

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HANWHA SOLUTIONS CORPORATION,

Petitioner,

v.

MAXEON SOLAR PTE. LTD.,

Patent Owner.

Case No. IPR2024-01199

U.S. Patent No. 8,878,053

**DECLARATION OF DR. ZACHARY HOLMAN REGARDING
CLAIMS 1-20 OF U.S. PATENT NO. 8,878,053**

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I, Zachary Charles Holman, Ph.D., declare as follows:

I. INTRODUCTION

1. My name is Zachary Charles Holman.

2. I am making this declaration at the request of Hanwha Solutions Corporation (“HSC” or “Petitioner”) as an independent expert consultant in this proceeding before the United States Patent and Trademark Office and to provide testimony pertinent to Petitioner’s Petition for *Inter Partes* Review of U.S. Patent No. 8,878,053 (“’053 patent”). I understand that Petitioner is challenging the patentability of claims 1-20 of the ’053 patent (“Challenged Claims”).

II. QUALIFICATIONS AND EXPERIENCE

3. I have been involved in the field of solar cell technology for over 19 years. My qualifications for forming the opinions set forth in this declaration are summarized below. Attached as **Appendix A** is my curriculum vitae, which describes my education, experience, and professional activities and lists, among other things, my publications and patents.

4. I received a Bachelor of Arts in Physics from Reed College in 2005. While pursuing my undergraduate degree, I researched the movement of electrons in semiconductor materials used for solar cells. My research was summarized in my undergraduate thesis, which was titled *Electron Transport in Amorphous Silicon*. My thesis explained how “[m]any mechanisms reduce the output of a solar cell

including imperfect incident light absorption, recombination of charge carriers, and poor charge transport through the cells,” and it described research that I conducted using time-of-flight measurement techniques to characterize electron transport in hydrogenated amorphous silicon. *See* Ex.1010-Holman-Thesis, 2-4. My thesis revealed trapping of electrons in defect states in amorphous silicon, which inhibited their collection at metal contacts. *See generally*, Ex.1010-Holman-Thesis.

5. I received a Doctor of Philosophy (“Ph.D.”) in Mechanical Engineering from the University of Minnesota in 2010. I started my Ph.D. program in September 2005. For the entire duration of my Ph.D., my research focused on the design, manufacture, and characterization of materials and layers used in solar cells. My Ph.D. thesis was titled *Germanium Nanocrystal Solar Cells*, and it described the use of thin films of plasma-synthesized germanium and silicon nanocrystals and their use in novel solar cells.

6. I co-authored multiple academic papers in the fields of semiconductor materials and solar cell technology while I was working on my Ph.D., including: A. LaLonde, Z Holman, et al., “Metal Coatings on SiC Nanowires by Plasma-enhanced Chemical Vapor Deposition,” *Journal of Materials Research* **20**, 549 (2005) (describing method for coating silicon carbide nanowires with metal nanoparticles); R. Gresback, Z. Holman, and U. Kortshagen, “Plasma Synthesis of Highly

Monodisperse Ge Nanocrystals and Self-assembly of Dense Nanocrystal Layers,” *Materials Research Society Symposium Proceedings* 974 (2007) (describing synthesis method for germanium nanocrystals using low pressure, nonthermal plasma); Z. Holman, R. Gresback, and U. Kortshagen, “Nonthermal Plasma Synthesis of Conductive Germanium Nanocrystal Films for Photovoltaic Applications,” *ISPC-18 Proc.* (2007) (describing the nonthermal plasma synthesis of germanium nanocrystals and reporting on the current-voltage measurements of highly porous films of such nanocrystals); R. Gresback, Z. Holman, and U. Kortshagen, “Nonthermal Plasma Synthesis of Size-Controlled, Monodisperse, Freestanding Germanium Nanocrystals,” *Applied Physics Letters* **91**, 093119 (2007) (describing the synthesis of monodisperse germanium nanocrystals via a nonthermal plasma approach); U. Kortshagen, Z. Holman, et al., “Plasma synthesis of group IV quantum dots for luminescence and photovoltaic applications,” *Pure and Applied Chemistry* **80**, 1901 (2008) (describing the application of silicon and germanium nanocrystals in solar cells); C.Y. Liu, Z. Holman, and U. Kortshagen, “Hybrid solar cells from P3HT and silicon nanocrystals” *Nano Letters* **9**, 449 (2009) (describing a new solar cell comprised of silicon nanocrystals and poly-3(hexylthiophene) and reporting the properties of such cells); C.Y. Liu, Z. Holman, and U. Kortshagen, “Optimization of Si NC/P3HT hybrid solar cells,” *Advanced Functional Materials*

20, 2157 (2010), and X. Pi, Z. Holman, and U. Kortshagen, “Silicon and Germanium Nanocrystal Inks for Low Cost Solar Cells,” *4th International Conference on Energy Sustainability ASME Conf. Proc.* **2**, 471 (2010) (presenting method for forming silicon and germanium thin films using nanocrystals).

