fundamental principles underpinning the field, the discussion moves into industrial and manufacturing processes that blend central ideas to provide an advanced understanding while explaining observable results. Fully-worked illustrations simplify complex processes, and end-of chapter questions help reinforce essential knowledge.

Google Scholar, 19,175 citations, *h*-index 50

A series of 5 papers on modeling of lithium-ion batteries has received over 7400 citations. This model has been widely adopted and is the industry standard.

11 issued patents.

VI. Service

A. Professional Contributions

The Electrochemical Society, the leading society for solid-state and electrochemical science and technology (member 1989-present).

Associate Editor for the *Journal of the Electrochemical Society*, July 2009-2011
Technical Editor for the *Journal of the Electrochemical Society* and *ECS Electrochemistry Letters*, 2012 – 2019, responsible for Fuel Cells, Electrolyzers and Energy Conversion.

- Fellows Selection Committee, 2010-2012
- Nominating Committee, 2007-2008, responsible for nomination of Society Presidential candidates
- Honors and Awards Committee member 2005 to 2009; Chair, C. W. Tobias Young Investigator Award subcommittee for 2008.
- Chair “Fuel Cell Coordinating Committee” 2005-2009, responsible for coordinating fuel cell symposia across society. Lead organizer for annual symposium on Proton Exchange Membrane Fuel Cells, which has more than 250 papers submitted.
- *Ad hoc* committee for long-range planning of society, 2002 to 2005
- Board of Directors, 2001-2003
- Chair, Energy Technology Division (2001-2003), See article written describing “The Energy Technology Division,” *Interface*, **11**, 29 (2002).
- Vice Chair Energy Technology Division, 1999-2001
- Secretary, Energy Technology Division, 1999
- Treasurer, Energy Technology Division, 1997-1999
- Advisory Board Member 1996-2002 for *Interface*, (quarterly publication of topical scientific articles and information of people, programs, and activities of the Electrochemical Society).

International Advisory Board for *Handbook of Fuel Cells*, W. Vielstich, A. Lamm, and H. A. Gasteiger, eds., Wiley 2002.

Member, Technical Advisory Board, organized by the National Academies (National Research Council) to review the Army Research Laboratory Sensors and Electron Devices Directorate, Adelphi Maryland, 2007-2012. Energy and Power, Electro-Optics and Photonics; RF and Electronics; Signal and Image Processing; and Directed Energy.

Member, Review Panel, The Air Force Office of Scientific Research (AFOSR), Multi-disciplinary University Research Initiatives (MURI) in biofuel cells, 2008.

DOE Hydrogen Program Annual Merit Review and Peer Evaluation, various years from 1995 to 2005.

NSF

Career Award Panel, 2006, 2010, 2011, 2019, 2020
SBIR Review Panel, 2008 and 2009
CBET and CMMI Panels, various

University of Limerick, Panel for Energy Chair, 2009.

AIChE Organize symposia on “tutorials on electrochemistry,” 2012 to present.

The Center for Transportation and the Environment, nonprofit located in Atlanta whose mission is to facilitate the research, development, demonstration, bridge to

commercialization, and market acceptance of advanced transportation technologies and alternative fuels. (www.cte.tv)

Chairman of the Board 2007-2012

Board of Directors 2005-2006, 2013-2015

Publications, Patents, and Technical Reports

1. A Concentrated Solution Theory Model of Transport in Solid-polymer-electrolyte Fuel Cells (with John Newman). *Proceedings of the Symposium on Fuel Cells*, edited by Ralph E. White and A. J. Appleby, proceedings volume 89-14, The Electrochemical Society, Pennington, N. J. (1989).
2. T. F. Fuller, J. Newman, Experimental Determination of the Transport Number of Water in Nafion 117 Membrane, *J. Electrochem. Soc.*, **139**, 1332-1337 (1992).
3. *Solid Polymer-electrolyte Fuel Cells*. July 1992. Doctoral dissertation. University of California, Berkeley.
4. T. F. Fuller, J. Newman, Convective Diffusion near a Consolute Point, *Int. J. Heat and Mass Transfer*, **36**, 347-351 (1993).
5. T. F. Fuller, J. Newman, Water and Thermal Management in Solid-polymer-electrolyte Fuel Cells, *J. Electrochem. Soc.*, **140**, 1218-1225 (1993).
6. M. Doyle, T. F. Fuller, J. Newman, Modeling of Galvanostatic Charge/Discharge of the Lithium/Polymer /Intercalation Cell, *J. Electrochem. Soc.*, **140**, 1526-1533 (1993).
7. T. F. Fuller, J. Newman, Electrochemical Processing (Introduction), *Kirk-Othmer Encyclopedia of Chemical Technology*, Vol. 9, fourth edition, M. Howe-Grant, ed., John Wiley & Sons, Inc., 111-123 (1994).
8. T. F. Fuller, M. Doyle, J. Newman, Simulation and Optimization of the Dual Lithium Ion Insertion Cell, *J. Electrochem. Soc.*, **141**, 1-10 (1994)
9. Relaxation Phenomena in Lithium Ion Insertion Cells, (with Marc Doyle and John Newman). *J. Electrochem. Soc.*, **141**, 982-990 (1994).
10. Simulation of the Dual Lithium Ion Insertion Cell (with Marc Doyle and John Newman). *Proceedings of the Symposium on Lithium Batteries*, N. Doddapaneni and A. R. Landgrebe, ed., proceedings volume 94-4, pp. 37-50, The Electrochemical Society, Pennington, N. J. (1994).
11. Relaxation Phenomena in Lithium Ion Insertion Cell and Simulation of the Sony Cell, (with Marc Doyle and John Newman). *Proceedings of the Symposium on Lithium Batteries*, N. Doddapaneni and A. R. Landgrebe, ed., proceedings volume 94-4, pp. 25-36, The Electrochemical Society, Pennington, N. J. (1994).
12. Modeling of Adiabatic and Isothermal Galvanostatic Discharge Behavior of the Lithium/Polymer/Insertion Cell (with Carolyn R. Pals, Marc Doyle, and John Newman). *Proceedings of the Douglas N. Bennion Memorial Symposium, Topics in Electrochemical*

Engineering. Proceedings Volume 94-22, pp. 248-263. Pennington, NJ: The Electrochemical Society, Inc., 1994.

