

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

CANADIAN SOLAR INC.,
Petitioner

v.

MAXEON SOLAR PTE. LTD.,
Patent Owner

Case IPR2024-01038¹
U.S. Patent No. 11,251,315

**DECLARATION OF DAVID L CARROLL, PH.D. IN SUPPORT OF
PATENT OWNER'S RESPONSE**

¹ IPR2024-01194 has been consolidated with the instant proceeding.

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I, David Carroll, Ph.D. declare as follows:

I. INTRODUCTION

1. I have been asked by counsel for Patent Owner Maxeon Solar Pte. Ltd. (“Patent Owner”) to provide my opinions on certain matters raised in the Petition for Inter Partes Review in IPR2024-01038 (Paper No. 1, “the Petition”)² filed by Petitioner Canadian Solar Inc. (“CSI”) with respect to U.S. Patent No. 11,251,315 (“the ’315 patent”), the declaration of Sanjay Banerjee, Ph.D. (Ex. 1003), the Decision Granting Institution of Inter Partes Review (Paper No. 13, “the Institution Decision”), and the transcript of the deposition of Dr. Banerjee taken on March 21, 2025. I was similarly asked to provide my opinions on matters raised in Petition for Inter Partes Review in IPR2024-01194 and Dr. Banerjee’s declaration in that proceeding. This declaration sets forth the opinions that I have reached to date regarding these matters.

2. I am not employed by Patent Owner or any affiliate or subsidiary thereof. I do not have a financial interest in Patent Owner.

3. My independent expert consulting services are being billed at my standard rate of \$400/hr (plus reasonable expenses). My compensation is not

² Unless otherwise indicated all references to Papers and Exhibits are with reference to the record in IPR2024-01038.

contingent on the outcome of this matter or on the content of my review, analysis, or testimony.

II. SUMMARY OF OPINIONS

4. As set forth in detail below, in my opinion, claims 10-16 and 19 of the '315 patent are not unpatentable in view of the grounds set forth in the two Petitions (i.e., the Petition in IPR2024-01038 and the Petition in IPR2024-01194).

III. QUALIFICATIONS

5. A true and correct copy of my *curriculum vitae* (CV) was included with the Declaration that I prepared in support of Patent Owner's Preliminary Response (Ex. 2001). My CV includes my complete qualifications and professional experience. The following is a brief summary of my relevant qualifications and professional experience.

6. In 1985, I received my Bachelor of Science degree in Physics from North Carolina State University ("N.C. State"). In 1993, I received my Ph.D. in Physics from Wesleyan University. My dissertation was titled Defect Formation and Electron Trapping in Oxides and comprised a study on the dynamic energy redistribution and statistics of charged defects in oxide materials.

7. I am currently a Professor in the Department of Physics at Wake Forest University and also serve as an Adjunct Associate Professor of Biomedical Engineering at the Virginia Tech – Wake Forest University School of Biomedical

Engineering and Sciences, and as an Adjunct Associate Professor of Cancer Biology at the Wake Forest School of Medicine. From 2003 to 2010, I was an Associate Professor in the Department of Physics at Wake Forest University and was a Director of the Center for Nanotechnology and Molecular Materials, during which time I was awarded tenure.

8. From 2002 to 2003, I was as an Associate Professor of Materials Science in the Department of Materials Engineering at Clemson University. At the same University, I was an Associate Professor of Physics from 2001 to 2002, and an Assistant Professor of Physics from 1997 to 2001 and awarded tenure.

9. From 1995 to 1997, I served as a research associate at the Max-Planck-Institut für Metallforschung, Institut für Werkstoffwissenschaft, in Stuttgart, Germany in 1994. From 1993 to 1995, I served as a Postdoctoral Research Associate in the Department of Materials Science and Engineering at the University of Pennsylvania.

10. At Wesleyan University, I served as an observational astronomer in the Van Vleck Observatories from 1987 to 1989, and as a graduate and research assistant in the Department of Physics from 1987 to 1992.

11. Beyond my academic experience, I have significant professional experience in the fields of physics, materials science, and solar technology. In 2001, I helped found Tetramer Technologies, an advanced materials company

dedicated to the development of market-driven materials and transitioning those materials from the lab to the market, and served as a technical advisor and board member from 2001 to 2003. I also helped found and served in the same positions at NanoTechLabs, a nanomaterial and nanocomposite application development company, from 2001-2004; PureLux, a nanotechnology lighting company, from 2007 to 2011; FiberCell, a laboratory-scale hollow fiber solar cell company, from 2007 to 2010; and Camel City Solar, a spin-out solar cell company from the Wake Forest Nanotechnology Center, from 2011 to 2013. I also served as a technical advisor at CeeLite, a clean technology lighting company, from 2011 to 2013, and VF Corporation, one of the world's largest apparel, footwear, and accessories companies, from 2013 to 2019. In 2022, I helped found Quoherent, a cutting-edge startup pioneering the next frontier in quantum computing, and have since served as a technical advisor.

12. I have received a number of awards and honors for my academic and professional accomplishments, including being named as a Fellow of the American Physical Society in 2013 and the International Association of Advanced Materials (Europe) in 2024. A complete a list of my awards and honors can be found in Section 2 of my CV.

13. I have authored several books and book chapters and my work has been published in nearly 300 publications since 1990, including numerous

publications on my work with solar cell technologies. A complete list of my publications and publication metrics are listed in Sections 3.1 to 3.3 of my CV.

14. I am an inventor on 35 issued U.S. patents, including patents related to solar cell technologies. A complete list of my patents can be found in Section 3.4 of my CV.

15. I have received over \$29 million in research grants from various federal and industrial funding sources, including over \$500,000 in research grants related to my work with solar cell technologies. A complete list of my research grants can be found in Section 3.5 of my CV.

16. I have presented my work at numerous scholarly conferences, including my work with solar cell technologies. A complete list of my scholarly presentations can be found in Section 3.6 of my CV.

17. My work with solar cell technologies has also been recognized by various publications, including EarthSky, ScienceDaily, and the Winston-Salem Journal. *See* Ex. 2016; Ex. 2017; Ex. 2018.

IV. DOCUMENTS CONSIDERED

18. In preparing this declaration and in forming the opinions set forth in this declaration, I reviewed the documents cited in this declaration, including the following:

Proceeding	Paper / Exhibit	Description
IPR2024-01038	Paper 1	Petition for Inter Partes Review of U.S. Patent No. 11,251,315
IPR2024-01194	Paper 1	Petition for Inter Partes Review of U.S. Patent No. 11,251,315
IPR2024-01038	Paper 13	Decision Granting Institution of <i>Inter Partes</i> Review
IPR2024-01194	Paper 12	Decision Granting Institution of <i>Inter Partes</i> Review
IPR2024-01038	Ex. 1001	U.S. Patent No. 11,251,315 (“the ’315 patent”)
IPR2024-01038	Ex. 1002	File History of U.S. Patent No. 11,251,315
IPR2024-01038	Ex. 1003	Declaration of Sanjay Banerjee, Ph.D. Regarding U.S. Patent No. 11,251,315
IPR2024-01194	Ex. 1003	Declaration of Sanjay Banerjee, Ph.D. Regarding U.S. Patent No. 11,251,315
IPR2024-01038	Ex. 1004	Curriculum Vitae of Sanjay Banerjee, Ph.D.
IPR2024-01038	Ex. 1005	U.S. Patent Pub. No. 2011/0214719, “Method of Fabricating a Back-Contact Solar Cell and Device Thereof” (“Li”)
IPR2024-01038	Ex. 1006	King, Sinton and Swanson, “Studies of Diffused Phosphorous Emitters: Saturation Current, Surface Recombination Velocity, and Quantum Efficiency,” IEEE Transactions On Electron Devices, Vol 37, No. 2 (Feb. 1990) (“King”)
IPR2024-01038	Ex. 1007	Marvin and Froedge, “Interdigitated Back Contact Silicon Solar Cell Analysis and Design Recommendations for Space Use,” AD-A220-414 (Sept. 30, 1989) (“Marvin-DTIC”)

Proceeding	Paper / Exhibit	Description
IPR2024-01038	Ex. 1008	Muller et al., “Ion Implantation for All-Alumina IBC Solar Cells with Floating Emitter,” <i>Energy Procedia</i> 55 (2014), 265-271 (“Muller”)
IPR2024-01038	Ex. 1011	Neuhaus and Munzer, <i>Industrial Silicon Wafer Solar Cells</i> , <i>Advances in OptoElectronics</i> , 1-15, at 11 (2007) (“Neuhaus”)
IPR2024-01038	Ex. 1015	U.S. Patent No. 4,234,352, “Thermophotovoltaic Converter and Cell for Use Therein” (“Swanson-352”)
IPR2024-01038	Ex. 1017	U.S. Patent No. 4,053,335, “Method of Gettering Using Backside Polycrystalline Silicon” (“Hu”)
IPR2024-01038	Ex. 1025	Ramappa and Benley, “Diffusion of Iron in Silicon Dioxide,” <i>Journal of the Electrochemical Society</i> 146(1) 3773-3777 (1999) (“Ramappa”)
IPR2024-01038	Ex. 1026	U.S. Patent Pub. No. 2006/0118868, “A Semiconductor Substrate Comprising a Support Substrate Which Comprises a Gettering Site” (“Yoshimura”)
IPR2024-01038	Ex. 1028	Liu et al. “Direct Observation of the Impurity Gettering Layers in Polysilicon-Based Passivating Contacts for Silicon Solar Cells,” <i>ACS Appl. Energy Mater.</i> 2018, 1, 2275-2282 (2018) (“Liu-1”)
IPR2024-01038	Ex. 1029	Liu et al., “Effective impurity gettering by phosphorous- and boron-diffused polysilicon passivating contacts for silicon solar cells,” <i>Solar Energy Materials and Solar Cells</i> 179 (2018) 136-141 (“Liu-2”)

Proceeding	Paper / Exhibit	Description
IPR2024-01038	Ex. 1035	Marvin and Froedge, “Analysis of Interdigitated Back Contact Silicon Solar Cells for Space Use,” IEEE (1989) (“Marvin-IEEE”)
IPR2024-01038	Ex. 2015	Granek et al., “Front surface passivation of n-type high-efficiency back junction silicon solar cells using front surface,” <i>Solar Energy Materials and Solar Cells</i> , 91(7) (2007)
IPR2024-01038	Ex. 2016	“Nanotechnology improves solar cell efficiency,” <i>EarthSky</i> , August 28, 2007 (accessible at https://earthsky.org/humanworld/nanotechnology-improves-solar-cell-efficiency ; last accessed October 14, 2024)
IPR2024-01038	Ex. 2017	“New Plastic Solar Cell Breaks Efficiency Record,” <i>ScienceDaily</i> , April 20, 2007 (accessible at https://www.sciencedaily.com/releases/2007/04/070419140902.htm), last accessed October 14, 2024)
IPR2024-01038	Ex. 2018	Capshaw-Mack, C., “Power Games: Project seeks to improve methods of harnessing solar energy,” <i>Winston-Salem Journal</i> , August 4, 2013 (accessible at https://journalnow.com/news/local/article_1d243ff0-fc9e-11e2-b607-001a4bcf6878.html ; last accessed October 15, 2024)
IPR2024-01038	Ex. 2022	Transcript of deposition of Sanjay Banerjee, Ph.D. taken March 21, 2025
IPR2024-01038	Ex. 2024	Lamers et al., “Towards 21% Efficient N-CZ IBC based on Screen Printing,” <i>26th European Photovoltaic Solar Energy Conference and Exhibition</i> , (2011) (“Lamers”)

Proceeding	Paper / Exhibit	Description
IPR2024-01038	Ex. 2025	Desa et al., “Optimization of p-type Screen Printed Interdigitated Back Contact Silicon Solar Cell with Aluminum Back Surface Field,” <i>International Journal of Engineering & Technology IJETIJENS</i> , 14(2) (2014) (“Desa”)
IPR2024-01038	Ex. 2026	Procel et al., “Analysis of the Impact of Doping Levels on Performance of Back Contact – Back Junction Solar Cells,” 4 th International Conference on Silicon Photovoltaics, SiliconPV 2014, Italy, 2014, pp 128-132, ScienceDirect (“Procel”)
IPR2024-01038	Ex. 2027	U.S. Patent No. 8,790,957 to Li et al.
IPR2024-01038	Ex. 2028	Schulz, Interface States at the SiO ₂ -Si Interface, <i>Surface Science</i> 132 (1983)
IPR2024-01038	Ex. 2029	Aoki, M., et al., “Intrinsic Gettering of Iron Impurities in Silicon Wafer,” <i>Japanese Journal of Applied Physics</i> , Vol. 30, No. 12B, Dec. 1991, pp. 3580-3583
IPR2024-01038	Ex. 2030	Ziebarth, B., et al., “Interstitial Iron Impurities at Grain Boundaries in Silicon: A First-Principles Study, <i>Physical Review B</i> 91 (2015)
IPR2024-01038	Ex. 2031	Portavoce A., et al., “Redistribution of Metallic Impurities in Si During Annealing and Oxidation: W and Fe,” <i>Defect and Diffusion Forum</i> , 2018, 383, pp. 17-22 (2019)
IPR2024-01038	Ex. 2032	Hajjiah et al., “The Impact of Interstitial Fe Contamination on N-Type Cz-Silicon for High Efficiency Solar Cells, <i>Solar Energy Materials and Solar Cells</i> 211 (2020)

Proceeding	Paper / Exhibit	Description
IPR2024-01038	Ex. 2033	Coletti, G., “Sensitivity of State-of-the-Art and High Efficiency Crystalline Silicon Solar Cells to Metal Impurities,” Prog. Photovolt: Res. Appl. 2013; 21:1163-1170
IPR2024-01038	Ex. 2034	Castellanos S., et al., “Exceeding 3ms Minority Carrier Lifetime in N-Type Non-Contact Crucible Silicon,” Energy Procedia 92, pp. 779-784 (2016)
IPR2024-01038	Ex. 2035	Sopori, B., “Impurities and Defects in Photovoltaic Si Devices: A Review,” 10 th Int’l Workshop on the Physics of Semiconductor Devices, Delhi, India, Dec. 13, 1999
IPR2024-01038	Ex. 2036	SIMS Detection Limits of Selected Elements in Si and SiO ₂ Under Normal Depth Profiling Conditions, EAG Laboratories
IPR2024-01038	Ex. 2037	Haarahiltunen, A., et al. Detection of Iron Contamination in Internally Gettered P-Type Silicon Wafer by Lifetime Measurements
IPR2024-01038	Ex. 2038	Liu et al, “Understanding the Impurity Gettering Effect of Polysilicon/Oxide Passivating Contact Structures Through Experiment and Simulation,” Solar Energy Materials and Solar Cells, 230 (2021)

V. ASSUMPTIONS

A. Date of Invention

19. I have been asked to assume that the date of the inventions of the claims of the '315 patent was December 22, 2014.

B. Person of Ordinary Skill in the Art

20. I have been asked to assume that a person having ordinary skill in the art is as described in the Petition, *i.e.*, a person “with an advanced degree involving the discipline of electrical engineering, applied physics, chemistry, or materials science, and at least two years of experience designing, developing, or researching in the field [of solar cell design or manufacture]” or, alternatively, a person with “a bachelor’s degree in electrical engineering, applied physics, or materials science, and at least three years of experience designing, developing, or researching in the field [of solar cell design or manufacture].”

21. At the time of the invention of the claims of the ’315 patent, I possessed at least such knowledge and experience. Further, I was aware of the understandings and capabilities of a person having the skill level described above.

VI. RELEVANT PATENT LAW STANDARDS

22. I have relied upon the following understandings of the applicable legal standards in reaching my opinions set forth in this Declaration.

A. Obviousness

23. I have been informed that a patent claim is invalid as being obvious in view of the prior art if the differences between the patented subject matter and the prior art are such that the subject matter as a whole would have been obvious at the time of the invention to a person having ordinary skill in the art. In making a

determination of obviousness, I understand that the following factors are analyzed:

(i) the scope and content of the prior art; (ii) the differences, if any, between the prior art and the claims at issue; (iii) the level of ordinary skill in the pertinent art; and (iv) objective evidence of non-obviousness, if any exists.

24. I have been informed that any of the following rationales are some of the acceptable bases for the conclusion that a claim is obvious: (i) the claimed invention is simply a combination of prior art elements according to known methods to yield predictable results; (ii) the claimed invention is a simple substitution of one known element for another to obtain predictable results; (iii) the claimed invention uses known techniques to improve similar devices (methods, or products) in the same way; (iv) the claimed invention was “obvious to try” because it was a choice from a finite number of identified, predictable solutions, with a reasonable expectation of success; (v) there is known work in one field of endeavor that may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces, if the variations would have been predictable to a person of ordinary skill in the art; or (vi) there is some teaching, suggestion, or motivation in the prior art that would have led a person of ordinary skill in the art to modify the prior art references or to combine prior art reference teachings to arrive at the claimed invention.