7. From 2010 to 2013, I was a postdoctoral researcher in the Photovoltaics and Thin-Film Electronics Laboratory at the Institute of Microengineering at Ecole Polytechnique Fédérale de Lausanne in Neuchâtel, Switzerland. I also served as a visiting professor with the Photovoltaics and Thin-Film Electronics Laboratory in 2014. While serving in these roles, I continued to research the design and manufacture of solar cells and their components.

8. While a postdoctoral researcher, I published extensively on silicon solar cells, including on passivation layers, transparent conductive oxide and metal contacts, contact resistance, parasitic absorption, and optimization of cell designs. Select peer-reviewed papers related to silicon solar cells that I co-authored while a postdoctoral researcher include: A. Descoeudres, Z. Holman, et al., “Improved amorphous/crystalline silicon interface passivation by hydrogen plasma treatment,” *Applied Physics Letters* **99**, 123506 (2011) (describing reducing recombination at silicon wafer surfaces with deposited amorphous silicon layers); Z. Holman, et al., “Current losses at the front of silicon heterojunction solar cells,” *IEEE Journal of*

Photovoltaics **2**, 7 (2012) (describing parasitic absorption in deposited emitters at the front of silicon solar cells); S. De Wolf, Z. Holman, et al., “High-efficiency silicon heterojunction solar cells: A review,” *Green* **2**, 7 (2012) (reviewing the status of silicon heterojunction solar cell science and technology); Z. Holman, et al., “Infrared light management in high-efficiency silicon heterojunction and rear-passivated solar cells,” *Journal of Applied Physics* **113**, 013107 (2013) (describing parasitic absorption in electrodes of silicon solar cells); and Z. Holman, et al., “Record infrared internal quantum efficiency in silicon heterojunction solar cells with dielectric/metal rear reflectors,” *IEEE Journal of Photovoltaics* **3**, 1243 (2013) (reporting a design for a silicon solar cell with record rear reflectance).

9. From 2013 to 2019, I was Assistant Professor in the School of Electrical, Computer and Energy Engineering at Arizona State University in Tempe, Arizona. In 2019, I became an Associate Professor, and, in 2023, I became a Professor, both again in the School of Electrical, Computer and Energy Engineering at Arizona State University. From 2019 to 2023, I also served as Director of Faculty Entrepreneurship in the Ira A. Fulton Schools of Engineering at Arizona State University. Since 2023, I have served as the Vice Dean for Research and Innovation of the Ira A. Fulton Schools of Engineering at Arizona State University.

10. My research interests as a professor include, among other things, contacts to solar cells, interconnection of solar cells, light management in silicon solar cells, and silicon-based tandem solar cells. While at Arizona State University, I have co-authored dozens of peer-reviewed articles in the field of solar cell technology, including: M. Boccard and Z. Holman, “Amorphous silicon carbide passivating layers for crystalline-silicon-based heterojunction solar cells,” *Journal of Applied Physics* **118**, 065704 (2015) (describing passivation layers for silicon solar cells); Y. Zhao, Z. Holman, et al., “Monocrystalline CdTe solar cells with open-circuit voltage over 1 V and efficiency of 17%,” *Nature Energy* **1**, 16067 (2016) (reporting the highest open-circuit voltage measured for a cadmium telluride solar cell, made by using an emitter from silicon solar technology); Z. Yu, M. Leilaieoun, and Z. Holman, “Selecting tandem partners for silicon solar cells using spectral efficiency,” *Nature Energy* **1**, 16137 (2016) (describing a methodology for designing tandem solar cells); K. Bush, Z. Holman, et al., “23.6%-efficient monolithic perovskite/silicon tandem solar cells with improved stability,” *Nature Energy* **2**, 17009 (2017) (describing improved perovskite/silicon tandem solar cells); B. Hallam, Z. Holman, et al., “Pre-fabrication gettering and hydrogenation treatments for silicon heterojunction solar cells: A possible path to >700 mV open-circuit voltages using low-lifetime commercial-grade p-type Czochralski silicon,” *Solar*