13. M. Doyle, T. F. Fuller, J. Newman, The Importance of the Lithium Ion Transference Number in Lithium/Polymer Cells, *Electrochim. Acta*, **39**, 2073-2081 (1994).

14. Metal Hydride Electrodes (with John Newman). *Modern Aspects of Electrochemistry*, Number 27, R. E. White *et al.*, ed., 359-382 (1995).

15. T. F. Fuller, F. Luczak, D. Wheeler, Electrocatalyst Utilization in Phosphoric Acid Fuel Cells, *J. Electrochem. Soc.*, **142**, 1752-1757 (1995).

16. The Measurement of a Complete Set of Transport Properties for a Concentrated Solid Polymer Electrolyte Solution (with Yanping Ma, Marc Doyle, Marca M. Doeff, Lutgard C. De Jonghe, and John Newman). *J. Electrochem. Soc.*, **142**, 1859-1868 (1995).

17. Theoretical Modeling of Battery Systems (with Marc Doyle and John Newman). Daniel A. Scherson, ed., Proceedings of the Symposium on the Science of Advanced Batteries (Cleveland, Ohio: The Ernest B. Yeager Center for Electrochemical Studies, Case Western Reserve University, 1995), pp. 152-163.

18. Influence of Rib Spacing in Proton-Exchange Membrane Electrode Assemblies (with Alan C. West). *J. Appl. Electrochem.*, **26**, 557-565 (1996).

19. PEM Fuel Cell Applications and their Development at International Fuel Cells, (with Mike Gorman and Leslie VanDine), 1996 Fuel Cell Seminar, Orlando, Florida.

20. *Proceedings of the Fourth Symposium on Carbonate Fuel Cell Technology*, (edited with J. Robert Selman, Isamu Uchida, David A. Shores, and Hartmut Wendt), proceedings volume 97-4, The Electrochemical Society, Pennington, N. J. (1997).

21. T. F. Fuller, Is a Fuel Cell in Your Future?, *Interface*, **6**, 26-32, Fall 1997.

22. Direct Methanol Fuel Cells for Transportation Applications, prepared for the Department of Energy under contract DE-AC08-96NV11984, December 1997.

23. T. F. Fuller, J. Newman, Diffusion, *Encyclopedia of Chemistry*, J. L. Lagowski, ed., Macmillian Publishing Company.

24. A Methanol Sensor for Portable Direct Methanol Fuel Cells (with Scott A. Calabrese Barton, Bryan L. Murach, and Alan C. West), *J. Electrochem. Soc.*, **145**, 3783-3788 (1998).

25. *Advances in Mathematical Modeling and Simulation of Electrochemical Processes and Oxygen Depolarized Cathodes and Activated Cathodes for Chlor-Alkali and Chlorate Processes*, (edited with J. Van Zee, P. C. Foller, and F. Hine), proceedings volume 98-10, The Electrochemical Society, Pennington, N. J. (1998).

26. *Proceedings of the Second International Symposium on Proton Conducting Fuel Cells II*, (edited with S. Gottesfeld), proceedings volume 98-27, The Electrochemical Society, Pennington, N. J. (1999).
27. Electrode Performance and Design for Strip-Cell Direct Methanol Fuel Cells (with Scott A. Calabrese Barton, T. Patterson, E. Wang, and Alan C. West, *Proceedings of the Second International Symposium on Proton Conducting Fuel Cells II*, proceedings volume 98-27, pp. 238-248, The Electrochemical Society, Pennington, N. J. (1999).
28. Mass and Heat Recovery System for a Fuel Cell Power Plant, U. S. Patent 6,007,931 (with P. R. Margiott and L. L. Van Dine) December 28, 1999.
29. Electrochemical Processing (Introduction) (with John Newman). Jacqueline I. Kroschwitz, Mary-Howe Grant, and others, eds. Kirk Othmer Concise Encyclopedia of Chemical Technology, 4th ed., pp. 703-704 (New York: John Wiley & Sons, Inc., 1999).
30. Mass Transfer Composite Membrane for a Fuel Cell Power Plant, U. S. Patent 6,048,383 (with R. D. Breault and L. L. Van Dine) April 11, 2000.
31. Start-up of a Cold Fuel Cell, U. S. Patent 6,068,941 (with D. J. Wheeler) May 30, 2000.
32. Start-up of a Frozen Fuel Cell, U. S. Patent 6,103,410 (with D. J. Wheeler) August 15, 2000.
33. Alcohol and Water Recovery System for Direct Aqueous Alcohol Fuel Cell Power Plant, U. S. Patent 6,110,613 August 29, 2000.
34. *The Global Climate Change, a Coordinated Response by Electrochemistry and Solid State Science and Technology* (edited with A. Weickowski, E. W. Brooman, E. J. Rudd, and J. Leddy), proceedings volume 2000-20, The Electrochemical Society, Pennington, N. J. (2000).
35. Mixed Reactant, Strip-Cell Direct Methanol Fuel Cells (with Scott A. Calabrese Barton, T. Patterson, E. Wang, and Alan C. West, *J. Power Sources*, **96**, 329-336 (2001).
36. Method and Apparatus for Regenerating the Performance of a PEM Fuel Cell, (with J. Donahue, J. Yi, and D. Yang) U. S. Patent 6,399,231, June 4, 2002.
37. T. F. Fuller, M. Perry, A Historical Perspective of Fuel Cells in the 20th Century, *Cells, J. Electrochem. Soc.*, **149**, S59-67 (2002).
38. The Energy Technology Division, *Interface*, **11**, 29, Summer 2002.