25. I have been informed that in order for a patent claim to be considered obvious, at the time the invention was made, each and every limitation of the claim must be present within the prior art, or within the prior art in combination with the general knowledge held by a person of ordinary skill in the art, and that such a person would have a reasonable expectation of success in combining these teachings to achieve the claimed invention. I also understand that the reason to select and combine features, the predictability of the results of doing so, and a reasonable expectation of success of doing so may be found in the teachings of the prior art themselves, in the nature of any need or problem in the field that was addressed by the patent, in the knowledge of a person of ordinary skill in the art in the field at the time, as well as in common sense or the level of creativity exhibited by a person of ordinary skill in the art. There need not be an express or explicit suggestion to combine references.

26. I understand that substituting one known element for another known element would have been obvious when it leads to reasonably predictable results.

27. I understand that a combination of elements would have been obvious when a person of ordinary skill in the art has a good reason to pursue the combination, which is among a finite number of known options within his or her technical grasp, and leads to reasonably expected results.

28. A prior art reference can be said to teach away when a person of ordinary skill in the art would be discouraged from following the path set out in the reference or would be led in a direction divergent from the path that was taken in the claimed invention. The mere disclosure of more than one alternative does not constitute a teaching away from alternatives that are not disclosed when the prior art does not criticize, discredit, or otherwise discourage the solution claimed in the alleged invention. Similarly, a prior art reference that merely expresses a general preference for an alternative invention does not teach away.

B. Inherency

29. I have been informed that a reference may disclose a limitation either explicitly or inherently. When a reference does not explicitly disclose a limitation explicitly, the doctrine in inherency may be relied upon only when the reference necessarily would have included or resulted in the unmentioned feature or quality. The fact that a certain thing may or even probably result from a given set of circumstances is not sufficient to render the result inherent.

30. I have been informed that inherency is not proven by showing that a particular feature would be more cost-effective. Stated differently, a reference does not inherently disclose a feature if implementing an embodiment of that reference in an allegedly cost-effective manner.

31. I have been informed that inherency is not proven by showing that an undetectable or unrecognized *de minimis* quantity may result.

VII. THE '315 PATENT

A. Solar Cell Background

32. A solar cell converts energy from sunlight, i.e., electromagnetic energy, into electricity. This conversion takes place when a photon strikes a solar cell—often made of silicon—and dislodges an electron (also thereby creating a “hole” or electron vacancy). Ideally, all electrons that are dislodged migrate to an emitter, which is connected to an electric circuit. Such electrons would then flow through the circuit and rejoin with the holes, but only after travelling through the circuit and thereby provide electrical power.

33. Solar cells often reside in a solar panel. This allows the electricity of multiple solar cells to be joined into a single device.

34. A solar cell designer is often concerned with numerous attributes, for example, mechanical reliability, cost, and efficiency. “Efficiency” in the solar field refers to the ratio of energy that is output by a solar cell relative to the amount of energy in the sunlight that it receives. In 2014—the time of the invention of the '315 patent—solar cells often had efficiencies of around 20%. Ex. 1011 (“In production, the average efficiency is estimated to be over 20%.”). A factor that heavily influence efficiency is “lifetime.” The term “lifetime” refers to the time

during which a dislodged electron lasts by itself before “recombining” with a hole. If an electron recombines before it is collected at the emitter and travels through the circuit, no electric power is harnessed from that electron. The longer the lifetime, the greater the chance electrons will travel through the emitter and have their energy harnessed before prematurely recombining with holes and, thus, the greater the efficiency of the solar cell. A “lifetime” is often much less than one second.

35. “Passivation” and “doping” are techniques used to reduce recombination and increase lifetime. (this increases efficiency).

36. Passivation is the process of covering a surface of a material with another material (often an oxide) to reduce recombination at the surface. Electrons and holes tend to recombine at such surfaces due to “dangling bonds” at a material’s surface. Simply, a “dangling bond” refers to outer-shell valence electrons of Si in this case, that is not fully interacting (or bonding) with another Si atom as it would do in the bulk of a perfect lattice. This means the stability requirements of filled and half-filled shells (Hund’s Rule) are not satisfied and this bond becomes extremely chemically active. Thus, it has the tendency to attract charges. The idea behind passivation is to saturate (so that they are not reactive) such dangling bonds, thereby reducing or eliminating their tendency to attract electrons or holes.

37. Doping is the introduction of a charged impurity into a substrate. It can have two roles. The first is to increase carrier number (n-type or p-type) thereby increasing overall conductivity of the substrate. Secondly it can be used in high concentrations to form front or back surface fields. This charge will repel either electrons or holes that have been separated, but not the other. By repelling either electrons or holes, the dopant reduces recombination, thereby increasing lifetime and efficiency.

38. Another impediment to solar efficiency is the presence of impurities (e.g., metals) within the silicon substrate. In 2014, two common ways of reducing such impurities were to (1) begin with pure (or near pure) substrates or (2) remove the impurities through a process called “gettering.” Neuhaus and Munzer, *Industrial Silicon Wafer Solar Cells*, Advances in OptoElectronics, 1-15, at 11 (2007) (“Neuhaus”), discloses that to improve the lifetime of charge carriers, manufacturers often use high-quality, pure semiconductor materials and carefully control the manufacturing process to reduce defects within the crystal lattice. *See* Ex. 1011, p. 11 (“[T]he IBC solar cell design requires extraordinarily high lifetime silicon starting material.”). These defects can act as recombination centers where electrons and holes prematurely recombine, reducing the lifetime of charge carriers. Gettering is usually accomplished by heating the substrate at an elevated temperature for a certain period of time. While helping to reduce impurities, such

thermal treatments have drawbacks, for example, they may increase stress within the solar cell, which can affect its mechanical stability.

B. The '315 Patent's Novel Solar Cell Fabrication Technique

39. The '315 patent discloses “solar cell fabrication techniques to improve solar cell lifetime, passivation and/or efficiency” (Ex. 1001, 3:17-21) in tunnel oxide passivated contact (“TOPCon”) solar cell configurations.³ The '315 patent discloses a solar cell fabricated by (1) forming a dielectric region (e.g., a tunnel oxide layer) over a silicon substrate, (2) forming an emitter region over the dielectric region, (3) forming a dopant region (e.g., a dopant source layer) on a surface of the silicon substrate, and (4) heating the solar cell above 900 degrees Celsius such that the surface of the solar cell is doped to a concentration of less than or equal to $2 \times 10^{18} \text{ cm}^{-3}$ and the emitter region contains contaminants gettered from the silicon substrate through the dielectric region. These fabrication steps are illustrated in Figures 1-4 (annotated below).

³ While the TOPCon moniker was not coined until 2013 by researchers at the Fraunhofer Institute for Solar Energy Systems, SunPower had been developing and optimizing solar cells employing tunnel oxide layers between the silicon substrate and doped polysilicon regions prior to 2013.

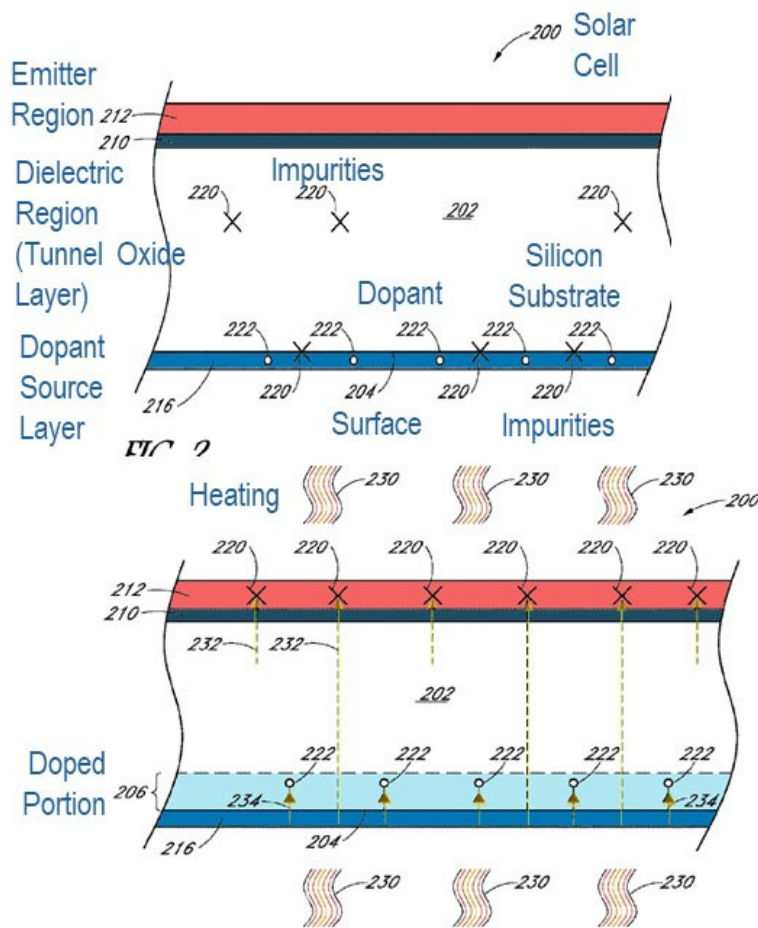


FIG. 2

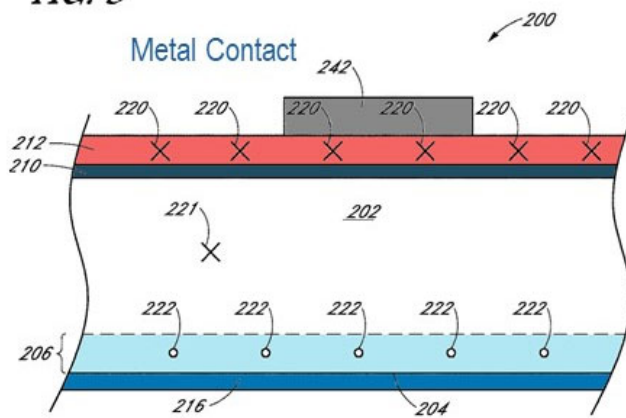


FIG. 3

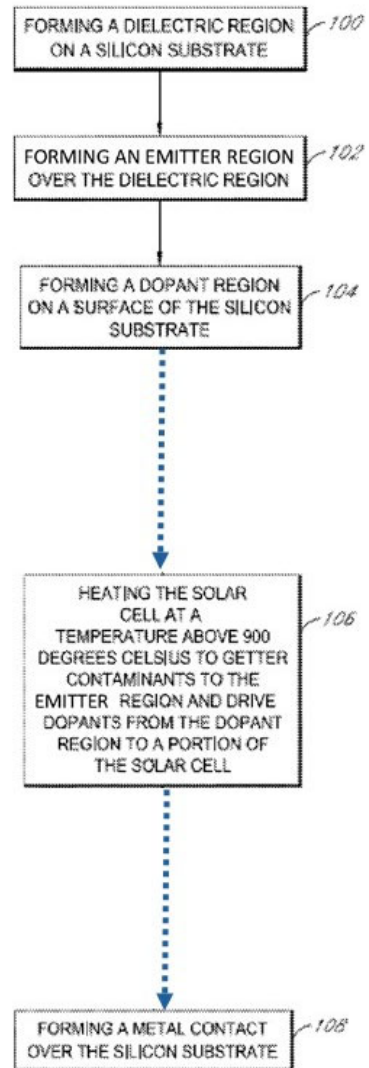


FIG. 1

Ex. 1001, Figs. 1-4 (annotated).

40. The '315 patent explains (and summarizes in Figure 11) that this particular combination of steps to form a solar cell provided increased efficiency that was both unique and unexpected. Figure 11 shows four processes where the heating temperature and surface dopant concentrations were varied and the gettering location, surface passivation, lifetime, and efficiency results were measured.⁴ *See* Ex. 1001, Fig. 11 (below, color annotations added).

⁴ I agree that an inadvertent error was made in Figure 11 that shows all the temperature settings to be less than or equal to 900 degrees Celsius. *See* Pet., 8 n.1. The original application included the same information as Table 1 in the specification, which was later amended to be Figure 11. Ex. 1002, p. 43. Table 1 in the original application correctly shows that the Example Processes C and D in Figure 11 should have temperature settings at greater than 900 degrees Celsius as described in the text. Ex. 1002, p. 43.

Variables			Results				
Example Process	Temp	Surface Dopant Conc.	Gettering Location	Surface Passivation	Lifetime	Efficiency	
A	≤ 900 deg-C	$2 \times 10^{18} \text{ cm}^{-3}$	non-poly	2 fA/cm^2	$\sim 3 \text{ msec}$	Baseline	
B	≤ 900 deg-C	$4 \times 10^{18} \text{ cm}^{-3}$	non-poly	5 fA/cm^2	$\sim 10 \text{ msec}$	Baseline	
> 900 deg-C	C	≤ 900 deg-C	$2 \times 10^{18} \text{ cm}^{-3}$	poly	2 fA/cm^2	$\sim 10 \text{ msec}$	+0.5 % abs.
> 900 deg-C	D	≤ 900 deg-C	$4 \times 10^{18} \text{ cm}^{-3}$	poly	5 fA/cm^2	$\sim 10 \text{ msec}$	Baseline

Table 1. Example Processes for Solar Cell Fabrication

FIG. 11

Ex. 1001, Fig. 11 (annotated).

41. In Example Process A, low temperature (e.g., ≤ 900 degrees Celsius) heating and low surface dopant concentration (e.g., $2 \times 10^{18} \text{ cm}^{-3}$) were used. The '315 patent explains that "[o]xides and/or tunnel oxides, such as the dielectric region . . . , can be barriers to gettering of the metal impurities 220 to emitter regions" and that "heating at temperature at 900 degrees Celsius or below can be insufficient to diffuse metal impurities through a tunnel oxide and into a polysilicon region." Ex. 1001, 5:15-20. Accordingly, the "Gettering Location" for Example Process A is the "non-poly" silicon substrate, rather than the "poly" emitter region. The combination of low temperature gettering and low surface dopant concentration allows for good surface passivation, but poor lifetime.

42. Example Process B also uses low temperature heating, but a higher surface dopant concentration (e.g., $4 \times 10^{18} \text{ cm}^{-3}$). Like Example Process A, the gettering location remains in the “non-poly” silicon substrate. The low temperature gettering and higher surface dopant concentration results in a good lifetime, but poor surface passivation. Example Processes A and B demonstrate the kind of trade-offs that are made when designing solar cells. Having a low surface dopant concentration results in good surface passivation, but poor lifetime; whereas a high surface dopant concentration results in good lifetime, but poor surface passivation. For both processes, the efficiency of the solar cell remained the same.

43. The unexpected result came from Example Process C, where high-temperature (e.g., > 900 degrees Celsius) heating and low surface dopant concentration are used. In this process, contaminants from the silicon substrate getter through the dielectric region and into the “poly” emitter region. At the same time, dopants are driven deeper into the silicon substrate from the surface of the silicon substrate resulting in a lower surface dopant concentration. At the time of the invention, it was not known whether high-temperature heating would getter contaminants through the dielectric region, while leaving this region intact and functional, or whether there would be some split between contaminants gettered between the surface of the “non-poly” silicon substrate and the “poly” emitter

region, such that lifetime would not show any improvement (which was the case for Example Process D, described below). Further, a person of ordinary skill in the art would not have expected lifetime to improve by high-temperature heating because the silicon substrate also contains oxygen defects, which would be enlarged at higher temperatures and increase the likelihood of Ingot Ring Defects, which would reduce lifetime. Example Process C, however, provided both improved surface passivation and lifetime, resulting in a 0.5% increase in efficiency over the other example processes.

44. Example Process D also produced an unexpected result in that high-temperature (e.g., > 900 degrees Celsius) heating did not further improve the lifetime beyond what a high surface dopant concentration already produced in a TOPCon solar cell configuration (e.g., Example Process B). Thus, Example Process D demonstrates that a high-temperature heating step alone does not yield improved efficiency in the claimed solar cell configuration unless the surface dopant concentration is low. In other words, the '315 patent requires a specific combination of fabrication steps and surface dopant concentration to improve the performance of a particular solar cell structure.