RRL 1700221 (2018) (describing improvement of silicon solar cells through gettering and hydrogenation); Z. Ni, Z. Holman, et al., “Resolving Spatial and Energetic Distributions of Trap States in Metal Halide Perovskite Solar Cells,” *Science* **367**, 1352 (2020) (reporting on the spatial and energetic distributions of trap states in metal halide perovskite single-crystalline and polycrystalline solar cells.); J. Xu, Z. Holman, et al., “Triple-halide Wide-band Gap Perovskites with Suppressed Phase Segregation for Efficient Tandems,” *Science* **367**, 1097 (2020) (describing efficient wide-band gap perovskite top cells using triple-halide alloys); and K. Chen et al., “Self-aligned selective area front contacts on poly-Si/SiO_x passivating contact c-Si solar cells,” *IEEE Journal of Photovoltaics* **12**, 678 (2022) (describing a method to pattern polycrystalline silicon / silicon dioxide layers in silicon solar cells). Additional journal articles, book chapters, and conference papers are described in further detail in my CV (**Appendix A**).

11. I have received numerous awards for both my teaching and research. For my teaching, I have been honored with the ASU Fulton Schools of Engineering Top 5% Teaching Award in 2023, 2017, and 2015. For my research, I have received the IEEE Stuart R. Wenham Young Professionals Award in 2019 and the NSF CAREER Award in 2019 (an award given to photovoltaic researchers), among other honors, prizes, and awards. My awards and honors are listed in my CV. I have also

received numerous research grants, as detailed in my CV, including eighteen grants from the Department of Energy's Solar Energy Technologies Office. Two exemplary grants are "Development of new metallization pastes for front-side tunnel oxide passivated contact crystalline silicon solar cells" and "ASU-NREL joint silicon solar cell research: passivated contacts, metallization, and bulk defects."

12. Among the courses I teach at Arizona State University are "Electrical Engineering 465/591: Photovoltaic Energy Conversion," "Electrical Engineering: 498/591: Solar Energy," and "Electrical Engineering 565: Solar Cells." I have also taught innovation and venture development courses that combine academic learning with an applied business development approach. Other courses I have taught are listed in my CV.

13. I have advised numerous doctoral students and other researchers in training. Students whom I have advised have won numerous honors and awards, including many best-paper awards at top solar conferences. A full list of students I have advised and their awards are provided in my CV.

14. Some of my many professional activities include being editor of the *IEEE Journal of Photovoltaics* since 2022; serving as an organizing member for the IEEE Photovoltaic Specialists Conference, World Conference on Photovoltaic Energy Conversion, and International Workshop on Silicon Heterojunction Solar

Cells; serving as a member and chair of the ASU Solar Fabrication Core Facility Board since 2020; being a reviewer for journals including *Journal of Applied Physics*, *ACS Nano*, *Solar Energy Materials and Solar Cells*, *Thin Solid Films*, *Nanotechnology*, and *IEEE Journal of Photovoltaics*; being a reviewer for grant proposals for the Department of Energy and the National Science Foundation; and serving as a session chair for numerous symposia and conferences on solar science and technology. A full list of my professional and outreach activities is provided in my CV.

15. My research, engineering and entrepreneurial endeavors have been regularly recognized by the industry. For example, Arizona PBS has reported on one of my start-up companies, SunFlex Solar, which has developed an improved method for interconnecting back-contact solar cells into solar modules. See “New Solar Panel Technology,” *Arizona PBS* (Mar. 29, 2023), available at <https://azpbs.org/horizon/2023/03/new-solar-panel-technology>. Also, I worked with two United States-based solar cell manufacturers relating to an instrument that I developed to analyze recombination in solar cells; copies of the instrument are now used in their research and development facilities. As another example, my research demonstrating a manufacturing technique for high-efficiency perovskite-silicon tandem solar cell was covered in *PV Magazine*, a leading solar cell industry

publication. See Emilliano Bellini, “New Manufacturing Technique for 26%-efficient Tandem Perovskite Solar Cell,” *PV Magazine* (Apr. 20, 2020), available at <https://www.pv-magazine.com/2020/04/20/new-manufacturing-technique-for-26-efficient-tandem-perovskite-solar-cell>.