39. *Proton Conducting Fuel Cells III*, (edited with S. Gottesfeld, J. Van Zee, and M. Murthy), proceedings volume 2002-31, The Electrochemical Society, Pennington, N. J. (2002).
40. Compact Fuel Gas Reformer Assemblage, (with R. Lesieur, and N. Cipollini) U. S. Patent Application 6,773,684, August 10, 2004.
41. Start up cascaded fuel cell stack (with R. Balliet) U. S. Patent Application 20050142407, June 2005.
42. Proton Exchange Membrane Fuel Cells V, In Honor of Supramaniam Srinivasan (edited with C. Bock, C. Lamy), *ECS Trans.* **1** (6), The Electrochemical Society, Pennington, N. J. (2006).
43. **T. F. Fuller** and Jeremy Meyers, Findings of the Fuel Cell Workshop, *ECS Trans.* **1** (6), 341 (2006).
44. **T. F. Fuller**, Mike Perry, and Carl Reiser, Applying the Lessons Learned from PAFC to PEM, *ECS Trans.*, **1** (8), 337 (2006).
45. **T. F. Fuller** and Gary Gray, Carbon Corrosion Induced by Partial Hydrogen Coverage, *ECS Trans.*, **1** (8), 345 (2006).
46. Proton Exchange Membrane Fuel Cells 6, (Edited with C. Bock, S. Cleghorn, H. Gasteiger, T. Jarvi, M. Mathias, M. Murthy, T. Nguyen, V. Ramani, E. Stuve, T. Zawodzinski, *ECS Trans.*, **3** (1), (2006).
47. Wu Bi, Gary Gray and **T. F. Fuller**, PEM Fuel Cell Pt/C Dissolution and Deposition in Nafion[®] Electrolyte, *Electrochem. Solid-State Lett.*, **10**, B101-104 (2007).
48. Cheng Chen, G. Levitin, D. Hess, **T. F. Fuller**, XPS Investigation of Nafion[®] Membrane Degradation, *J. Power Sources*, **169**, 288-295 (2007).
49. **T. F. Fuller**, K. Gallagher, Chapter 6. Phosphoric Acid Fuel Cells (PAFC), book chapter in *Materials for Fuel Cells*, Michael Gasik editor, Woodhead Publishing Limited, Cambridge, UK, ISBN 1 84569 330, 209-247.
50. Kevin Gallagher, David Wong, and **T. F. Fuller**, The Effect of Transient Potential Exposure on the Electrochemical Oxidation of Carbon Black in Low-Temperature Fuel Cells, *ECS Trans.*, **11** (1), 993-1002 (2007).
51. Wu Bi, **T. F. Fuller**, Temperature Effects on PEM Fuel Cells Pt/C Catalyst Degradation, *ECS Trans.*, **11** (1), 1235-1246 (2007).
52. Cheng Chen, **T. F. Fuller**, H₂O₂ Formation under Fuel-cell Conditions, *ECS Trans.*, **11** (1), 1127-1137 (2007).

53. Norimitsu Takeuchi, **T. F. Fuller**, Modeling of Transient State Carbon Corrosion for PEMFC Electrodes, *ECS Trans.*, **11** (1), 1021-1029 (2007).
54. *Proton Exchange Membrane Fuel Cells 7*, (Edited with H. Gasteiger, S. Cleghorn, V. Ramani, T. Zhao, T. V. Nguyen, A. Haug, C. Bock, C. Lamy, and K. Ota, *ECS Trans.*, **11** (1), (2007).
55. Wu Bi, **T. F. Fuller**, Temperature Effects on PEM Fuel Cells Pt/C Catalyst Degradation, *J. Electrochem. Soc.*, **155**, (2) B215 (2008).
56. Wu Bi, **T. F. Fuller**, Modeling of PEM Fuel Cell Pt/C Catalyst Degradation, *J. Power Sources*, **178**, 188-196 (2008).
57. Kevin Gallagher, David Wong, **T. F. Fuller**, The Effect of Transient Potential Exposure on the Electrochemical Oxidation of Carbon Black in Low-Temperature Fuel Cells, *J. Electrochem. Soc.*, **155**, B488-B493 (2008).
58. Norimitsu Takeuchi, **T. F. Fuller**, Modeling and Investigation of Design Factors and their Impact on Carbon Corrosion of PEMFC Electrodes, *J. Electrochem. Soc.*, **155**, B770-B775 (2008).
59. Rajeswari Chandrasekaran, Wu Bi, **T. F. Fuller**, Robust Design of Battery/Fuel Cell Hybrid Systems—Methodology for Surrogate Models of Pt Dissolution and Mitigation, *J. Power Sources*, **182**, 546-557 (2008).
60. Kevin Gallagher, Bryan Pivovar, **T. F. Fuller**, Electro-osmosis and Water Uptake in Polymer Electrolytes in Equilibrium with Water Vapor at Low Temperatures, *ECS Trans.*, **16** (2), 297-307 (2008).
61. Norimitsu Takeuchi, **T. F. Fuller**, Investigation of Carbon Loss on the Cathode during PEMFC Operation, *ECS Trans.*, **16** (2), 1563-1571 (2008).
62. **T. F. Fuller**, Kevin Gallagher, Transport Properties of Concentrated Electrolytes and their Impact on Electrochemical Systems, *Tutorial Symposium on Electrochemical Engineering, in Honor of Professor John Newman's 70th Birthday*, *ECS Trans.*, **16** (13), 117-125 (2008).
63. *Proton Exchange Membrane Fuel Cells 8*, (Edited with H. Gasteiger, V. Ramani, C. Lamy, H. Nakagawa, H. Uchida, K. Shinohara, M. Inaba, S. Mitsushima, P. Shirvanian, S. Cleghorn, P. Strasser, and T. Zawodzinski), *ECS Trans.*, **16** (2), (2008).
64. T. Bradley, B. A. Moffitt, **T. F. Fuller**, Dimitri Mavris, David E. Parekh, Design studies for hydrogen fuel cell powered unmanned aerial vehicles, *Collection of Technical Papers—AIAA Applied Aerodynamics Conference, 26th AIAA Applied Aerodynamics Conference 2008*, AIAA 2008-6413.