C. The '315 Patent Prosecution History

45. It is my understanding that the Examiner agreed that the claimed invention was patentable:

4. The following is an examiner's statement of reasons for allowance: Claims **1 – 20** are allowable over the prior art of record because none of the prior art whether taken singularly or in combination, especially when these limitations are considered within the specific combination claimed, to teach:

portion of the silicon substrate is formed at the back side of the solar cell and a first dielectric region formed over the silicon substrate, wherein the first dielectric region is formed over the front side of solar as recited in the independent claim **1**; and portion of the silicon substrate is formed at the front side of the solar cell; a dielectric region formed over the silicon substrate, wherein the dielectric region is formed over the back side of solar; a first emitter region having metal impurities formed over the dielectric region as recited in the independent claim **10**.

Ex. 1002, p. 207.

46. While the Examiner allowed these claims without issuing any rejections, I note that a significant number of references cited during prosecution resulted from previous searches in related patents.

VIII. CLAIM CONSTRUCTION

47. I have been asked to apply the plain and ordinary meaning of the terms of the challenged claims as those terms would have been understood by a person of ordinary skill in the art at the time of the invention (i.e., in 2014).

IX. CSI HAS NOT SHOWN THAT ANY CHALLENGED CLAIM IS UNPATENTABLE

A. All Grounds Fail to Satisfy the “emitter region having metal impurities” Limitation

48. All of CSI's grounds fail to satisfy the limitation “a first emitter region having metal impurities formed over the dielectric region,” as recited in

independent claim 10. Because all other challenged claims depend from claim 10, all of CSI's grounds fail.

49. CSI and Dr. Banerjee concede that primary reference Li (Ex. 1005) does not include any mention of a "first emitter region having metal impurities" (Pet., 44-45; Ex. 1003, ¶ 155), and I understand that CSI and Dr. Banerjee rely on inherency. However, CSI and Dr. Banerjee do not show that "metal impurities" are necessarily present in Li's material layer, which CSI alleges corresponds to the "emitter region" of claim 10. CSI's contention is premised on numerous faulty assumptions.

1. CSI Improperly Presumes a High Level of Iron Impurity in Li's Substrate

50. CSI speculates that metal impurities, specifically iron, are inherently present in Li's substrate and that they are present in large quantities. CSI states that "the Skilled Artisan would have immediately recognized that **substantial** metal impurities were known to exist in **all** such [single crystalline or multicrystalline silicon] substrates." Petition at 45-46 (emphasis added). I disagree that "substantial" metal impurities were known to exist in "all" silicon substrates. This error is consequential as whether metal impurities would necessarily be in the material layer 506 of Li depends on the starting concentration of any metal impurities in substrate (e.g., substrate 508). This is because diffusion is related to the differential in concentration. Dispersed material (e.g., impurities in a matrix)

generally diffuse from regions of high concentration to regions of lower concentration. Generally, the smaller the difference between the higher and lower concentrations, the less diffusion occurs.

51. CSI appears to have found a reference that discloses “high” impurity concentrations and then assumed—without any support and indeed contrary to the evidence—that such concentrations would necessarily have been present in Li. CSI cites Dr. Banerjee’s declaration in which he opines that “iron impurities in multicrystalline silicon substrates were known to be as high as 10^{14} - 10^{16} cm⁻³ in concentration.” Ex. 1003, ¶ 89. Dr. Banerjee appears to have cherry-picked a source reflecting a higher level of impurities than were available in 2014. Dr. Banerjee admitted that a concentration of 10^{14} - 10^{16} cm⁻³ was large. Ex. 2022 at 84:2.

52. Li would not necessary include the large impurity concentrations mentioned by Dr. Banerjee. Rather, Li could employ the far purer substrates. In 2014, substrates with impurity concentrations as low as 10^{11} or 10^{12} were widely known. Ex. 2033 at 1165. Li does not state that its substrate includes metal impurities. Further, Li does not include any other disclosure that would indicate “large” metal impurity concentrations would be desirable much less necessary.

53. Far more pure forms of silicon were available in 2014 and such silicon was employed as substrates for use in solar cells. Indeed, as revealed by Neuhaus

(Ex. 1011), “the IBC [Interdigitated Back Contact] solar cell design requires extraordinarily high lifetime silicon starting material” and “SunPower is using wafers with lifetimes greater than 1 millisecond and a thickness of 200 μm .” Ex. 1011 at p. 11. Notably, SunPower is the assignee of the patent that Li issued as. Ex. 2027. Thus, not only would the substrate of Li not be required to have a “high” impurity concentration, but it could also have been made of “extraordinarily high lifetime silicon starting material” SunPower. Such materials were known to have impurity concentrations as low as 10^{12} with μmsec lifetimes. Ex. 2032 at 4; Ex. 2033.

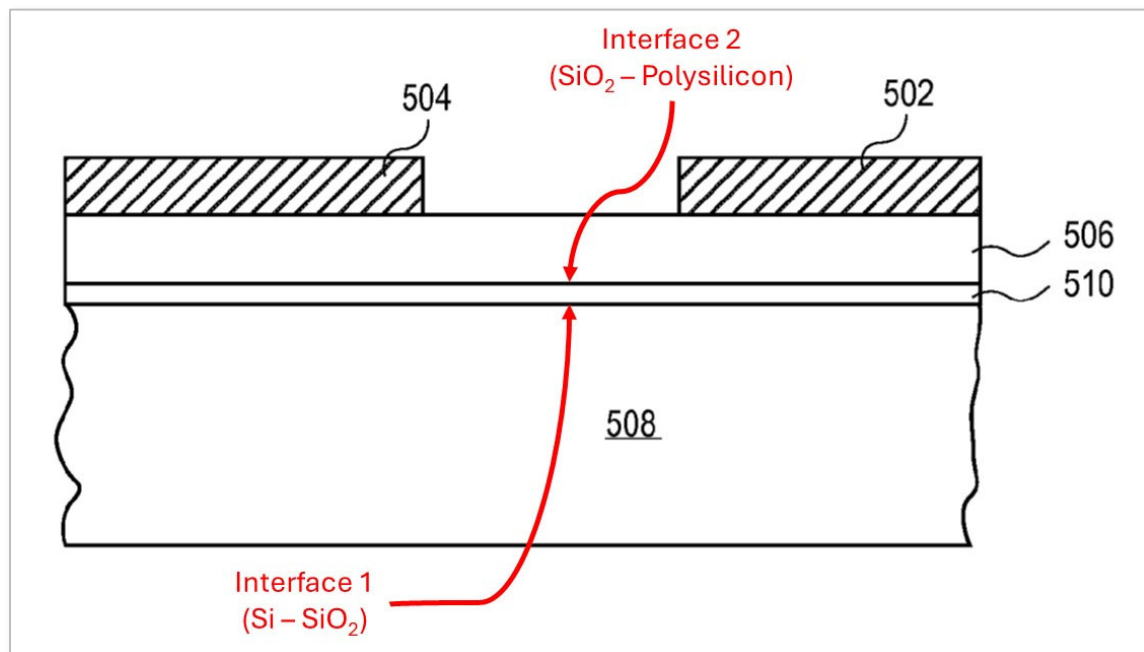
54. For the foregoing reasons, it was improper for Dr. Banerjee and CSI to assume the substrate in Li has a large impurity concentration.

2. *CSI Ignores “Pileup” that Would Occur at the Si-SiO₂ and SiO₂-Polysilicon Interfaces*

55. Another flaw in CSI’s analysis is its failure to account for “pileup” of metal impurities at the interfaces that exist between the substrate 508 of Li and the material layer 506 of Li. The phenomenon of “pileup” is where impurities congregate at an interface between two materials. This is caused by a misalignment of the electronic bands and energy levels of the two materials.

56. Even assuming that the substrate 508 of Li includes metal impurities and those impurities were forced out of the substrate, there are two interfaces in Li between substrate 508 and material layer 506 at which pile up would occur. The

first is the interface between the silicon substrate 508 and the dielectric film 510. The second is the interface between the dielectric film 510 and the material layer 506. These are illustrated as “Interface 1” and “Interface 2,” respectively, below:



Ex. 1005, Fig. 5A (annotated).

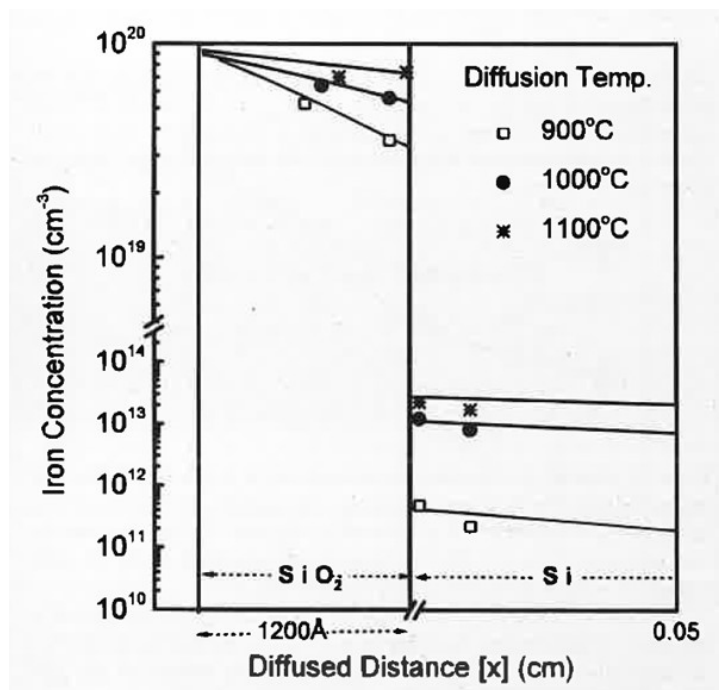
57. That pile up would occur does not appear to be in serious dispute.

Ramappa (Ex. 1025), upon which CSI relies, states as follows:

The SiO₂-Si interface is known to act as a sink for impurities. Normally, an impurity tends to segregate or remain at the interface if it reduces the interfacial free energy or stress. Metallic impurities including iron have been reported to have a tendency to accumulate in the oxide near the interface. This “pileup” characteristic introduces a discontinuity in the concentration profile of iron from the oxide into silicon.

Ex. 1025, p. 3775 (footnote references omitted).

58. The “discontinuity” mentioned in the passage above is depicted in, for example, Figure 5 of Ramappa:



Ex. 1025, Fig. 5.

59. Figure 5 of Ramappa (above) shows a concentration difference across the SiO₂-Si interface of many orders of magnitude. In the SiO₂, iron concentration measures near 10²⁰ cm⁻³ (in any event well above 10¹⁹ cm⁻³). By contrast, in the silicon, the concentration varies between approximately 10¹¹ cm⁻³ and approximate 2×10¹³ cm⁻³. With particular reference to the concentrations at 900°C, the lowest measured value in the SiO₂ is above 3×10¹⁹ cm⁻³, and the highest measured value in the Si was approximately 5×10¹¹ cm⁻³. That is a difference of a factor of over sixty million (60,000,000). Stated differently, for every 60,000,000 atoms

measured on one side of the SiO₂-Si interface, only one atom was measured on the other side.

60. Applying Ramappa's teaching of a concentration difference across the SiO₂-Si interface undermines CSI's gettering argument. Assuming a beginning impurity concentration in Li's substrate of $1 \times 10^{11} \text{ cm}^{-3}$, a decrease in concentration across the SiO₂-Si interface by a factor of sixty million would result in a concentration in the silicon oxide layer of $\sim 1.67 \times 10^3 \text{ cm}^{-3}$. Even if there were perfect gettering through the silicon oxide layer (an assumption that is highly charitable in favor of CSI), and assuming a similar decrease across the SiO₂-polysilicon interface (which I think is a reasonable assumption due to similar misalignment issues at the Si-Poly interface as would be present in the SiO₂-Si interface, Ex. 2038) would result in a concentration in the polysilicon of approximately 2.7 atoms per 100,000 cubic centimeters of silicon. Considering that there are approximately 5×10^{22} atoms of silicon per cubic centimeter, this is approximately one atom of iron impurity for every 1.8×10^{27} atoms of silicon. Even assuming a starting impurity concentration of $1 \times 10^{14} \text{ cm}^{-3}$, i.e., the lower end of Dr. Banerjee's range, would result in a concentration in the polysilicon of far less than one atom per cubic centimeter ($10^{14} \text{ cm}^{-3} / (6 \times 10^7)^2 = 0.027 \text{ cm}^{-3}$). Such *de minimis* amounts would be less than the concentration that can be detected by any reasonable detection means. For example, Liu-1 shows that the detection limit for

iron is $5 \times 10^{15} \text{ cm}^{-3}$. Detection methods that were available other than the SIMS method disclosed by Liu had similar sensitivities and would not be able to detect the concentrations of 10^{11} , Exs. 2036, 2037 and 0.027 cm^{-3} mentioned above.

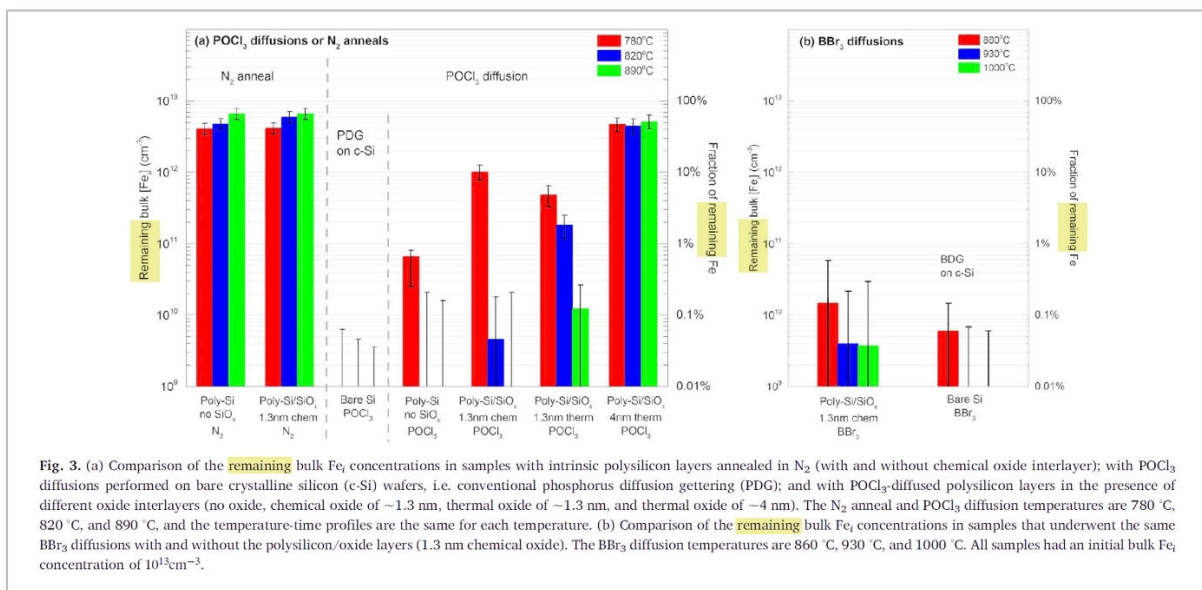
61. To reiterate, even the above concentrations are likely much higher than would result in Li due to the difference in the duration of the heating step. Ramappa discloses a 90 minute heat treatment duration. Ex. 1025, p. 3773 (“Iron at the surface of the SiO_2 was then diffused by thermal annealing in a nitrogen ambient for *a duration of 90 min* at several temperatures over the range of 800-1000°C.”) (emphasis added). Li, by contrast, likely has a much shorter duration, e.g., likely no more than 5 minutes.

62. Although Dr. Banerjee concedes that pileup would occur, he did not undertake any analysis to determine the extent of such pileup. Ex. 2022 at 68:22-69:4. That was a serious oversight. In order to properly determine whether any metal impurities that began in Li’s substrate 508 would getter to material layer 506, it would be necessary to perform such an analysis. Only by doing such an analysis would one be able to determine that any metal impurities in Li’s substrate 508 would necessarily migrate to material layer 506.

63. Relatedly, CSI and Dr. Banerjee commit another serious error in assuming that references that disclose metal impurities being drive out of a silicon substrate reveal that metal impurities are driven into a polysilicon layer. Such an

assumption ignores that, in Li, the polysilicon layer is separated by an oxide layer *and two interfaces*. CSI's and Dr. Banerjee's collective assumption is false, as pileup will occur at those two interfaces.

64. For example, CSI alleges that Liu-2 supports its theory because it allegedly shows a decrease in impurity concentration in a silicon substrate under certain conditions. Pet., 50. However. In this regard, the Petition's assertion that Liu-2 "observed gettering *through* the 'chemical oxide interlayers' in the range of 1.3 nm (in the same thickness range contemplated by Li)" is incorrect. See Pet., 50. Liu-2 measured impurities that *remained* a silicon substrate after a 78-minute heat treatment (much longer than what would be expected in Li). This is made clear in, among other places in Liu-2, Figure 3:



Ex. 1029, Fig. 3 (annotated).