16. I am also an entrepreneur and have founded three companies to bring new solar technology to market. In 2021, I co-founded Beyond Silicon, Inc. (“Beyond Silicon”), which is developing perovskite/silicon tandem solar cells. Beyond Silicon was a finalist for the American-Made Perovskite Startup Prize. In 2020, I co-founded SunFlex Solar LLC (“SunFlex Solar”), which develops interconnected back-contact solar cells using aluminum foil for improved efficiency and durability. SunFlex Solar won the American-Made Solar Prize and has a partnership with a US solar panel manufacturer to commercialize its interconnection technology. In 2016, I co-founded Swift Coat, Inc. (“Swift Coat”), which has developed a transparent coating for solar panels that prevents dust buildup that would otherwise reduce solar panel efficiency. Swift Coat has also won a contract from NASA to deposit similar coatings—but modified to provide an anti-fogging functionality—on the inside of the helmet of NASA’s next generation xEMU space suit. In 2018, I received the Gordon and Betty Moore Foundation Inventor

Fellowship to support my efforts to accelerate the translation of my research to market.

17. I am being compensated for my work on this matter at my standard hourly consulting rate of \$500 per hour. My opinions are based on my own views and understanding of the prior art, the knowledge of a person of ordinary skill in the art, and the '053 patent. My compensation is not dependent on and in no way affects the substance of my statements, opinions, or conclusions in this declaration and it is also not dependent on any testimony I give or on the outcome of this proceeding.

18. I have no financial interest in Petitioner or Patent Owner. I similarly have no financial interest in the '053 patent, and I have had no contact with the named inventors of the '053 patent.

III. LEGAL PRINCIPLES

19. I am not an attorney. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the law was provided to me by Petitioner's attorneys.

A. Scope of Opinion

20. I have been informed and understand that the petitioner in an *inter partes* review may request cancellation of claims as unpatentable only on grounds that such claims are anticipated or would have been obvious to a person of ordinary

skill in the art at the time of the purported invention, and only on the basis of prior art consisting of patents and/or printed publications. My opinions in this matter address only such grounds.

B. Anticipation

21. I have been informed that a patent claim is anticipated and therefore unpatentable if every element of the claim is present in a single prior art reference.

C. Obviousness

22. I understand that a claim is unpatentable if, at the time the alleged invention was made, it would have been obvious to a person of ordinary skill in the art. I understand that a claim can be obvious based on the teachings or suggestions of either a single prior art reference or a combination of two or more prior art references. I understand that the obviousness analysis requires an understanding of the scope and content of the prior art, any differences between the prior art and the alleged invention, and the level of ordinary skill in evaluating the pertinent art.

23. I understand that in order to be considered for obviousness, prior art must be analogous to the patent at issue. I further understand that art is analogous if it either pertains to the same field of endeavor as the patent at issue or, alternatively, if it is reasonably related to the problem faced by the inventor(s) of the patent at issue.

24. I understand that a claim would have been obvious if it unites old elements with no change to their functions or alters prior art by mere substitution of one element for another known in the field such that the combination yields predictable results. Also, I understand that obviousness does not require a physical combination or example, but rather is concerned with what the combined teachings would have taught or suggested to persons of ordinary skill in the art at the time of the alleged invention.

25. In connection with obviousness, I have been informed that there must have been some reason or motivation for a person of ordinary skill in the art to have combined or modified the relevant teachings in the prior art to obtain the claimed invention, and one of ordinary skill in the art must have had a reasonable expectation of success making the combination or modification.

26. I understand that a claim would have been obvious if a person of ordinary skill in the art would have had reason to combine multiple prior art references or add missing features to reproduce the alleged invention recited in the claims. I further understand that there is no rigid requirement of finding an express teaching, suggestion, or motivation to combine within the references, although such an express teaching or suggestion may be helpful in identifying a reason for the combination.

27. If a person of ordinary skill in the art can implement a predictable variation, that variation is likely unpatentable as obvious. For the same reason, if a technique has been used to improve one device and a person of ordinary skill in the art would have recognized that it would improve similar devices in the same way, using the technique to make such an improvement would have been obvious.