65. K. G. Gallagher, R. M. Darling, **T. F. Fuller**, Carbon–Support Corrosion Mechanisms and Models, in *Handbook of Fuel Cells—Advances in Electrocatalysis, Materials, Diagnostics and Durability*, edited by Wolf Vielstich, Hubert A. Gasteiger, and Arnold Lamm, Volume 5, John Wiley & Sons, Ltd. ISBN: 0-471-49926-9.
66. Wu Bi, Qunhui Sun, Yulin Deng, **T. F. Fuller**, The Effect of Humidity and Oxygen Partial Pressure on Degradation of Pt/C Catalyst in PEM Fuel Cell, *Electrochim. Acta*, **54**, 1826-1833 (2009).
67. Kevin Gallagher, Bryan Pivovar, **T. F. Fuller**, Electro-osmosis and Water Uptake in Polymer Electrolytes in Equilibrium with Water Vapor at Low Temperatures, *J. Electrochem. Soc.*, **156**, B330-B338 (2009).
68. R. Melsert, R. Chandrasekaran, T. Bandhauer, **T. F. Fuller**, J. Meisel, Design of a Hybrid Electric Vehicle, Energy 2030 Conference 2008, 1-5, *IEEE Energy 2008*. doi:10.1109/ENERGY.2008.4781055
69. Cheng Chen, **T. F. Fuller**, Modeling of Hydrogen Peroxide Formation in PEMFCs, *Electrochim. Acta*, **54**, 3984-3995 (2009).
70. Qunhui Sun, Wu Bi, **T. F. Fuller**, Yong Ding, Yulin Deng, Fabrication of Aligned Polyaniline Nanofiber Array via a Facile Wet Chemical Process, *Macromolecular Rapid Communication*, **30**, 1027-1032 (2009).
71. Cheng Chen, **T. F. Fuller**, The Effect of Humidity on the Degradation of Nafion Membrane, *Polymer Degradation and Stability*, **94**, 1436-1447 (2009).
72. Norimitsu Takeuchi, Emily N. Jennings, **T. F. Fuller**, Investigation and modeling of carbon oxidation of Pt/C under dynamic potential condition. *ECS Trans.*, **25** (1), 1045-1054 (2009).
73. *Proton Exchange Membrane Fuel Cells 9*, (Edited with P. Bele, S. Cleghorn, H. Gasteiger, C. Hartnig, T. Jarvi, D. Jones, C. Lamy, V. Ramani, P. Shirvanian, P. Strasser, H. Uchida, T. Zawodzinski, P. Zelenay, *ECS Trans.*, **25** (1), (2009).
74. Cheng Chen, **T. F. Fuller**, XPS Analysis of Membrane Degradation in PEM Fuel Cells, *J. Electrochem. Soc.* **156**, B1218-B1224 (2009).
75. Bradley, T. H., Moffitt, B. A., **Fuller, T. F.**, Mavris, D. N., Parekh, D. E., “Design Method Comparisons for Fuel Cell Powered Unmanned Aerial Vehicles, *AIAA Journal of Aircraft*, **46** (6) 1957-1964 (2009).
76. T. Bradley, B. A. Moffitt, Dimitri Mavris, **T. F. Fuller**, David E. Parekh, “Hardware in the Loop Performance Simulation for a Fuel Cell Powered Aircraft,” *AIAA Journal of Propulsion and Power*, **25**, 1336-1344 (2009).

77. Kevin G. Gallagher, **T. F. Fuller**, “Kinetic Model of the Electrochemical Oxidation of Graphitic Carbon in Acidic Environments,” *Phys. Chem. Chem. Phys.*, **11**, 11557–11567 (2009).

78. Norimitsu Takeuchi, **T. F. Fuller**, Modeling and Investigation of Carbon Loss on the Cathode Electrode during PEMFC Operation, *J. Electrochem. Soc.*, **157**, B135-B140 (2010).

79. Kevin G. Gallagher, Gleb Yushin, **T. F. Fuller** “The Role of Microstructure in the Electrochemical Oxidation of Model Carbon Catalyst Supports in Acidic Environments,” *J. Electrochem. Soc.*, **157**, B820-B830 (2010).

80. Eric W. Ping, R. Wallace, J. Pierson, **T. F. Fuller**, C. W. Jones, Highly Dispersed Palladium Nanoparticles on Ultra-Porous Silica Mesocellular Foam for the Catalytic Decarboxylation of Stearic Acid, *Microporous & Mesoporous Materials*, **132**, 174-180, 2010.

81. **T. F. Fuller**, K. Evanoff, V. L. George, E. L. Redmond, G. Yushin, J. Sassen, J. Allred, L. Nall, Cathodes for Lithium Air Cells using Ionic Liquids, Digest in 44th Power Sources Conference, Las Vegas, June 2010.

82. Eric W. Ping, K. Venkatasubbaiah, **T. F. Fuller**, C. W. Jones, Oxidative Heck Coupling using Pd(II) Supported on Organosilane-Functionalized Silica Mesocellular Foam, *Top. Catal.*, **53**, 1048-1054 (2010).