65. Liu-2 did not measure impurities that traveled *through* an oxide layer.

66. Liu-1 is likewise unhelpful to CSI. Liu-1 was performed under specific conditions that almost assuredly would not be present in Li. Liu-1 discloses a heating step that takes place over 78 minutes; Li's dopant diffusion step is likely much shorter, as I explain in section IX.A.3.b below. Liu-1 grew a silicon oxide layer under specific conditions. Ex. 1028 at p. 2276. Li does not indicate any similarities to that process. Liu-1 employed a "heavily" doped polysilicon layer and does not indicate its results would be seen in other circumstances. In Li, the polysilicon layer begins undoped and is only doped (to some unspecified degree) during the step that CSI alleges causes gettering. In any event, CSI fails to show that the relevant conditions of Liu-1 necessarily would have been present in Li.

3. *CSI Fails to Consider Characteristics of Li's Dielectric Film That Are Relevant to Whether Gettering Would Occur*

67. CSI erroneously assumes that gettering will occur across Li's dielectric film 510 without considering all of the numerous relevant considerations. CSI and Dr. Banerjee appear to have concluded that gettering would occur during Li's dopant diffusion step, which in one embodiment occurs at 950°C, simply because (i) that temperature is close to the temperature used in the '315 patent and certain other references and (ii) gettering occurred in the '315 and those references. Such an approach is technically unsound. Indeed, the references upon which CSI

relies reveals that whether gettering will occur depends on numerous factors, many of which CSI failed to consider much less show would necessarily be present in Li.

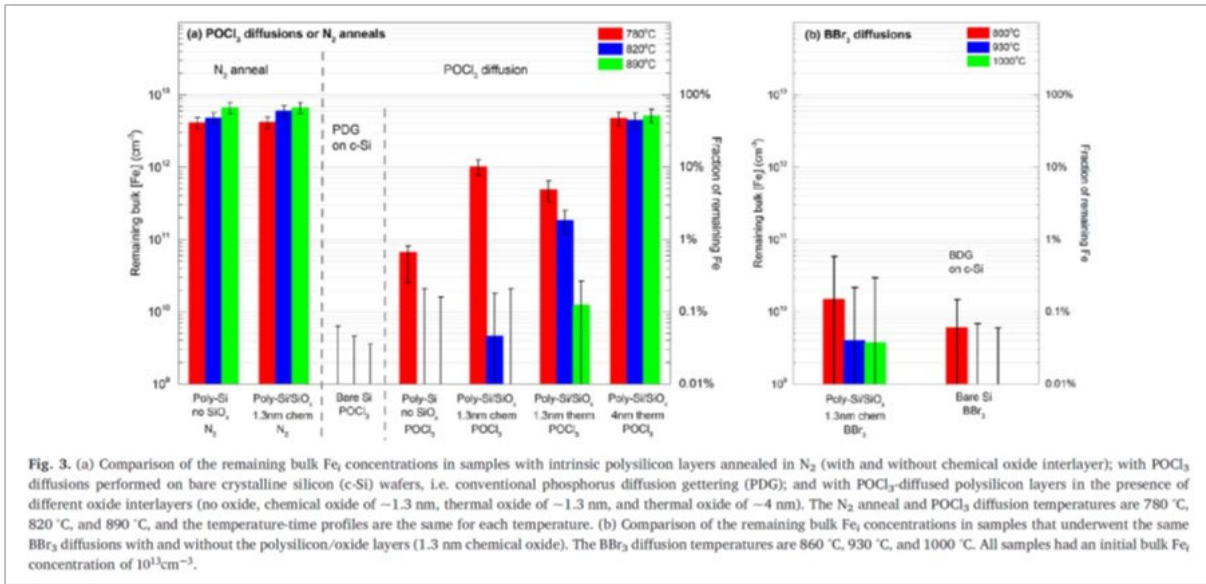
a. Whether gettering would occur across a dielectric layer depends on many factors

68. CSI and Dr. Banerjee take an overly-simplistic view of the issue of potential gettering through Li's silicon oxide layer 510. They treat the issue as if it were dependent only on temperature. That is erroneous. Whether impurities would travel through Li's oxide layer 510 and into Li's polysilicon material layer 506 depend on a number of factors, including (i) the duration of the heating, (ii) the method by which the oxide layer 510 and polysilicon material layer 506 are formed, (iii) the thermal history of the oxide layer 510 and polysilicon material layer 506, and (iv) the thickness and doping concentration of the polysilicon layer 506.

69. That gettering depends on numerous factors cannot seriously be questioned. Even the references relied upon by CSI state this fact. For example, Liu-2 states that there are large "[d]iscrepancies in the reported iron solubility in SiO₂" and "the results are contradictory," which "make it difficult to assess and quantify the blocking mechanisms of the oxide interlayer" between a substrate and a polysilicon film. Ex. 1029, p. 140. Further, both Hu and Liu-2 reported that polysilicon layers need to be deposited under optimum fabrication conditions for gettering to occur. Ex. 1017, 4:26-28 ("The polycrystalline silicon deposition

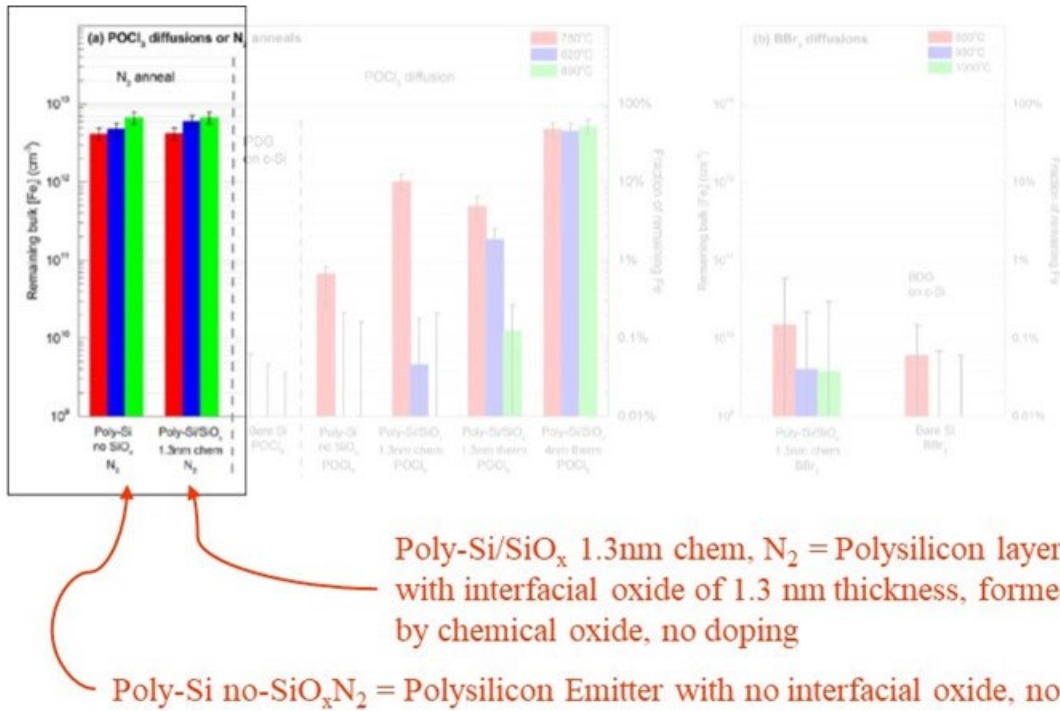
temperature has a diverse number of effects and must be optimized for suitable use in gettering.”); Ex. 1029, p. 141 (“The presence of the oxide interlayer hinders the gettering effectiveness, although at optimum polysilicon fabrication conditions...the blocking effect is small.”). That is, the gettering of metal impurities into a polysilicon layer is not a simple and straightforward process that inevitably occurs at a certain temperature, as alleged by CSI and Dr. Banerjee. Pet. 45, 47; Ex. 1003, ¶¶ 155, 160.

70. Liu-2 (1) discloses configurations where gettering into polysilicon layers will not occur, and (2) contradicts CSI’s claims related to the teachings of Hu and Ramappa. Liu-2 compared the gettering effectiveness of polysilicon layers by “varying the interlayer oxide properties (chemical oxide, thermal oxide of different thicknesses, and no oxide), and replacing the dopant diffusions with nitrogen anneals.” Ex. 1029, p. 137. Figure 3 of Liu-2 shows the results of this comparison, where effective gettering out of the substrate (but not accounting for pileup) is indicated by a low bar (or no bar) on the chart. Ex. 1029, p. 139 (shown below).



Ex. 1029, Fig. 3.

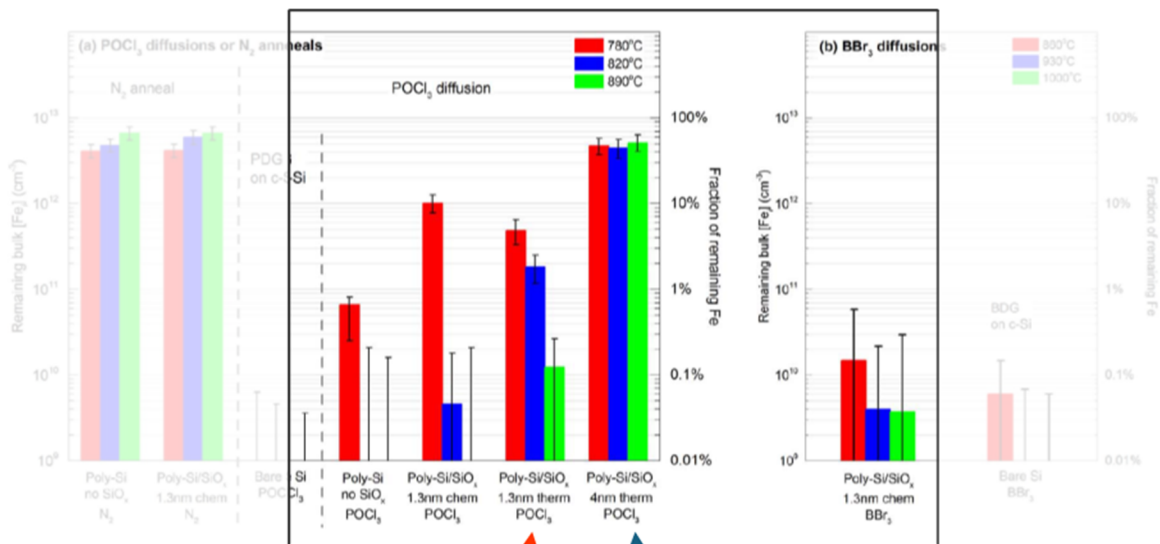
71. Starting from the left, Figure 3 shows that “intrinsic [(i.e., undoped)] polysilicon films . . . do not have a significant gettering action . . . with or without the oxide interlayer.” Ex. 1029, p. 139. This is shown in Figure 3:



Ex. 1029, Fig. 3 (modified, annotated).

72. Liu-2 states that “more effective gettering could be achieved in more heavily doped samples.” Ex. 1029, p. 140. Thus, with Li being silent about the doping concentration of its polysilicon layer, gettering of metal impurities into Li’s polysilicon layer would not have been inevitable.

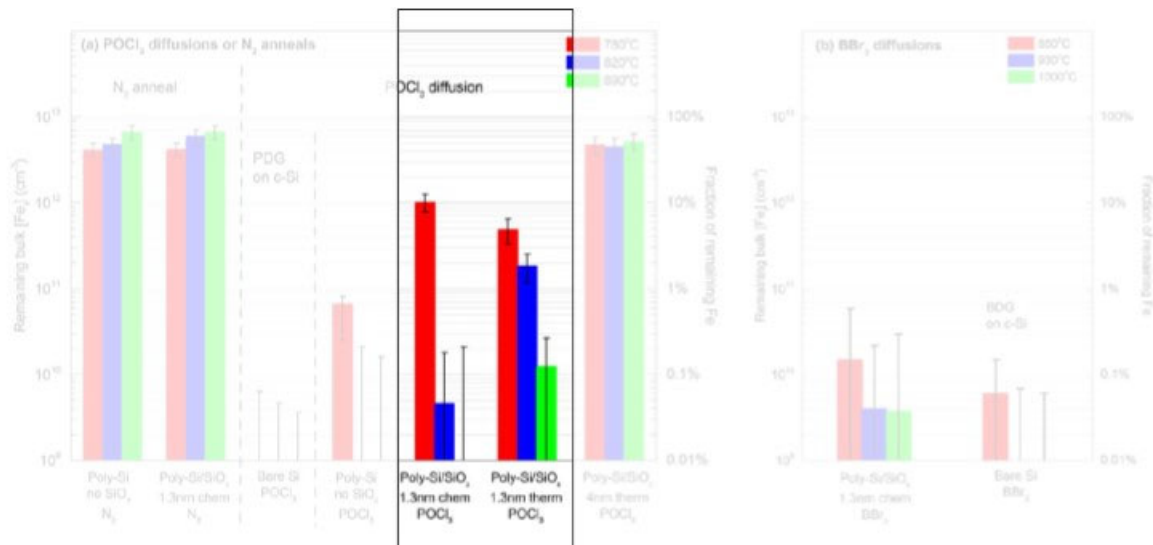
73. Figure 3 of Liu-2 also shows that “[t]he gettering effectiveness of both polysilicon contacts and diffused c-Si wafers . . . increase[s] with increasing diffusion temperature, for both POCl₃ and BBr₃ diffusions,” but “[f]or samples with a 4-nm thick thermal oxide interlayer, ineffective gettering is observed for all diffusion temperatures.” Ex. 1029, pp. 139-40, Fig. 3 (annotated below).



Ex. 1029, Fig. 3 (annotated).

74. This finding of Liu-2 directly contradicts CSI's and Dr. Banerjee's argument that "iron diffuses readily across silicon dioxide layers even much thicker (50-100nm)." See Pet., 47 (discussing Ramappa); Ex. 1003, ¶ 161. Neither CSI nor Dr. Banerjee offer an explanation regarding this apparent contradiction with Liu-2. These results reveal that gettering of metal impurities into polysilicon layer through oxide layers can be a possibility under certain process conditions, but gettering *cannot necessarily happen under any condition*.

75. Figure 3 of Liu-2 further shows that gettering effectiveness is related to how the oxide layer is grown. Ex. 1029, Fig. 3 (annotated below). Liu-2 states that “[t]he different gettering effectiveness of the chemical and thermal oxides of the same thickness likely relate to the different oxide density achieved by the two growth methods.” Ex. 1029, p. 140.



Gettering for n-type (POCl₃) doped Polysilicon with 1.3 nm oxide is more effective for chemically grown oxide versus thermally grown oxide

Ex. 1029, Fig. 3 (annotated).

76. In contrast, Li is silent on how its dielectric film is formed.

77. In sum, Liu-2 teaches that a variety of structural and process dependent variables influence whether an oxide layer will allow effective gettering. CSI has not shown that these variables in Li are such that gettering of metal impurities through Li's dielectric film is inevitable.

78. Liu-2's teachings about gettering contradict CSI's and Dr. Banerjee's assertions related to Hu and Ramappa. Hu discloses "[a]n integrated circuit structure [(i.e., not a solar cell)] . . . which provides for gettering with a backside layer of polycrystalline silicon" that is "either undoped or suitably doped with oxygen." Ex. 1017, Abstract, 3:24-27. CSI and Dr. Banerjee claim that Hu teaches "metal impurities in the silicon substrate would have naturally and inevitably getterred to the backside polysilicon 'material layer' of Li." Pet., 47; Ex. 1003, ¶ 160. But according to Liu-2, undoped (or intrinsic) polysilicon films have an "inability . . . to getter bulk impurities." Ex. 1029, p. 139. Neither CSI nor Dr. Banerjee reconciles the teaching of Liu-2 with Hu regarding the gettering effectiveness of polysilicon. Liu-2 explains the fabrication of the polysilicon film as follows:

The polysilicon films used in this work come from partially recrystallized a-Si films deposited by PECVD at low temperature of ~250°C, while those used in microelectronics for backside gettering purposes consist of polysilicon deposited by CVD at much higher temperatures of 600-800°C. In addition, the recommended film thickness for backside polysilicon gettering is 500 nm to 3 µm, which is much thicker than our 30–40 nm deposited a-Si films, offering more grain boundary area for impurity segregation and relaxation. . . . [T]he provision of a sufficient amount of grain boundaries is important for the gettering action of intrinsic polysilicon layers, that is, the thickness

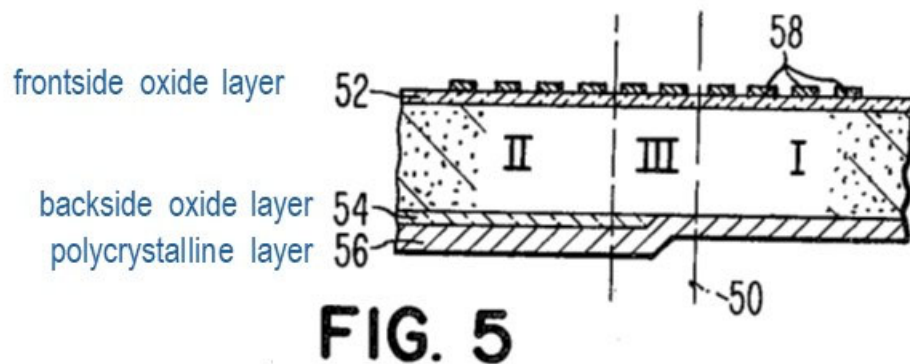
ratio of the polysilicon film to the bulk crystalline silicon substrate, where impurities are gettered from, should be considered.