28. I understand that when considering obviousness, it is important not to use the benefit of hindsight derived from the patent being considered. I also understand that one of ordinary skill in the art has ordinary creativity (i.e., is not a mindless automaton).

29. In sum, I understand that a determination of whether a claim would have been obvious is based upon the following non-exclusive considerations:

- whether prior art references teach or disclose known concepts combined in familiar ways, such that when combined they would yield predictable results;
- whether a person having ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- whether the claimed elements represent one of a limited number of known design choices, where those skilled in the art would have had a reasonable expectation of success in implementing that design choice;

- whether a person having ordinary skill would have been motivated based on the prior art to combine known elements in the manner described in the claim;
- whether there is a teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and
- whether the alleged invention applies a known technique that had been used to improve at least one similar device or method in a similar way.

30. I further understand that certain additional factors, commonly referred to as secondary considerations or objective indicia, may support or rebut the obviousness of a claim. I understand that secondary considerations include, among other things, commercial success of the patented invention, skepticism of those having ordinary skill in the art at the time of invention, unexpected results of the invention, any long-felt but unsolved need in the art that was satisfied by the alleged invention, the failure of others to make the alleged invention, praise of the alleged invention by those having ordinary skill in the art, copying of the alleged invention by others in the field, and contemporaneous and independent invention by others. I understand that there must be a nexus (i.e., a connection) between any such secondary considerations and the alleged invention. I also understand that secondary considerations cannot be used to overcome anticipation. I further understand that

contemporaneous and independent invention by others is a secondary consideration tending to show obviousness.

31. I reserve the right to respond to any allegations that Patent Owner may put forth in this proceeding suggesting that secondary considerations tend to rebut the obviousness of any claim of the '053 patent as discussed in this declaration.

D. Claim Dependency

32. I understand patents may include two types of claims: independent claims and dependent claims. An independent claim stands alone and simply recites the limitations it covers. In contrast, a dependent claim depends from either an independent claim or another dependent claim, and incorporates all the limitations recited in the claim or claims from which it depends along with the limitations it recites itself.

E. Written Description

33. I have been informed and understand that an application is required to describe the claim limitations contained in the application. I understand this requirement is called the “written description requirement.” I have been informed and understand that to satisfy the written description requirement, the patent’s specification must describe the claimed invention with enough detail for a person of

ordinary skill in the art to reasonably conclude that the inventor had possession of the claimed invention at the time of filing.

* * *

34. The analysis that follows in this declaration is in accordance with the above-stated legal principles.

IV. MATERIALS CONSIDERED

35. In forming my opinions, in addition to my knowledge and experience, I have considered the materials cited herein and listed in **Appendix B**.

V. PRIORITY DATE

36. I have been informed that the priority date of the '053 patent is February 20, 2008. I have formed my opinions in reference to this priority date. Should Patent Owner suggest a different priority date, I reserve the right to revise my opinions accordingly.

VI. LEVEL OF ORDINARY SKILL IN THE ART

37. I understand that when considering the claims of the '053 patent and the prior art, I must do so from the perspective of one of ordinary skill in the art as of the patent's effective priority date.

38. I have been informed and I understand the factors to be considered in determining who would be a person of ordinary skill in the art include: (1) the types of problems encountered in the art; (2) the prior art solutions to those problems; (3)

the rapidity with which innovations are made; (4) the sophistication of the technology; and (5) the educational level of active workers in the field.

39. Based on these factors as well as my experience and expertise, a person of ordinary skill in the art as of the claimed priority date of the '053 patent (also called, a "POSITA") would have had (1) an advanced degree in applied physics, chemistry, electrical engineering, materials science, mechanical engineering, or a related discipline and (2) at least one year of experience designing, developing, or researching the design and/or manufacture of solar cells or related technologies. Alternatively, a person of ordinary skill in the art would have had (1) a bachelor's degree in one of the aforementioned disciplines and (2) at least two years of experience designing, developing, or researching the design and/or manufacture of solar cells or related technologies. Additional work experience may compensate for less formal education, and vice versa.

40. My analysis and opinions herein regarding the '053 patent have been based on the perspective of a person of ordinary skill in the art as of the priority date for the '053 patent (i.e., February 20, 2008).