83. Rajeswari Chandrasekaran, Alexandre Magasinki, G. Yushin, **T. F. Fuller**, Analysis of Lithium Insertion/De-Insertion in a Silicon Electrode Particle at Room Temperature, *J. Electrochem. Soc.*, **157**, A1139-A1151 (2010).

84. *Polymer Electrolyte Fuel Cells 10*, (Edited with H. Gasteiger, H. Uchida, V. Ramani, A. Weber, T. Schmidt, P. Strasser, P. Shirvanian, M. Inaba, M. Edmundson, F. Büchi, D. Jones, C. Lamy, R. Mantz, S. Narayan, R. Darling, T. Zawodzinski , *ECS Trans.*, **33** (1), (2010).

85. P. Trogadas, **T. F. Fuller**, The effect of particle size distribution on Pt stability, *ECS Trans.*, **33** (1), 115-124 (2010).

86. Xiaoyu Ding, S. Didari, **T. F. Fuller**, T. A. Harris, A New Fabrication Technique to Manufacture an MEA using Direct Coating of Nafion onto Catalyzed GDL, *ECS Trans.*, **33** (1), 255-265 (2010).

87. Alexandre Magasinki, Bogdan Zdyrko, Igor Kovalenko, Benjamin Hertzberg, Ruslan Burtovyy, **T. F. Fuller**, Igor Luzinov, G. Yushin, Towards Efficient Binder for Li-ion

Battery Si-Based Anodes: Polyacrylic Acid, *Applied Materials & Interfaces*, **11**, 3004-3010 (2010).

88. Todd Bandhauer, Srinivas Garimella, **T. F. Fuller**, A Critical Review of Lithium Battery Thermal Issues, *Critical Reviews in Electrochemical and Solid State Science and Technology, CRES³T, J. Electrochem. Soc.*, **158**(3), R1-R25 (2011).

89. Eric W. Ping, J. Pierson, R. Wallace, J. T. Miller, **T. F. Fuller**, C. W. Jones, On the Nature of the Deactivation of Supported Palladium Nanoparticle Catalysts in the Decarboxylation of Fatty Acids, *J. Appl. Catalysis*, **396**, 85-90 (2011).

90. R. Chandrasekaran, T. F. Fuller, Analysis of the Lithium-Ion Insertion Silicon Composite Electrode / Separator / Lithium Foil Cell, *J. Electrochem. Soc.*, **158**, A859-871 (2011).

91. Alexander S. Rattner, Ananda Krishna Nagavarapu, Srinivas Garimella, **T. F. Fuller**, Modeling of a Flat Plate Membrane-Distillation System for Liquid Desiccant Regeneration in Air-Conditioning Applications, *Int. J. Heat and Mass Transfer*, **54**, 3650-3660 (2011).

92. **T. F. Fuller**, Diagnostics for PEMFC Performance and Durability, *ECS Trans.*, **41** (1), 621 (2011).

93. **T. F. Fuller**, The Importance of Water Content (λ) on Electroosmotic Drag and Degradation in PEMFCs, *ECS Trans.*, **41** (1), 79 (2011).

94. Erin L. Redmond, Brian P. Setzler, Pavol Juhas, Simon J. L. Billinge, and **T. F. Fuller**, Surface Energy Effects on Catalyst Degradation in Low-Temperature PEMFCs, Diagnostics for PEMFC Performance and Durability, *ECS Trans.*, **41** (1), 751 (2011).

95. P. Trogadas, **T. F. Fuller**, The Effect of Uniform Particle Size Distribution on Pt Stability, *ECS Trans.*, **41** (1), 761 (2011).

96. Xiaoyu Ding, **T. F. Fuller**, and Tequila A. L. Harris, Effects of Annealing Conditions on the Performance of Solution Cast Nafion[®] Membranes, *ECS Trans.*, **41** (1), 1537 (2011).

97. *Polymer Electrolyte Fuel Cells 11*, (Edited with H. Gasteiger, H. Uchida, V. Ramani, A. Weber, T. Schmidt, P. Strasser, P. Shirvanian, M. Inaba, M. Edmundson, F. Büchi, D. Jones, C. Lamy, R. Mantz, S. Narayan, R. Darling, T. Zawodzinski, *ECS Trans.*, **41** (1), (2011).

98. P. Trogadas, E. Pinot, **T. F. Fuller**, Composite, Solvent-Casted Nafion[®] Membranes for Vanadium Redox Flow Batteries, *Electrochem. Solid-State Lett.*, **15**, A5-A8 (2012).