Ex. 1029, p. 139.

79. In contrast to Liu-2, Hu is a microelectronics patent and discloses polycrystalline silicon films formed within the ranges identified by Liu-2 as being typical of those in microelectronics. *See* Ex. 1017, 14:58-15:10 (claiming a layer of polysilicon, “wherein the temperature for depositing said layer is between about 680°C and 800°C and the thickness of said layer being between about 5000 Å and 50000 Å” (i.e., 500 nm to 5 µm)). In view of these teachings, it would be improper, as CSI apparently does, to conclude that Li would permit gettering because Hu permits gettering, without considering the foregoing factors (e.g., thickness of the polysilicon layer, ratio of thickness of polysilicon layer to bulk silicon substrate, temperature of formation of polysilicon layer, etc.).

80. Regarding Ramappa, which discloses a “quantitative analysis of diffusion of iron in silicon dioxide,” CSI claims that “iron diffuses readily across silicon dioxide layers even much thicker (50-100nm) than the 1-2 nm layer used by Li.” Pet., 47; Ex. 1003, ¶ 161. Liu-2, however, teaches that “[f]or samples with a 4-nm thick thermal oxide interlayer, ineffective gettering is observed for all diffusion temperatures.” Ex. 1029, p. 140; *see also* U.S. Patent Pub. No. 2006/0118868, “A Semiconductor Substrate Comprising a Support Substrate

Which Comprises a Gettering Site” (“Yoshimura”), Ex. 1026, ¶¶ [0047], [0054] (teaching that “the group of impurity metals [can] hardly pass through the SiO₂ film” that was 50 nm thick). Moreover, Hu discloses “an oxide layer on frontside 52 and backside 54” that extends across region I, but not region II, of the structure, and “it was expected that gettering would take place in region I, but not in region II because of the presence of an intermediary oxide barrier.” Ex. 1017, 8:29-44, FIG. 5 (annotated below).



Ex. 1017, Fig. 5 (annotated).

81. In view of Liu-2, Yoshimura, and Hu— all of which disclose oxide layers that prevent gettering—CSI do not reconcile how it can assert that a 100 nm oxide layer would allow for gettering.

82. Thus, the art demonstrates “it [is] difficult to assess and quantify the blocking mechanisms of the oxide interlayer” without at least the information about its numerous variables, such as formation processes, temperatures, densities, dopants, thickness, etc. Ex. 1029, p. 140.

83. CSI failed to consider those factors, as outlined below. Indeed, Li is silent as to many. Thus, CSI's assertion that "metal impurities in the silicon substrate would have naturally and inevitably gettered to the backside polysilicon 'material layer' of Li" (Pet., 47; Ex. 1003, ¶ 160) through the dielectric film is speculation.

b. CSI did not consider the duration of Li's dopant diffusion step

84. The extent to which any impurities in Li's substrate 508 would, during Li's dopant diffusion step, (i) getter out of Li's substrate 508, (ii) migrate across the Si-SiO₂ interface, (iii) getter through oxide layer 510, (iv) migrate across the SiO₂-polysilicon interfacial region, and (v) become trapped in Li's material layer 506 would depend on the duration of that dopant diffusion step. CSI glosses over that crucial detail.

85. Indeed, whether impurities in Li's substrate 508 would even make it to the Si-SiO₂ interface is heavily dependent on the duration at which the substrate is exposed to elevated temperatures. Any impurities in Li's substrate likely would not all be on the top surface of the substrate. In fact, due to surface cleaning operations that were common in 2014, it is possible that fewer impurities would have been at the surface of substrate 508 than in the interior of substrate 508. *See, e.g.,* Ex. 1011 at 2 ("After etching, the wafer is cleaned to remove metal and

organic contaminants that would cause an increase of surface and bulk recombination during the following high-temperature process steps.”).

86. Dr. Banerjee cites a “Handbook of Photovoltaics” for the contention that Li’s dopant diffusion step may have lasted 5-15 minutes. Ex. 1003, ¶ 107 n.1. Dr. Banerjee does not contend that such times necessarily would have been involved in the process of Li. Instead, he testified only that “[i]t probably would have been in that range.” Ex2022 at 92:5-6.

87. The dopant diffusion step in Li could reasonably be shorter than that range, and in my opinion likely would not have been longer than 5 minutes. Determining the precise time would require knowledge of many factors, including the concentration of dopants in dopant source layers 202 and 204, and the desired dopant profiles in the polysilicon layers. Li fails to disclose those relevant details. Regardless, under reasonable assumptions (e.g., assuming the concentration of dopants in dopant source layers 202 and 204 was not low, the desired dopant profiles in the polysilicon layers was not high, etc.), Li’s dopant diffusion step may be able to be as short as 5 minutes. I have personally been involved in many instances in which layers were doped in a fashion similar to those disclosed in Li, and in all instances, the times that I employed were approximately 5 minutes.

88. A person of ordinary skill in the art would not have been motivated to subject the substrate of Li to the recited 950°C for longer than necessary to achieve

the stated function of that step, *i.e.*, to transfer dopants from the source layers 502 and 504 to portions 512 and 514. Ex. 1005, ¶ [0045].

89. To the extent that the references upon which CSI relies specify the duration of the heat treatments that allegedly resulted in gettering, those durations are much longer than 5 minutes. In Ramappa, the samples were heated for 90 minutes. Ex. 1025, p. 3773 (“Iron at the surface of the SiO₂ was then diffused by thermal annealing in a nitrogen ambient for *a duration of 90 min* at several temperatures over the range of 800-1000°C.”) (emphasis added). Hu does not disclose a duration in the portion cited by CSI (5:61-6:6); however, in an example cited by Dr. Banerjee during his deposition, wafers were oxidized at 970°C for 70 minutes. Ex. 1017, 8:24-28 (“These were then oxidized at 970° C in the ambients, sequentially dry oxygen for *5 minutes*, steam *60 minutes*; and dry oxygen *5 minutes* to form 2700 Angstroms of SiO₂ films on both sides of each wafer.”) Liu-1 and Liu-2 disclose a heat treatment process that occurs over a total of 78 minutes: 40 minutes total at 890°C, 19 minutes of ramp-up time between 700°C and 890°C; and 19 minutes of ramp-down time between 890°C and 700°C. Ex. 1028, p. 2776 (“POCl₃ diffusion was carried out at 890 °C for a total of *40 min* The samples were loaded in and out of the furnaces at 700 °C, with a *ramp-up and ramp-down rate of 10 °C/min.*”) (emphasis added); Ex. 1029, p. 137 (“Phosphorus diffusions were carried out at 780 °C, 820°C, and 890 °C for the same total time of *40*

*min. . . . The loading and unloading temperature was 700 °C, and the **ramp-up and cool-down rate was 10 °C/min.**”).*

90. The durations of the references cited above are much longer than what would be required in Li. However, even if Dr. Banerjee’s expected duration were used for Li (at least 5 minutes), that fact would seriously undermine CSI’s reliance on references that disclose durations well over ten times as long.

c. CSI did not consider the method of formation of Li’s dielectric film 510

91. CSI failed to consider how Li’s dielectric film 510 is fabricated. Li does not explicitly disclose that detail, and CSI does not assert that any particular method would have been inherent.

92. That oversight is consequential. The method of formation of a dielectric layer can have a profound impact as to whether impurities will getter through that layer. This is because a variety of variables contribute to the atomic order at the interface during formation. Among these is temperature, time, and partial pressures of O₂. Of course as Growth stresses and viscosity of thermal oxides on silicon and polysilicon January 2006 Journal of Materials Research 21(01):209 – 214 DOI: 10.1557/jmr.2006.0017 H. Kahn N. Jing M. Huh A.H. Heuer showed there are significant differences in the interface structure and internal stresses of such films which means that diffusion characteristics are quite different.

This means it is not apparent that thermally activated diffusion processes that work for one type of film will work for the other.

93. Dr. Banerjee appears to agree that the formulation process impacts diffusivity. Dr. Banerjee speculated that Li's oxide layer 510 could be grown by either a "wet" or "dry" process (wet and dry thermal oxidation are two methods for growing silicon dioxide (SiO_2) on silicon wafers, differing in their oxygen source and growth rate, with wet oxidation using water vapor (H_2O) for faster growth and dry oxidation using oxygen gas (O_2) for slower, higher-quality oxide) and that a person of ordinary skill in the art likely would have used a dry process. Ex. 2022 at 109:9-110:4. Dr. Banerjee further testified that he "would expect higher diffusivity through wet versus dry." Ex. 2022 at 110:12-13. In other words, Dr. Banerjee suspects that Li would more likely be implemented with a process that would result in *less* diffusivity.

d. CSI did not consider the thermal history of Li's dielectric film 510 or polysilicon layer 506

94. The thermal history of a material plays a key role in the diffusivity of that material. This is because heat treatments can impact the crystalline structure of the material, i.e., heat can rearrange the atomic structure of the material. That structure is highly relevant to how easily impurities move within the structure. Indeed, the references upon which CSI relies acknowledge the role that thermal histories play; that is why they spell out the processes in fine detail. *See, e.g.*, Ex.

1028 at p. 2276 (providing temperature and time details for layer formation, diffusion etc.); Ex. 1029 at p. 137 (same).

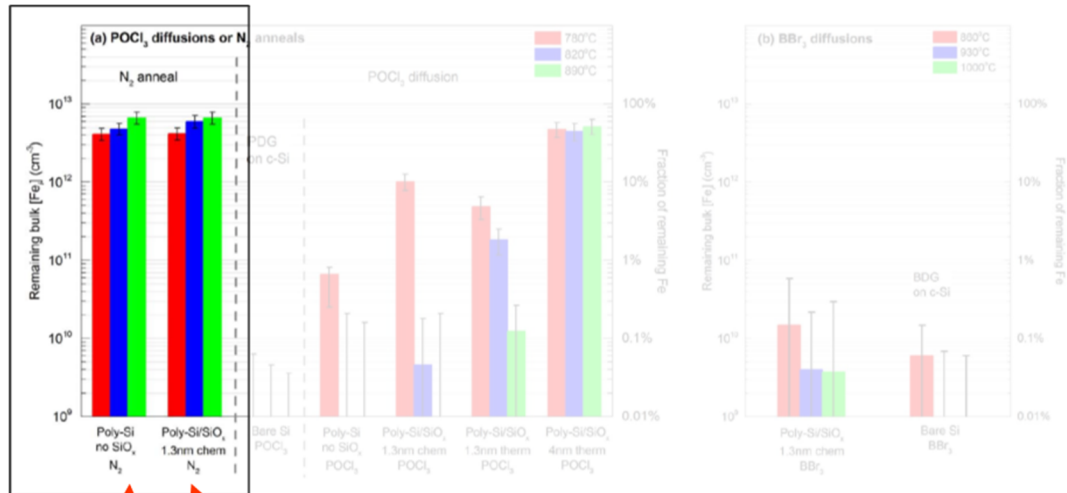
95. Neither CSI nor Dr. Banerjee considered the thermal histories of any of Li's silicon oxide layer 510, Li's polysilicon material layer 506, or the layers in the references upon which they relied. According to CSI and Dr. Banerjee, alleged diffusivity in the references it cites mandates the same diffusivity in the former. I disagree. Without conducting any sort of analysis as to the thermal histories of the layers, that contention is technically unsupported.

e. CSI did not consider the thickness of or doping concentrations in Li's polysilicon layer

96. Whether metal impurities would be gettered into Li's polysilicon layer 506 depends on (i) the thickness of that layer and (ii) the extent to which that layer is doped. CSI and Dr. Banerjee failed to consider either factor.

97. With respect to thickness, Liu-2 teaches that "the thickness ratio of the polysilicon film to the bulk crystalline silicon substrate, where impurities are gettered from, should be considered." Ex. 1029 at p. 139. Notwithstanding this admonition, CSI failed to consider the thickness of the material layer 506 of Li (which allegedly corresponds to the claimed emitter region) much less the thickness ratio of that layer to substrate 508 of Li. This was a serious oversight as any technically sound argument that Li inherently getters impurities would have considered this factor.

98. With respect to doping, low doping would weigh against effective gettering, as Liu-2 states that “more effective gettering could be achieved in more heavily doped samples.” Ex. 1029, p. 140. This is shown in Figure 3 of Liu-2:



Poly-Si/SiO_x 1.3nm chem, N₂ = Polysilicon layer with interfacial oxide of 1.3 nm thickness, formed by chemical oxide, no doping

Poly-Si no-SiO_xN₂ = Polysilicon Emitter with no interfacial oxide, no doping

Ex. 1029, Fig. 3 (annotated).

99. Li is more similar to the arrangements depicted on the far left of Figure 3 of Liu-2 than the other arrangement of Liu-2 (although there remain many sharp distinctions mentioned elsewhere in this declaration). Li includes a material layer 506 (which CSI alleges corresponds to the claimed “emitter region having metal impurities”). However, that layer (material layer 506) is initially undoped. It is later doped but not until the very same process that CSI alleges causes gettering. Pet., 2 (“Li’s process of heating the solar cell to 950°C to diffuse

dopants into the polysilicon regions will necessarily result in metal impurities being present in Li's polysilicon emitter regions.”). Further, Li is silent as to the extent of doping of material layer. Thus, while Liu-1 discloses impurity relocation when a “heavily phosphorous-doped polysilicon layer” is present, neither CSI nor Dr. Banerjee show that Li has such a “heavily” doped layer *at any time*. Thus, with Li being silent about the doping concentration of its polysilicon layer, it cannot be said that gettering of metal impurities into Li's polysilicon layer is inevitable.

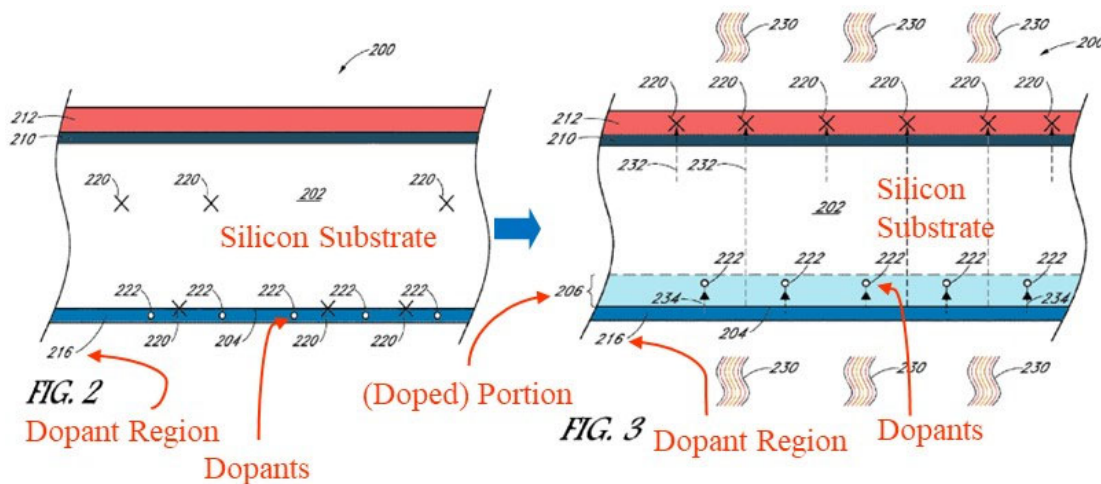
4. *Li and the '315 Patent Employ Different Dopant Diffusion Processes and Heating Steps*

100. CSI's attempts to draw parallels between the process outlined in the '315 patent and Li fail. Li and the '315 patent use different doping processes and high-temperature heating steps at different stages of their respective fabrication processes. These differences would affect whether metal impurities are present in the emitter region, as set forth in further detail below.

a. The '315 Patent and Li Use Different Doping Processes

101. The '315 Patent and Li employ different doping processes. CSI incorrectly states that “*just like the 315 Patent*, Li describes diffusing dopants at the front surface to form the front portion 520 . . . *with a gaseous N-type dopant source*.” Pet., 21 (emphases added, internal quotations omitted). However, the '315 patent does not dope the front surface with a “gaseous N-type dopant source”;

rather, the '315 patent discloses that “a dopant region 216 can be formed on a surface 204 of the silicon substrate 202,” and a high-temperature heating step drives “the dopants 222 from the dopant region 216 to a portion 206 of the silicon substrate 202.” Ex. 1001, 4:55-56, 5:64-67, Figs. 2 and 3 (annotated below).



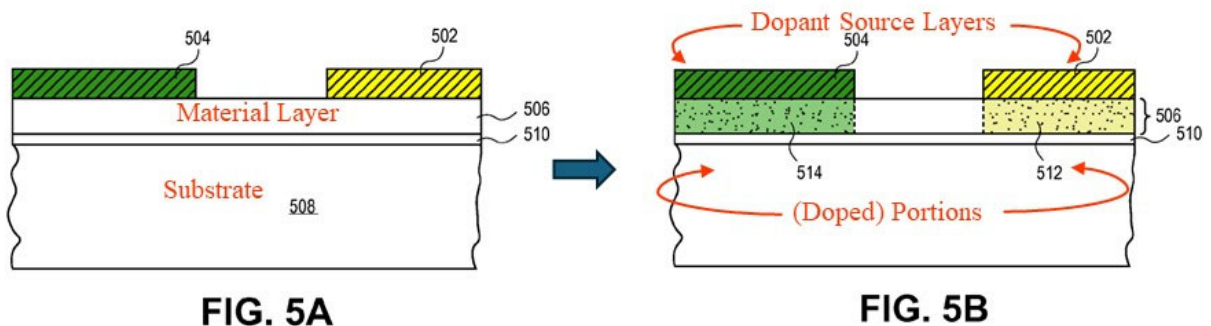
Ex. 1001, Figs. 2 and 3 (annotated).

102. Figure 3 of the '315 patent shows the portion 206 that is doped by driving dopants 222 from the dopant region 216 in the silicon substrate 202. Accordingly, the '315 patent is not “just like” Li because it does not disclose a “gaseous” (delivery of dopant) drive-in method.

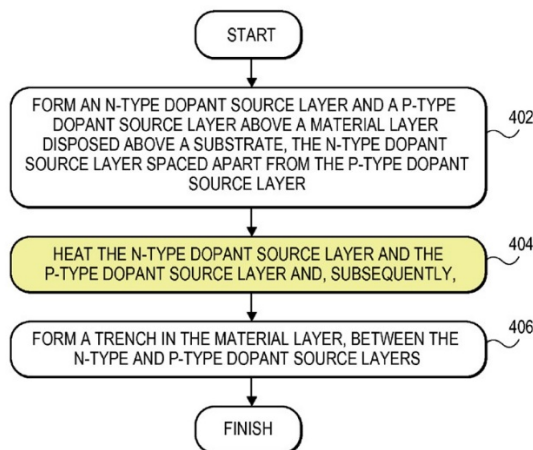
b. The '315 Patent and Li Use Different Heating Steps

103. CSI conflates different dopant diffusion steps. CSI asserts that the '315 patent discloses that “heating the solar cell above 900°C can get metal impurities into the emitter region and at the same time *perform diffusion of the dopant*,” and that “[i]n Li, dopant diffusion is conducted above 900°C, *just like in*

the 315 Patent.” Pet., 44 (emphases added); *see also* Ex. 1003, ¶ 170. In making that allegation, CSI improperly conflates (1) the high-temperature heating step that diffuses dopants into the front surface of the substrate in the ’315 patent (discussed above) and (2) Li’s diffusing of dopants into the emitter region on the back of the substrate. Li discloses that the high-temperature (950°C) dopant diffusion step occurs when the “material layer” (e.g., the emitter region) is doped. *See* Ex. 1005, ¶¶ [0044]-[0045] (explaining that dopant source layers 502, 504 are heated to transfer dopants into portions 512, 514), Fig. 4 (operation 404 of flowchart 400), Figs. 5A, 5B (annotated below).



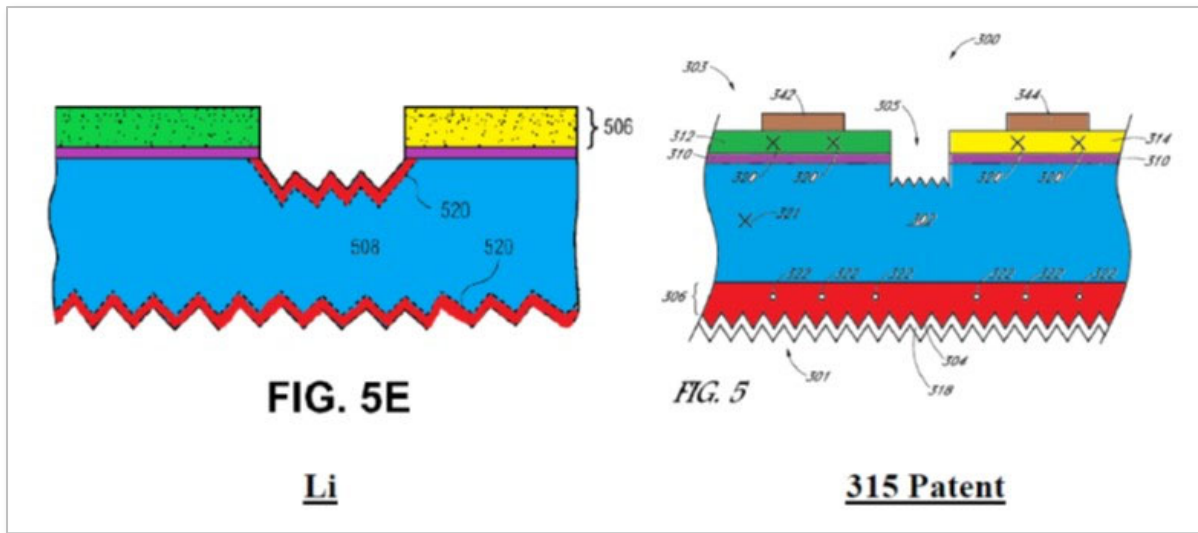
FLOWCHART 400



Ex. 1005, Figs. 4, 5A, and 5B (annotated).

104. The high-temperature heating step in Li dopes the emitter regions, whereas the high-temperature heating step in the '315 patent dopes the silicon substrate. The “dopant regions 520” in Li, which CSI identifies as the doped portion of the silicon substrate, are not formed until several steps later by “heating substrate 508 . . . in the presence of a gaseous N-type dopant source.” Ex. 1005, ¶ [0049]. Thus, Li does not perform dopant diffusion “just like in the 315 Patent” because the high-temperature heating step is performed at different times and to drive in dopants at different regions. These timing differences are significant because a person of ordinary skill in the art would have understood the need to account for the thermal history of the substrate when implementing additional heating steps.

105. A comparison of Figure 5E in Li with Figure 5 of the '315 patent (annotated by CSI and Dr. Banerjee) confirms these differences between the dopant processes and heating steps of the '315 patent and Li. *See* Pet., 21 (reproduced below).



Pet., 21 (reproducing Li, Fig. 5E (left) and '315 patent, Fig. 5 (right)).

106. The above comparison reveals that unlike the doped portion 306 of the '315 patent (red), dopant regions 520 in Li (also red) are on the front surface of the substrate 508 **and in the trench**, indicating that substrate doping occurred after the trench was formed. By contrast, in the '315 patent, no doping occurred in the trench, indicating that doping occurred before the trench was formed. Moreover, the profile of the dopant regions 520 in Li follows the textured surface profile indicating that doping was performed after texturing, unlike the '315 patent. See Pet., 21 (figure comparison). The doped portion 306 of the '315 patent also extends further into the silicon substrate 302 than the dopant regions 520 in Li, which is consistent with the high-temperature heating step for driving dopants into the silicon substrate disclosed by the '315 patent, and not the “gaseous” drive-in method disclosed by Li. See Pet., 21 (figure comparison).

107. Li uses a “two-step heating approach for the back and front of the solar cell.” Pet., 51, n.8; Ex. 1003, ¶ 169. I understand that CSI and Dr. Banerjee contend that “it would ... have been obvious to the Skilled Artisan to combine the two heating steps of Li into a single heating step for the doping of the front and back sides of the solar cell.” Pet., 51, n.8; Ex. 1003, ¶ 169. However, it is unclear what conclusion CSI and Dr. Banerjee seek to draw from that contention. Dr. Banerjee admitted that his opinions are “not premised on that [contention].” Ex. 2022 at 130:19; *see also id.* at 131:5-7 (“[W]hether those thermal processing steps are in a single step or a two-step, it doesn’t really matter.”).

108. Regardless, I disagree that such a modification would have been obvious. Dr. Banerjee proposes “using a single loading of the solar cell into a single heating furnace after the deposition of the back side dopant sources onto the polysilicon layer and include the gaseous dopant for diffusion [sic] the front portion.” Ex. 1003, ¶ 169. That is, Dr. Banerjee proposes introducing a gaseous dopant at the emitter doping stage shown in Figure 5B of Li. Immediately, Dr. Banerjee recognizes the problem that a gaseous phosphorus (i.e., n-type) dopant will cross-dope the p-type polysilicon region, so he further proposes depositing “a diffusion mask” on the backside of the substrate. Ex. 1003, ¶ 169. But the purpose of Li’s invention is to avoid the “ledge” feature, “which may undesirably result from partial mask 210 lift-off 218 and/or undercut 220 of mask 206 during the etch

process,” so re-introducing a mask over the same problematic region would not have been obvious. Ex. 1005, ¶ [0031].

5. *CSI Fails to Acknowledge the Decreased Gettering that Would Occur Under Its Li-Muller Combination*

109. CSI bases its inherency argument on a patchwork of isolated disclosures for disparate references while inexplicably excluding teachings that undermine its theory. CSI’s approach is even more faulty in the context of its Li-Muller combination.

110. CSI suggests that replacing phosphorus dopants via the method of Li with adding boron dopants via ion-implantation is an obvious and straightforward change. Pet., 64-65. That is erroneous for the reasons set forth in section IX.B.2 below. Further, that change would further decrease the likelihood that any metal impurities in Li’s substrate would be gettered to Li’s material layer 506. Liu-1 and Liu-2 discuss the decreased gettering observed when boron-doped silicon is used and more particularly when ion-implantation is used. According to Liu-1, “B[oron]-doped poly-Si layer on its own exhibits a poor gettering effect.” Ex. 1028 at p. 2279; *see also id.* Fig. 7. Liu-2 discloses that ion implantation of boron leads to less gettering, speculating that the reason for this is because a boron-rich layers (BRLs) are effective gettering sites and that “[s]amples doped via ion implantation and subsequent annealing in inert gas do not have such BRLs.” Ex. 1029 at p. 138.

6. *Neither Hu Nor Ramappa Remedy the Deficiencies of Li with Respect to the “emitter region having metal impurities” Limitation*

111. CSI does not overcome the deficiencies of its inherency theory by proposing a theory based on Li “in further view of Hu, Ramappa.” Pet., 5 (grounds 3 and 4).

112. As an initial matter, I understand that Dr. Banerjee testified that all of his unpatentability opinions are premised on the contention that Li inherently discloses gettering of metal impurities from its substrate to its material layer. Ex. 2022 at 67:15-22 (“Q: Correct me if I am wrong, but I believe in your four grounds or bases for invalidity, you’re relying on the concept of inherency; specifically that Li inherently would getter impurities from the substrate into the material layer. Is that right? A: Yes.”); *see also id.* at 181:20 (Dr. Banerjee admitting that he is “not introducing new steps” in his ground 3 and ground 4 opinions).

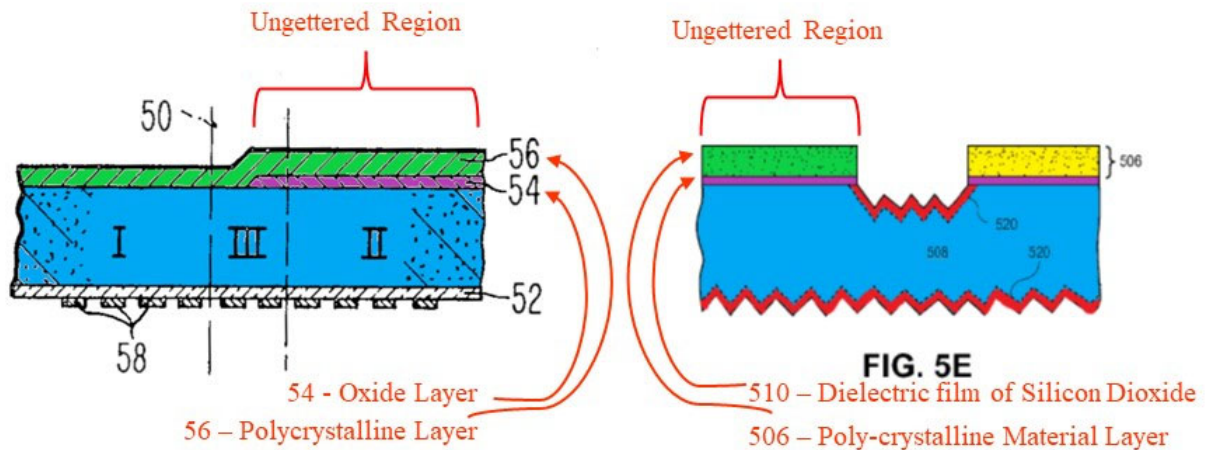
113. Regardless, the contentions of CSI and those made by Dr. Banerjee for grounds 3 and 4 are unsound. CSI contends that Li “further in view of” Hu and Ramappa satisfies claim 10’s “emitter region having metal impurities.” Pet., 69-73; Ex. 1003, ¶¶ 213-223. I disagree for the following reasons.

- a. Hu does not disclose gettering of metal impurities across an oxide layer into a polycrystalline layer

114. CSI relies on irrelevant disclosure of Hu. CSI asserts that Hu teaches the “gettering of metal impurities from a silicon ‘semiconductor body’ into a

‘polycrystalline layer’ on the backside of the silicon at temperatures of 1000°C or less.” Pet., 70. Similarly, Dr. Banerjee claims that Hu teaches “heating a ‘semiconductor ‘body’ and ‘polycrystalline layer’ at 1000°C or less, results in ‘getterable impurities... [diffusing] to, and becom[ing] trapped in, the polycrystalline silicon film.’” Ex. 1003, ¶ 217. However, neither CSI nor Dr. Banerjee addresses Hu’s explicit disclosure of a region where the polycrystalline layer is separated from the silicon by an oxide layer and gettering does not occur. Ex. 1017, 8:39-44.

115. Figure 5 of Hu illustrates both “region I,” which has a polycrystalline layer 56 deposited on the backside of the silicon wafer 50, and “region II,” which has a backside oxide layer 54 formed between the silicon wafer 50 and the polycrystalline layer 56. Ex. 1017, Fig. 5 (annotated, below left). Similarly, Li discloses dielectric film 510 between the poly-crystalline material layer 506 and substrate 508. This is depicted in the images below.



Ex. 1017, Fig. 5 (annotated)

Ex. 1005, Fig. 5E (annotated)

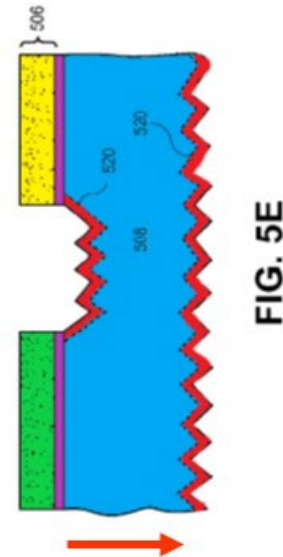
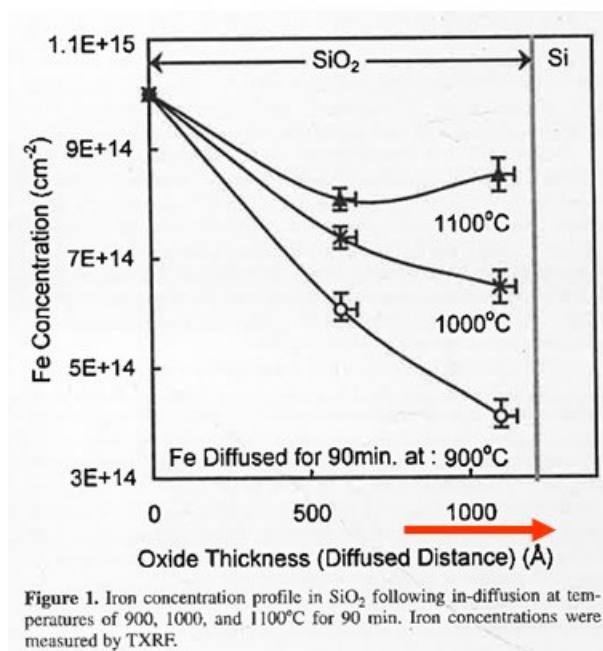
116. Hu explains that “it was expected that gettering would take place in region I, but not in region II because of the presence of an intermediary oxide barrier.” See Ex. 1017, 8:39-44. Table I of Hu confirmed that Region II between the backside oxide layer 54 and the semiconductor body 50 is “ungettered.” Ex. 1017, 9:47-54 (Table 1 annotated below).