99. K. Evanoff, J. Kahn, A. A. Balandin, A. Magasincki, W. J. Ready, **T. F. Fuller**, G. Yushin, Toward Ultra-thick Battery Electrodes: Aligned Carbon Nano-tube Enabled Architecture, *Advanced Materials*, **24**, 533–537 (2012).
100. E. L. Redmond, B. P. Setzler, P. Juhas, S. J. L. Billinge, **T. F. Fuller**, In-situ monitoring of particle growth at PEMFC cathode under accelerated cycling conditions, *Electrochem. Solid-State Lett.*, **15**, B72-B74 (2012).
101. P. Trogadas, **T. F. Fuller**, *Durability Testing, book chapter in Polymer electrolyte membrane and direct methanol fuel cell technology* (PEMFCs and DMFCs), Christoph Hartnig, Christina Roth, editors, Woodhead Publishing Limited, Cambridge (2012) ISBN 978-1-84569-774-7.
102. P. Trogadas, **T. F. Fuller**, Polymer Membrane Degradation Mechanisms in a PEFC, book chapter in *Polymer Electrolyte Fuel Cells: Science, Applications and Challenges*, edited by Alejandro A. Franco, Pan Stanford Publishing.
103. X. Ding, S. Didari, **T. F. Fuller**, T. A. L. Harris, A New Membrane Electrode Assembly Fabrication Process for Directly Coating Catalyzed Gas Diffusion Layers, *J. Electrochem. Soc.*, **159**, B746-B753 (2012).
104. Gas Sparging for Transport of Dissolved Species through a Barrier, S. Reece, **T. F. Fuller**, D. Burchell, U. S. Patent Application PCT/US2013/056714 Docket Number SNCC-0067, August 27, 2012.
105. E. L. Redmond, P. Trogadas, F. M. Alamgir, **T. F. Fuller**, The effect of platinum oxide growth on platinum stability in PEMFCs, *ECS Trans.*, **50** (2) 1369-1376 (2012).
106. *Polymer Electrolyte Fuel Cells 12*, edited with H. A. Gasteiger, *et al.*, *ECS Trans.*, **50** (2) (2012).
107. T. Bandhauer, T. F. Fuller, and S. Garimella, Electrochemical-thermal modeling and microscale phase change for passive internal thermal management of lithium ion batteries, Sandia National Laboratory Report, SAND2012-0074, DOI: 10.2172/1038186
-
108. J-T. Lee, N. Nitta, J. Benson, **T. F. Fuller**, G. Yushin, Comparative Study of Solid Electrolyte Interphase on Graphite in Full Cells Using X-ray Photoelectron Spectroscopy, Secondary Ion Mass Spectroscopy, and Electron Microscopy, *Carbon*, **52**, 388-397 (2013).
109. Chenyang Shi, E. L. Redmond, B. P. Setzler, A. Mazaheripour, P. Juhas, **T. F. Fuller**, and S. J. L. Billinge, Anomalous Bond Softening and Disorder below 2 nm Diameter in Carbon Supported Platinum Nanoparticles from the Temperature Dependent Peak Width of the Atomic Pair Distribution Function, *J. Phys. Chem. C*, **117**, 7226-7230 (2013).

110. Xiaoyu Ding, **T. F. Fuller**, T. A. L. Harris, Effects of Annealing Conditions on the Performance of Solution Cast Nafion® Membranes, *J. Electrochem. Soc.*, **160**, F793-F797 (2013).

111. Xiaoyu Ding, **T. F. Fuller**, T. A. L. Harris, Predicting Fluid Penetration during Slot Coating onto Porous Substrates, *Chem. Eng. Sci.*, **99**, 67-75 (2013).

112. B. P. Setzler, KwangSup Eom, **T. F. Fuller**, Investigation of transport phenomena in PEMFC through 1-D macro-homogeneous model, *ECS Trans.*, **58** (1), 95-107 (2013).

113. *Polymer Electrolyte Fuel Cells 13*, edited with H. A. Gasteiger, *et al.*, *ECS Trans.*, **58** (1) (2013).

114. Xiaoyu Ding, **T. F. Fuller**, T. A. L. Harris, A simulation model to approximate penetration of a non-Newtonian fluid into a porous media during slot die coating, *J. Coatings Technology and Research*, **11**, 83-87 (2014).

115. T. Bandhauer, S. Garimella, **T. F. Fuller**, Temperature Dependent Electrochemical Heat Generation in a Commercial Lithium-Ion Battery, *J. Power Sources*, **247**, 618-628, (2014).

116. KwangSup Eom, Arnaud Bordes, Tapesh Joshi, Inhwon Do, **T. F. Fuller**, The Design of a Li-ion Full-cell battery using Nano-silicon and Multi-layer Graphene Composite Anode, *J. Power Sources*, **249**, 118-124 (2014).

117. Rajiv R. Jaini, **T. F. Fuller**, Overcoming Mass-Transfer Limitations in the Dual Bed Colloidal Suspension Reactor, *Int. J. of Hydrogen Energy*, **39**, 2462–2471 (2014).

118. Arnaud Bordes, KwangSup Eom, **T. F. Fuller**, The Effect of Fluoro-ethylene carbonate additive content on the formation cycling and capacity fade of Li-ion full cell employing nano Si-graphene anode, and its optimization, *J. Power Sources*, **257**, 163-169 (2014).

119. Erin L. Redmond, Brian P. Setzler, Faisal Alamgir, and **T. F. Fuller**, Elucidating the Oxide Growth Mechanism on Platinum at the Cathode in PEMFCs, *Phys. Chem. Chem. Phys.* **16**, 5301 (2014).

120. Panagiotis Trogadas, **T. F. Fuller**, Peter Strasser, “Carbon as Catalyst and Support for Electrochemical Energy Conversion,” *Carbon*, **75**, 5-42 (2014).

121. Xiaoyu Ding, J. P. Ebin, T. A. L. Harris, Z. Li, **T. F. Fuller**, Extended Analytical Models of Fluid Penetration Depth during Slot-die Coating onto Porous Media, *AIChE Journal*, **60**, 4241-4252 (2014).

122. *Polymer Electrolyte Fuel Cells 14*, edited with H. A. Gasteiger, *et al.*, *ECS Trans.*, **16** (3) (2014).

123. Tapesh Joshi, KwangSup Eom, Gleb Yushin, **T. F. Fuller**, "Effects of Dissolved Transition Metals on the Electrochemical Performance and SEI Growth in Lithium-ion Batteries," *J. Electrochem. Soc.*, **161**, A1915-A1921 (2014).

124. T. Bandhauer, Srinivas Garimella, **T. F. Fuller**, Electrochemical Thermal Modeling to Evaluate Battery Thermal Management Strategies: Part I. Side Cooling, *J. Electrochem. Soc.*, **162**, A125-A136 (2015).