TABLE I			
Column	Region	Mean Generation Current Nano Amp/cm ²	Remarks
1-4	II	108	ungettered transition region gettered
5-6	III	3.4	
7-10	I	1.7	

117. Accordingly, Hu does not disclose gettering impurities into the polycrystalline layer formed over an oxide layer.

- b. Ramappa does not disclose gettering metal impurities across an oxide layer into a polycrystalline layer

118. Ramappa's teachings directly contradict CSI's and Dr. Banerjee's assertions that "[b]ased on Ramappa, it would be apparent to the Skilled Artisan that iron would readily diffuse across the thin 1-2 nm silicon dioxide layer of Li into the polysilicon layer." Pet., 72-73; Ex. 1003, ¶ 161. Ramappa does not contemplate gettering or the diffusion of metal impurities from a silicon oxide layer into a polysilicon layer. *See generally* Ex. 1025. Rather, as shown in Figure 1, Ramappa analyzes iron traveling from a SiO₂ layer into silicon bulk, not out of the silicon bulk. *Compare* Ramappa, Ex. 1025, Fig. 1 *with* Li, Ex. 1005, Fig. 5E (annotated, below right). Applying this teaching to Li, as CSI and Dr. Banerjee propose, a person of ordinary skill in the art would have understood that the diffusion of metal impurities in Li's structure would be away from the polycrystalline material layer 506.



Ex. 1025, Fig. 1 (annotated) (left) and Ex. 1005, Fig. 5E (annotated) (right).

119. There is also no teaching in Ramappa about a silicon oxide layer acting as a tunnel oxide barrier layer between a substrate and a polysilicon material layer. The context and direction of diffusion studied in Ramappa are opposite from what is required for gettering metal impurities from Li's substrate 508 to the polycrystalline material layer 506.

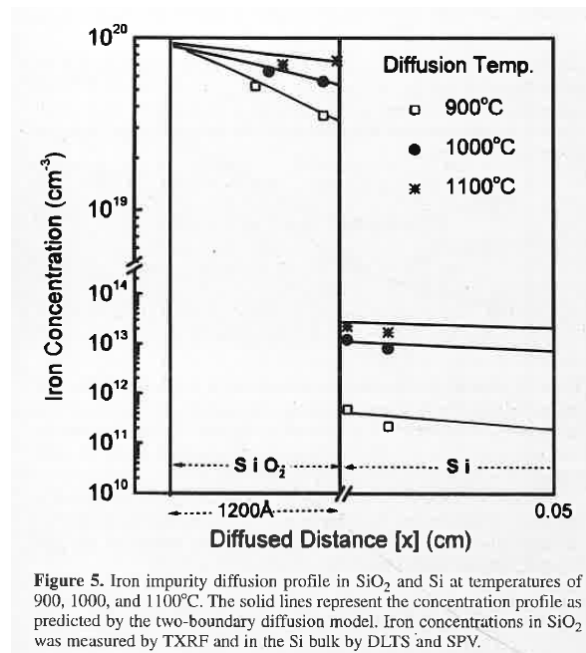
120. The findings in Ramappa suggest that a SiO₂-Si interface (including the SiO₂-Si interface in Li) would act as a barrier, preventing diffusion and thereby impeding any gettering process. Ramappa discloses that:

[I]t is observed that in agreement with previous published literature iron has a strong tendency to preferentially segregate to the SiO₂ side of the SiO₂-Si interface. This strong segregation tendency seemingly

impedes the diffusion of iron from SiO₂ into the silicon bulk. In the process the segregation could lead to supersaturation of iron impurity and eventually precipitation which in turn could provide detrimental to the gate oxide integrity.

Ex. 1025, p. 3776 (emphasis added).

121. Ramappa discloses that the SiO₂-Si interface acts as “a sink for impurities” and does not readily allow iron to pass, as illustrated in Figure 5 (below).



Ex. 1025, Fig. 5.

122. I discuss this in more detail in section IX.A.2.

123. In sum, a person of ordinary skill in the art reading Ramappa would have concluded that the SiO₂-Si interface would act as “a sink for impurities” just as Ramappa says is known to be. A person of ordinary skill in the art would not

read Ramappa as supporting CSI's theory that metal impurities would be allowed to be gettered into a polycrystalline material layer from a silicon substrate and through a silicon oxide layer.

- c. Hu and Ramappa taken together do not teach gettering metal impurities across an oxide layer into a polycrystalline layer

124. Based on the teachings of Hu and Ramappa, a person of ordinary skill in the art would not have found it obvious that Li would include metal impurities in its polysilicon material layer. From the combination of Hu's structure and Ramappa's disclosure that "iron has a strong tendency to preferentially segregate to the SiO₂ side of the SiO₂-Si interface . . . [, which] impedes the diffusion of iron from SiO₂ into the silicon bulk" (Ex. 1025, p. 3776), a person of ordinary skill in the art would have concluded that Region II in Hu is ungettered because of the oxide layer between the silicon and polysilicon layers. Thus, applying Hu's and Ramappa's teachings to Li's structure, a person of ordinary skill in the art would have concluded that metal impurities are not gettered into Li's polysilicon material layer due to the presence of Li's silicon dioxide film between its substrate and polysilicon material layer.

125. CSI and Dr. Banerjee do not mention the oxide layer in Hu nor provide an explanation for Ramappa's express teaching that "[t]he SiO₂-Si interface is known to act as a sink for impurities." Ex. 1025, p. 3775.

B. All Grounds Fail Because It Would Not Have Been Obvious to Implement Li with the Claimed “dopant concentration”

126. For Grounds 1 and 3, CSI and Dr. Banerjee rely on three references: King (Ex. 1006); Swanson-352 (Ex. 1015); and Marvin (Ex. 1035). Pet., 23-35; Ex. 1003, ¶¶ 109-132. Those references disclose outdated and solar cell configurations that would have been incompatible with Li. A person of ordinary skill in the art would not have considered either of those references when determining a suitable dopant concentration for the portion of the silicon substrate at the front side of the solar cell in Li. More recent and more relevant references—such as Granek (Ex. 2015), Lamers (Ex. 2024), Desa (Ex. 2025), and Procel (Ex. 2026)—show the use of higher dopant concentrations on the front surface of substrates to eliminate the need for a thick oxide passivation layers, as in the solar cell configurations of King, Swanson-352, and Marvin.

127. For Grounds 2 and 4, based on the combination of Li and Muller (Ex. 1008), CSI and Dr. Banerjee propose a new solar cell configuration that would not have been obvious absent CSI’s hindsight based on the ’315 patent. Pet., 57-66; Ex. 1003, ¶¶ 184-201. The proposed solar cell would have been achieved only through hindsight. CSI and Dr. Banerjee propose significant modifications to Li’s solar cell—by adding ion-implanting steps, changing dopant polarities, adding new passivation layers, reversing fabrication order, and adding masking techniques—all of which contradicts Li’s goal of reducing the number of process operations.

1. *Grounds 1 and 3: A Person of Ordinary Skill in the Art Would Not Have Been Motivated to Combine Li with King, Swanson-352, or Marvin*

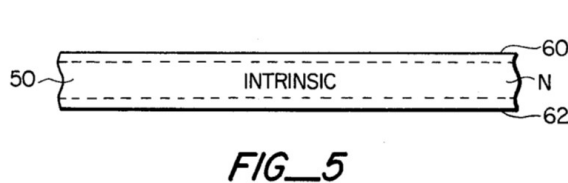
128. CSI's and Dr. Banerjee's obviousness argument is contradicted by the prior art itself, which discloses different and conflicting dopant concentrations depending on various design parameters, such as the radiation environment, the thickness of the silicon oxide passivation layer, and the shape of the dopant profile. CSI and Dr. Banerjee also do not account for the teachings of more recent references, such as Granek, Lamers, Desa, and Procel, that show that higher dopant concentrations were used and preferred for back-contact solar cells with thin silicon oxide passivation layers.

- a. King, Swanson-352, and Marvin disclose a dopant concentration related to an outdated solar cell structure that would not have been obvious to combine with Li

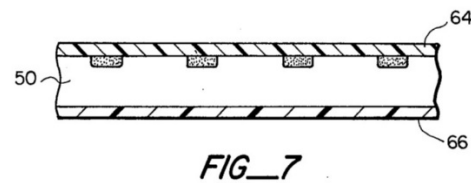
129. In the proposed combinations with Li, CSI and Dr. Banerjee do not adequately explain why a person of ordinary skill in the art would have found it obvious to look to the different solar cell configurations of King, Swanson-352, and Marvin to determine a dopant concentration in the front side of the solar cell. Indeed, a person of ordinary skill in the art would have understood that these solar cell structures are incompatible with Li and would not have followed them.

130. The disclosures in King, Swanson-352, and Marvin hearken back to an era when Interdigitated Back Contact (IBC) cells included thick silicon oxide

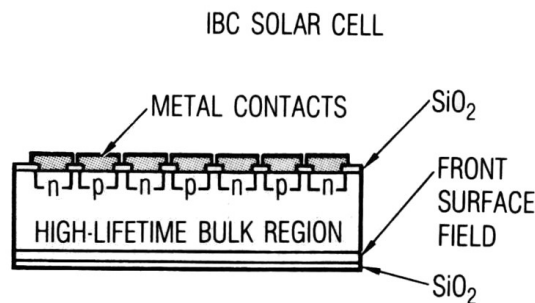
passivation layers formed over both sides of the silicon substrate. *See* Ex. 1006, p. 366 (explaining its experimental method included “lightly doped silicon substrate that has identical planer dopant diffusion with thermal oxide passivation on both sides of the wafer.”); Ex. 1015, 4:45-61 (disclosing “[S]hallow diffused regions 60 and 62 are formed in the opposing surfaces of the wafer by the diffusion of an N type dopant . . . [and] silicon oxide layers 64 and 66 are then formed on the surfaces of substrate 50.”); Ex. 1035, p. 822 (annotated figure below, left). Swanson-352 discloses that its silicon oxide layers were about 175 nm thick. *See* Ex. 1015, 4:61-66, Figs. 5 and 7 (below).



Ex. 1015, Fig. 5

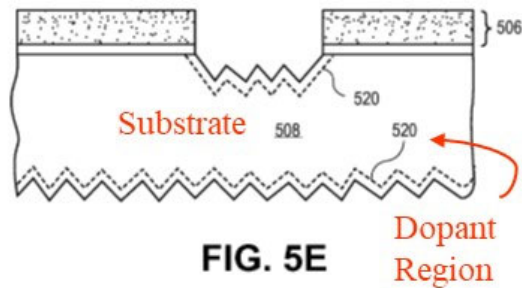


Ex. 1015, Fig. 7



Ex. 1035, Fig. 1.

131. By contrast, Li does not disclose using a passivation oxide layer at all on the front side of its substrate.



See Ex. 1005, Fig. 5E.

132. CSI and Dr. Banerjee do not take into account the differences in the solar cell structures between Li and the cited references and do not explain how or whether the presence of the silicon oxide passivation layer in King, Swanson-352, and Marvin would affect doping concentrations. This was a consequential oversight, as revealed by Granek and Muller.

133. Granek shows a correlation between the thickness of the silicon oxide passivation layer and the dopant concentration on the front side of the substrate. Granek analyzes similar solar cell performance characteristics as King did, and compares the results of “thin thermal oxides” (i.e., 2007 technology) against a “thick 105 nm antireflection oxide passivation” (i.e., 1990s technology in King, Swanson-352, and Marvin). See Ex. 2015, p. 2. Granek plots dopant profiles for different dopant concentrations using a thin 10 nm thermal oxide passivating layer (unfilled shapes $\square$, $\diamond$, $\triangle$, ∇) and one dopant profile for a thick 105 nm oxide passivation (filled shape $\bullet$). See Ex. 2015, p. 2, FIG. 4 (annotated below).

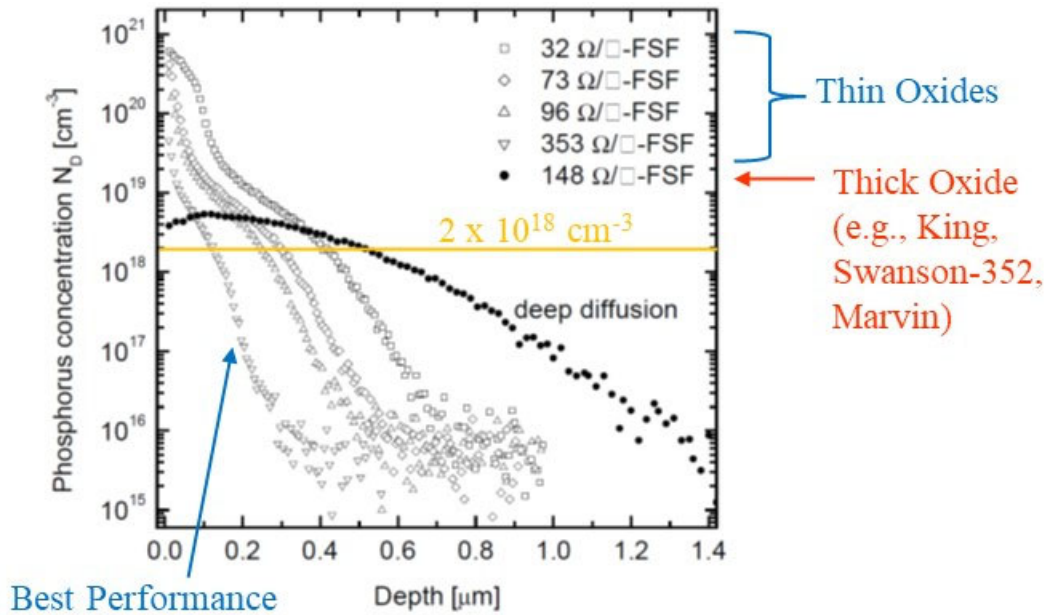


Figure 4: Secondary ion mass spectrometry (SIMS) profiles of the studied phosphorus dopant profiles measured for untextured samples after all high temperature processing steps. Sheet resistance FSF was calculated by integrating the dopant profiles using the mobility model from Masetti [9].

Ex. 2015, Fig. 4 (annotated).

Table II. Summary of the results for the textured samples with different front surface field diffusions.

n^+ diffusion [Ω/sq.]	$\rho_{base} = 1 \Omega \text{ cm}$ low-level-injection		$\rho_{base} = 10 \Omega \text{ cm}$ high-level-injection	
	J_{0s} [fA/cm ²]	$V_{OC, Limit}$ [mV]	J_{0s} [fA/cm ²]	$V_{OC, Limit}$ [mV]
32	1170	615	1180	615
73	290	651	296	651
96	138	671	161	667
353	31	710	36	706
148 (deep)	38	705	40	703
no diffusion	27	714	31	710

Ex. 2015, Table II (annotated).

134. There are a number of reasons why attention should be paid to the diffusion characteristics of the structures that are actually used in the device as opposed to model systems in which the heterogeneity and inhomogeneities of the structure are not reflected. For instance strain fall off from interfaces can run into a film for nms. This can mean that a significant fraction of the volume of the film has a completely different diffusion coefficient than bulks. When coupled with the local fields of a nearby interface this can mean that thin films can behave very different from bulk.

135. Accordingly, Granek's proposed dopant concentration for producing a front surface field was much higher than Swanson-352 and required a different thickness of an oxide passivation layer. At a minimum, Granek proves that "front surface doping concentration" is dependent on the thickness of the front side oxide passivation layer and that it was not settled in 1990.

136. Moreover, Muller teaches adopting thin silicon oxide layers with "quite strong doping on the front side" that create a front surface field capable of suppressing UV-illumination degradation and improving long term UV-stability of the passivation. Ex. 1008, pp. 267-70 (~10 nm thick thermal oxide used in experimentation); Ex. 2015, p. 3 (same).

137. A person of ordinary skill in the art would not have found it obvious to adopt design parameters for solar cell structures from the 1990s (such as those

solar cell structures disclosed by King, Swanson-352, and Marvin) that were no longer in use. Moreover, it would not have been obvious to a person of ordinary skill in the art to adopt King, Swanson, and Marvin's front surface doping concentrations that are tied to front side oxide passivation layers, where Li does not include such a layer. Neither CSI nor Dr. Banerjee addresses these significant technical differences and show why it would have been obvious to modify Li's solar cell configuration based on the incompatible solar cell teachings of King, Swanson-352, and Marvin.

b. King, Swanson-352, and/or Marvin do not disclose an "optimum" dopant concentration

138. CSI's statement that "[b]y December 22, 2014, it had been known for decades that the front portion formed in the silicon substrate of a back-contact solar cell should be optimally doped at a concentration of approximately $2 \times 10^{18} \text{ cm}^{-3}$ or less" is incorrect. Pet., 15. Dr. Banerjee also makes a similar incorrect statement. Ex. 1003; ¶ 74. Marvin contradicts both CSI's and Dr. Banerjee's positions, disclosing two different doping concentrations based on a solar radiation environment. See Ex. 1035, pp. 826-27 (recommending a doping concentration of $5 \times 10^{18} \text{ cm}^{-3}$ for terrestrial environments and $1 \times 10^{18} \text{ cm}^{-3}$ for high-radiation environments). I understand that Dr. Banerjee attempted to downplay Marvin's disclosure of $5 \times 10^{18} \text{ cm}^{-3}$ for terrestrial environments on the basis that such doping concentration was only for a concentrator environment. Ex. 2022 at 60:15-

21. Dr. Banerjee misreads Marvin. Marvin clearly associates a doping concentration of $5 \times 10^{18} \text{ cm}^{-3}$ in a 1-sun environment. For example, Marvin states that “the baseline cell [described in Table 2] was near optimum for 1 sun.” Ex. 1035, p. 825. Table 2 states a doping concentration of $5 \times 10^{18} \text{ cm}^{-3}$:

Table 2. Baseline cell design	
p ⁺ width	35 μm
n ⁺ width	145 μm
p ⁺ thickness	1.0 μm
n ⁺ thickness	0.3 μm
p thickness	50 μm
t _n in base	136 μs
	1.10 μs (a)
	0.32 μs (b)
t _n in p ⁺ contact	0.128 μs
	78 ns (a)
	78 ns (b)
t _p in n ⁺ contact	32.6 ns
	12 ns (a)
	12 ns (b)
FSF doping	5E18 p type
FSF thickness	0.5 μm
Doped region spacing	20 μm
(a) After radiation scenario 1:	
	K _L = 2.5E-11 for p base
	K _L = 1.10E-9 for p ⁺ region
	K _L = 3.10E-8 for n ⁺ region
(b) After radiation scenario 2:	
	K _L = 8.40E-11 for p base
	Other K _L same as scenario 1

Ex. 1035, p. 823 (partial, annotated).

139. Marvin also discloses that the same doping concentration is important in a terrestrial concentrator application. Ex. 1035, p. 827. However Marvin makes clear that $5 \times 10^{18} \text{ cm}^{-3}$ is “near optimal” in “1 sun” or “planar” applications. A person of ordinary skill in the art would understand that “planar,” as used in Marvin, refers to “1 sun” applications.

140. CSI and Dr. Banerjee select a front surface doping recommendation of $1 \times 10^{18} \text{ cm}^{-3}$ for a solar cell intended for use in space (i.e., a high-radiation environment)—even though Dr. Banerjee’s proposed combination was a terrestrial

application (*see* Ex. 20103:9-13)—and asserts that “Marvin’s focus on high radiation environments, such as space, would not have deterred the Skilled Artisan from combining with Li because Li does not limit its back-contact solar cell to low radiation or terrestrial environments.” Pet., 33; Ex. 1003, ¶ 128. However, an “optimum” dopant concentration will vary based on design parameters. *See* Ex. 1035, p. 823 (“Since optimization is achieved by selecting parameters which produce the results desired to meet specific performance requirements, it is necessary to first understand how each parameter affects cell performance.”); *see also id.* at p. 827 (“The light intensity to be used and the radiation environment affect the [Interdigitated Back Contact cell] design to a greater extent than in conventional cells.”).

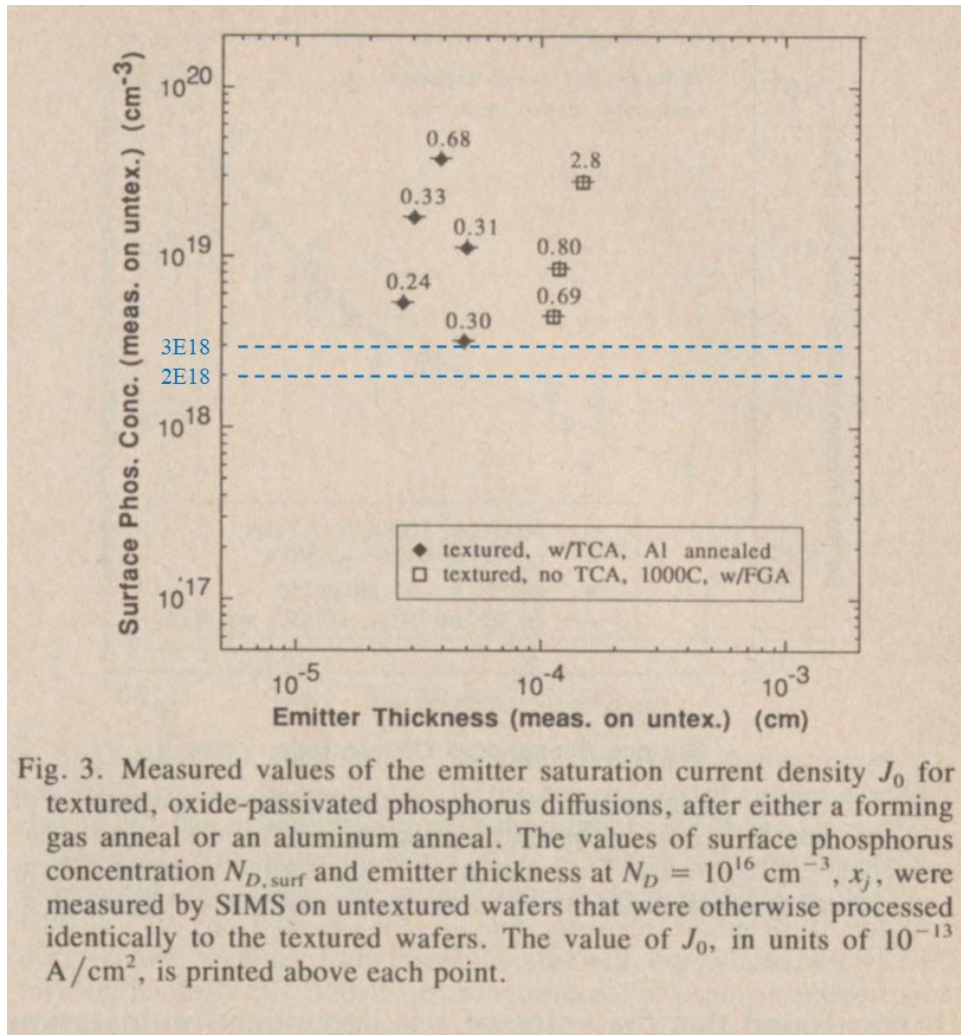
141. Similarly, Swanson-352 discloses a photovoltaic cell designed for use in a high-radiation environment:

The means for receiving ***concentrated radiation*** includes a housing having a radiation receiving window, a secondary concentrator defined by walls of the housing within the window, and a chamber for confining the concentrated radiation. A radiator element may be positioned within the chamber for receiving the concentrated radiation, and the photovoltaic cell is positioned within the chamber in close proximity to the radiator element for receiving radiated energy from the radiator.

Ex. 1015, 2:13-22 (emphasis added).

142. Thus, like Marvin, Swanson-352's disclosure of a "surface dopant concentration" of $1 \times 10^{18} \text{ cm}^{-3}$ is indicative of the structure and radiation environment of that *particular* solar cell and not an "optimum" doping concentration for any solar cell. Ex. 1015, 4:49-51. CSI and Dr. Banerjee do not address that Swanson-352 is designed as a concentrator solar cell and do not explain why a person of ordinary skill in the art would have looked to a solar cell designed for a high-radiation environment to determine an "optimum" dopant concentration in Li. Indeed, during his deposition, Dr. Banerjee noted that optimum design parameters in a concentrator application will be different than those of a non-concentrator environment. Ex. 2022 at 61:14-17, 62:5-8.

143. Finally, King's conjecture about a surface dopant concentration of $1 \times 10^{18} \text{ cm}^{-3}$ of a passivated emitter being "probably near optimum in [saturation current density] J_0 when [the solar cell] has a textured front surface" appears to be either highly approximated or aspirational. Ex. 1006, p. 369. Figure 3 of King does not show any samples near that dopant concentration. *See* Ex. 1006, Fig. 3 (annotated in blue below).



Ex. 1006, Fig. 3 (annotated).

144. Moreover, neither CSI nor Dr. Banerjee addresses the disparity of dopant concentrations disclosed in Marvin ($5 \times 10^{18} \text{ cm}^{-3}$ for terrestrial environment) and King, especially in light of the fact that King, as with Marvin, was also analyzing a one sun environment. *See* Ex. 1006, p. 369. In my opinion, a person of ordinary skill in the art, reading King as a whole, would not have found it obvious to set an upper limit of dopant concentration for a surface of the substrate where no dopant concentration in King was below that limit.

145. Rather than blindly implementing a dopant concentration of 1×10^{18} cm^{-3} , as CSI alleges is disclosed in King, Swanson-352, or Marvin (only in the space environment), a person of ordinary skill in the art would have chosen a dopant concentration that was appropriate for the particular application.

146. CSI and Dr. Banerjee provide few details regarding what that application is in their theory. However, Dr. Banerjee seems to envision a terrestrial and one-sun application. Specifically, Dr. Banerjee testified that, with respect to his proposed combination “I think my baseline assumption is it is meant for terrestrial applications.” Further, Dr. Banerjee attempted to deflect from Marvin’s disclosure of 5×10^{18} cm^{-3} by suggesting that “the specific value such as 5E18 that’s relevant for concentrators may not be relevant for nonconcentrator applications.” Ex. 2022 at 62:5-8. (As noted above, Dr. Banerjee’s suggestion is incorrect.) Regardless, under the terrestrial, 1-sun application upon which CSI’s theory appears to be based, a person of ordinary skill in the art would have been more likely to employ a dopant concentration at least as high as those in Granek (greater than 2×10^{18}), Lamers (3×10^{18}), Desa (10^{19}), or Procel (3.47×10^{18}). These references reflect the trend in the industry before 2014 that it was preferable to use thinner passivation layers and higher dopant concentrations.

147. Indeed, because Li does not include a passivation layer at all, a person of ordinary skill in the art likely would have chosen a dopant concentration even

higher than those disclosed in Granek, Lamers, Desa, and Procel. This is because the designer would have understood that the only guard against recombination would have been the dopants. That is, there was no passivation layer to reduce surface recombination. Thus, more dopants would be required than in the situation in which a passivation layer also aids in reducing recombination.

148. Dr. Banerjee's reliance on Swanson-352 is improper. Design parameters, such as dopant concentrators, are heavily influenced by whether the solar cell is designed for a concentrator application or a one-sun application. Dr. Banerjee readily admitted to this fact. For example, he testified that "the specific value such as 5E18 that's relevant for concentrators may not be relevant for nonconcentrator applications." Ex. 2022 at 62:5-8. He also testified that "the optimal parameters would be different between concentrator versus nonconcentrator." Ex. 2022 at 66:22-67:1. Swanson-352 is a concentrator application. Ex. 1015 at Abstract ("Disclosed is a thermophotovoltaic converter which includes a parabolic cone radiation *concentrator* portion and a processor portion including a radiator which absorbs *concentrated radiation* and generates incandescent radiation.") (emphasis added). Indeed, Swanson-352 discloses that through its design solar radiation is concentrated to approximately 20,000 times. Ex. 1015 at 3:22-26. Accordingly, a person of ordinary skill in the art would not have followed Swanson-352's teachings, which are specific to a concentrator

environment, when choosing a dopant concentrator in CSI's non-concentrator construct.

2. *Grounds 2 and 4: A Person of Ordinary Skill in the Art Would Not Have Been Motivated to Combine Li with Muller*

149. CSI's and Dr. Banerjee's proposed combination of Li and Muller creates an entirely new solar cell, which would not have been obvious to create without the benefit of hindsight in view of the '315 patent. Li discloses doping the front surface of the substrate by heating substrate 508 "in the presence of a gaseous N-type dopant source." *See* Ex. 1005, ¶ [0049]. In contrast, Muller does not use a gaseous drive-in method, but ion-implanting to achieve "very lowly doped" front surface regions on n-type IBC solar cells.

150. When Muller used an N-type dopant source (e.g., phosphorus) as disclosed in Li to create a front surface field (FSF) profile, it was found that the "[c]ells with FSF degraded strongly under UV-illumination due to the instable SiO₂ passivation on the front side." Ex. 1008, p. 265. The degradation was severe, in which "[t]he efficiency of FSF cells dropped dramatically by more than 50%." Ex. 1008, p. 271. Muller, however, noted that "[t]he degradation of the cells investigated by Granek *et al.* was efficiently suppressed by using a quite strong doping on the front side." Ex. 1008, p. 269. Thus, a person of ordinary skill in the art, looking to determine the specific dopant concentration to use for the **N-type** dopant regions disclosed in Li, would have concluded from Muller that using an

extremely weak doping concentration (i.e., $< 2 \times 10^{18} \text{ cm}^{-3}$) would fail and that a “quite strong doping” should be considered. Ex. 1008, p. 269. A person of ordinary skill in the art would have understood that Muller teaches away from using a low doping concentration for the n-type dopant region in Li.

151. Without a suitable dopant concentration for the N-type dopant region in Li, CSI proposes to significantly modify Li’s solar cell to replace Li’s diffused N-type dopant region with Muller’s floating front emitter (“FFE”). As Muller discloses ion implanting the front surface region with a **P-type** dopant source (e.g., boron) to create the FFE (Ex. 1008, p. 265), CSI and Dr. Banerjee propose “insert[ing] Muller’s ion-implanted boron FFE process steps for the front side” of Li’s solar cell (Pet., 65; Ex. 1003, ¶ 199). This would involve the following additional processing steps:

- Adding an ion-implanting process (Pet., 61);
- Changing the polarity of the n-type doped portion 520 formed by a gaseous dopant process disclosed by Li and replacing it with a p-type doped portion formed by ion-implanting boron (Pet., 61; Ex. 1003, ¶ 192);
- Adding “aluminum oxide and silicon nitride passivation” layers not disclosed by Li (Pet., 61; Ex. 1003, ¶ 192);

- Reversing the order of fabrication disclosed by Li to ion-implant the front dopant regions first, instead of last (Pet., 65; Ex. 1003, ¶ 199); and
- Masking the backside to diffuse the trench region (Pet., 65; Ex. 1003, ¶ 199).

152. It is evident that CSI's and Dr. Banerjee's proposed combination of Li and Muller creates an entirely new solar cell, which would not have been obvious to create without the benefit of hindsight in view of the '315 patent. Moreover, it would not have been obvious to combine Li and Muller because the proposed modification of Li's fabrication process increases the number of processing steps, which expressly contradicts Li's objective to achieve "a reduction in the sheer number of process operations." Ex. 1005, ¶ [0024].

153. Neither CSI nor Dr. Banerjee identifies any perceived benefits that would outweigh the drawbacks of increasing the number of processing steps. The Petition states that combining the ion-implanted front floating emitter and aluminum oxide and silicon nitride passivation layers of Muller with Li would have been obvious "because of its *better* solar cell efficiency and resistance to UV degradation." Pet., 61 (emphasis added). However, by "better," CSI apparently means that, under the specific circumstances of the Muller investigation, boron was a better dopant than phosphorus. Neither CSI nor Dr. Banerjee set out to prove,

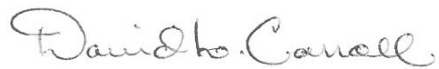
much less showed, that Muller would have been “better” (e.g., more efficient) than Li as is.

X. CONCLUSION

154. In my opinion, based on my review of the '315 patent, the materials referenced above, and my knowledge of what a person of ordinary skill in the art would have known at the time of the invention, CSI fails to show that any challenged claim is unpatentable.

155. I declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true and that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Date: April 8, 2025

A handwritten signature in cursive script that reads "David Carroll".

David Carroll, Ph.D.