125. T. Bandhauer, Srinivas Garimella, **T. F. Fuller**, Electrochemical Thermal Modeling to Evaluate Battery Thermal Management Strategies: Part II. Edge and Internal Cooling, *J. Electrochem. Soc.*, **162**, A137-A148 (2015).

126. KwangSup Eom, Jaehan Jung, Jung Tae Lee, Valentin Lair, Tapesh Joshi, Seung Woo Lee, Gleb Yushin, Zhiqun Lin, **T. F. Fuller**, Improved Stability of Bare Sn Electrode with High Quality SEI Formation for Lithium-ion Battery, *Nano Energy*, **12**, 314-321 (2015).

127. Brian Setzler, **T. F. Fuller**, A Physics-Based Impedance Model of a Proton Exchange Membrane Fuel Cell Exhibiting Low Frequency Inductive Loops, *J. Electrochem. Soc.*, **162**, F519-F530 (2015).

128. Gregory D. Chipman, **T. F. Fuller**, Vertically Integrated Projects: Improving the Overall University Competition Experience, Proceedings of the ASME 2015 International Mechanical Engineering Congress and Exposition, IMECE2015, November 13-19, 2015, Houston.

129. Andrew Star and **T. F. Fuller**, FIB+SEM Tomography and Numerical Simulation of Corroded PEM Fuel Cell Cathodes, *ECS Trans.*, **69** (17), 431-441 (2015).

130. *Polymer Electrolyte Fuel Cells 15*, edited with H. A. Gasteiger, *et al.*, *ECS Trans.*, **69** (17) (2015).

131. Panagiotis Trogadas, Vijay Ramani, Peter Strasser, **T. F. Fuller**, and Marc-Olivier Coppins, Hierarchically Structured Nanomaterials for Electrochemical Energy Conversion, *Angewandte Chemie*, **128** (1), 128-156 (2016).

132. **T. F. Fuller**, Bigger and Better, *Nat. Energy, News & Views*, **1**, 16003 (2016).

133. Byeongyong Lee, Chongmin Lee, Tianyuan Liu, Kwangsup Eom, Zhongming Chen, Suguru Noda, **T. F. Fuller**, Hee Dong Jang, Seung Woo Lee, "Redox-Active, Hierarchical Crumpled Graphene Electrodes for Rapid Electrochemical Energy Storage," *Nanoscale*, **8**, 12330-12338 (2016).

134. Rajiv R. Jaini, Brian P. Setzler, Andrew G. Star, **T. F. Fuller**, Investigating the Solid Electrolyte Interphase Formed by Additive Reduction Using Physics-Based Modeling, *J. Electrochem. Soc.*, **163**, A2185-A2196 (2016).

135. Andrew Star and **T. F. Fuller**, FIB+SEM Tomography and Numerical Simulation of Corroded PEM Fuel Cell Cathodes, *ECS Trans.*, **75** (14), 431-441 (2016).

136. Sejoon Park, Chung Woo Son, Sungho Lee, Dong Young Ki, Cheolmin Park, Kwang Sup Eom, **T. F. Fuller**, Han-Ik Joh, Seong Mu Jo, Multicore-shell nanofiber architecture of polyimide/ polyvinylidene fluoride blend for thermal and long-term stability of lithium ion battery separator, *Scientific Reports*, **6**, 36977 (2016).

137. *Polymer Electrolyte Fuel Cells 17*, edited with D. J. Jones, *et al.*, *ECS Trans.*, **75** (14) (2016).

138. KwangSup Eom, Jung-Tae Lee, Martin Oschatz, Stefan Kaskel, Gleb Yushin, **T. F. Fuller**, “A Stable Lithiated Silicon-Chalcogen Battery via Synergetic Chemical Coupling between Silicon and Selenium,” *Nat. Comm.*, **8**, 13888 (2017).

139. Cheol-Ho Lee, Jin-Mun Yun, Sungho Lee, Seong Mu Jo, Kwang-Sup Eom, Doh C. Lee, Han-Ik Joh, **T. F. Fuller**, “Bi-axial grown amorphous molybdenum sulfide bridged with oxygen on graphene oxide as a superior stable and efficient nonprecious catalyst for electrochemical hydrogen production,” *Scientific Reports*, **7**, 41190 (2017).

140. Andrew G. Star, T. F. Fuller, “FIB-SEM Tomography Connects Microstructure to Corrosion-induced Performance Loss in PEMFC cathodes,” *J. Electrochem. Soc.*, **164**, F901-F907 (2017).

141. *Polymer Electrolyte Fuel Cells 17*, edited with D. J. Jones, *et al.*, *ECS Trans.*, **80** (8) (2017).

142. L. Deligianni, G. S. Frankel, T. Fuller, Looking Back 2: High Impact Papers and Their Authors, *The Electrochemical Society Interface*, **26** (3), 9-12 (2017).

143. *Electrochemical Engineering*, T. F. Fuller and John Harb, John Wiley and Sons Inc., 2018. ISBN: 978-1119004257

144. G. D. Chipman, T. F. Fuller, “Adapting Vertically Integrated Projects to University Team Competitions,” Proceedings of the ASME International Mechanical Engineering Congress and Exposition,” 2017, **5**, Article Number: UNSP V005T06A010 (published 2018). 10.1115/IMECE2017-71354

145. Rajiv R. Jaini, Brian P. Setzler, Uma Ranjagopalan, T. F. Fuller “Investigating Changes in the Morphological Structure of High-Temperature, Calendar-Aged Li-Ion Cells,” *J. Electrochem. Soc.*, **165**, A3125-A3135 (2018). DOI: 10.1149/2.0761813jes

146. *Polymer Electrolyte Fuel Cells and Electrolyzers 18*, edited with D. J. Jones, *et al.*, *ECS Trans.*, **86** (13) (2018).

147. Uijin Chang, JungTae Lee, Jin-Mun Yun, Byeongyoung Lee, Seung Woo Lee, Han-Ik Joh, KwangSup Eom, **T. F. Fuller**, “*In-situ* self-formed nano-sheet MoS₃/r-GO material showing superior performance as a new LIB cathode,” *ACS Nano* **13**, 1490–1498 (2019). DOI: 10.1021/acsnano.8b07191.

148. Andrew G. Star, **T. F. Fuller**, “Combining Tomographic Imaging and In Silico Computation for Rapid Effective PEMFC Cathode Transport Characterization,” *Chem. Eng. Sci.*, **201**, 309-318 (2019). 10.1016/j.ces.2019.02.018

149. Jonathan B. Grunewald, Ankit Verma, Aashutosh N. Mistry, Navneet Goswami, Partha Mukherjee, and **T. F. Fuller**, Mesoscale Physics in the Catalyst Layer of Proton Exchange Membrane Fuel Cells, *J. Electrochem. Soc.*, **166**, F3089-F3092 (2019).

150. Zhengyuan Fang, Andrew G. Star, **T. F. Fuller**, The Effect of Carbon Corrosion on the Wettability of PEM Fuel Cell Electrodes, *J. Electrochem. Soc.*, **166**, F709 (2019). 10.1149/2.0231912jes

151. Jonathan B. Grunewald, Aashutosh N. Mistry, Ankit Verma, Navneet Goswami, Partha Mukherjee, and **T. F. Fuller**, Modeling Proton Exchange Membrane Fuel Cell Cathode Catalyst Layers with the Lattice-Boltzmann-Method-Direct-Numerical-Simulation Framework, *Polymer Electrolyte Fuel Cells and Electrolyzers 19*, *ECS Trans.*, **92** (8) (2019).

152. *Polymer Electrolyte Fuel Cells and Electrolyzers 19*, edited with D. J. Jones, *et al.*, *ECS Trans.*, **92** (8) (2019).

153. Z Fang, MS Lee, JY Kim, JH Kim, TF Fuller, The effect of carbon support surface functionalization on PEM fuel cell performance, durability, and ionomer coverage in the catalyst layer, *J. Electrochem. Soc.*, **167** (6), 064506 (2020).

154. Navneet Goswami, , Aashutosh N. Mistry, Jonathan B. Grunewald, T. F. Fuller, Partha Mukherjee, Corrosion-Induced Microstructural Variability Affects Transport-Kinetics Interaction in PEM Fuel Cell Catalyst Layers, *J. Electrochem. Soc.*, **167**, 084519 (2020).

155. Thermal runaway in a prismatic lithium ion cell triggered by a short circuit, Malcolm P. Macdonald, Sriram Chandrasekaran, Srinivas Garimella, Thomas F. Fuller, *Journal of Energy Storage* **40**, 102737 (2021)

156. Two-Phase Dynamics and Hysteresis in the PEM Fuel Cell Catalyst Layer with the Lattice-Boltzmann Method, Jonathan B. Grunewald, Navneet Goswami, Partha P. Mukherjee, and Thomas F. Fuller, *J. Electrochem. Soc.*, 168, 024521 (2021)
157. Active Material Interfacial Chemistry and its Impact on Composite Magnetite Electrodes, Gonzalez, Miguel; Minnici, Krysten; Risteen, Bailey; Wang, Lei; Housel, Lisa; Renderos, Genesis; Takeuchi, Kenneth; Takeuchi, Esther; Marschilok, Amy; Fuller, Thomas; Reichmanis, Elsa, *ACS Appl. Energy Mater.* 2021, 4, 9, 9836–9847.
158. Sastry, K.V., Fuller, T.F., Grijalva, S., Taylor, D.G., Leamy, M.J., “Electric Vehicle Smart Charging to Maximize Renewable Energy Usage in a Single Residence,” Proceedings of the 47th Annual Conference of the IEEE Industrial Electronics Society (IECON 2021), Toronto, Canada, Oct. 13-16, 2021
159. Mechanistic understanding of coupled degradation-performance interactions in PEM Fuel Cell Catalyst Layers, Navneet Goswami, Jonathan B. Grunewald, Thomas F. Fuller, and Partha P. Mukherjee, *J. Mater. Chem. A*, 10, 15101-15115 (2022).
160. Understanding the role of polymer interactions within binders in composite lithium-ion anodes, Miguel A. Gonzaleza, W. Henry Freer, Meng Wang, Seunghyun Jeon, Thomas F. Fuller, Elsa Reichmanis, Amy Marschilok, *J. Phys. Chem. C*, 126, 46, 19603-19617 (2022)
161. Chapter 5, Fuel Cells and Hydrogen Production, Renewable Fuels, Thomas F. Fuller, *Renewable Fuels: Sources, Conversion, and Utilization*, Cambridge University Press, 161 (2022).
162. Grid-Favorable, Consumer-Centric, On/Off Smart Charging of Electric Vehicles in a Neighborhood, KV Sastry, TF Fuller, S Grijalva, DG Taylor, MJ Leamy, 2022 IEEE Vehicle Power and Propulsion Conference (VPPC), Merced, CA, USA, 2022, pp. 1-6, doi: 10.1109/VPPC55846.2022.10003326
163. J. Fernandez, K. Sastry, S. Grijalva, M. Leamy, D. Taylor and T. Fuller, "Sequential Energy Scheduling Approach to Support Decentralized Smart Charging of Electric Vehicles," 2022 North American Power Symposium (NAPS), Salt Lake City, UT, USA, 2022, pp. 1-6, doi: 10.1109/NAPS56150.2022.10012143.
164. Application of Open-Source, Python-Based Tools for the Simulation of Electrochemical Systems, E.L. Molel, T. F. Fuller, *J. Electrochem. Soc.*, **170**, 103501 (2023).
-