41. I have the qualifications and experience necessary to assess the '053 patent based on the perspective of a person of ordinary skill in the art, including as of the priority date for the '053 patent. *See* Section II (Qualifications and

Experience). For example, by 2008, I had a degree in physics. I also had over three years of experience designing, developing, or researching the design and/or manufacture of solar cells, as my research for my Ph.D. and undergraduate thesis was focused on the design and manufacture of components used in solar cells. *See* Section II (Qualifications and Experience).

VII. TECHNOLOGY BACKGROUND

A. Overview of Solar Cells

42. A solar cell is a solid-state electrical device that absorbs solar radiation (sunlight) and converts that solar radiation to electricity. An individual solar cell generates electricity when it is exposed to solar radiation by directing excited electrons around an external circuit. Ex.1016-Komp, 2-4; Ex.1010-Holman-Thesis, 1-2. To generate a usable amount of energy, a single solar cell is typically not used in isolation; instead, multiple solar cells are electrically connected to each other to form a solar module. Ex.1016-Komp, 49-51. An example solar module is below, which is the BP MSX-120 Solar Module that was available before 2008 and includes “72 multicrystalline silicon solar cells” that are electrically connected to each other.



Ex.1017-BP-MSX-120, 1. Multiple solar modules are connected together in a solar array to generate larger amounts of electricity. Ex.1016-Komp, 34-36, 49-53.

43. The design and manufacture of solar cells have been studied for several decades. A solar cell is typically made of a slab of silicon, called a “wafer,” and thin layers added to each side of the wafer. Ex.1016-Komp, 13-14, 20-21, 30-34. The thin layers can be made of many materials, including silicon. Silicon can come in different forms depending on how its atoms are organized. Ex.1016-Komp, 25-29, 37-39. For example, silicon can be “monocrystalline” if its atoms are all arranged in a perfectly periodic structure—a crystal. Ex.1016-Komp, 27-29; Ex.1018-Nelson, 179 (“Materials can be prepared as single crystals (monocrystalline) or as polycrystalline or multicrystalline wafers.”); *see also* Ex.1010-Holman-Thesis, 19-

20. Silicon can also be “polycrystalline” silicon (also called “polysilicon”), which means that it has multiple crystalline regions or “grains,” but they are not aligned with each other, resulting in “grain boundaries” at their interfaces. Ex.1016-Komp, 37-38; Ex.1018-Nelson, 179. A third type of silicon, amorphous silicon, is also utilized by some solar cells and has a non-crystalline structure—a somewhat randomized arrangement of atoms. Ex.1016-Komp, 40-47; Ex.1010-Holman-Thesis, 20-22. These three types of silicon have long been used in solar cells and were well-established in the art prior to 2008. Ex.1016-Komp, 25.

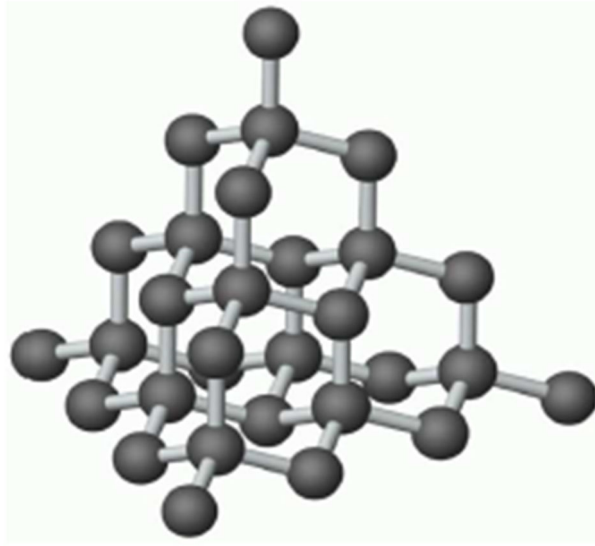
44. Prior to 2008, it was well known that solar cells had wafers or layers that were doped with phosphorus or boron to create PN junctions, solar cells included metal contacts to connect the cells to each other, and the front side of solar cells were textured and had anti-reflective coatings. The following sections briefly discuss these concepts.

1. Doping

45. In typical solar cells, chemical elements are introduced into silicon wafers or silicon layers to change the material properties of the silicon in the region where the elements are present. Ex.1010-Holman-Thesis, 23-24. The process for introducing these chemical elements, which are typically boron or phosphorus, is known as doping. *E.g.*, Ex.1018-Nelson, 181-182. As explained below, doping

introduces extra “electrons” or “holes,” which can alter the behavior of electrons that are excited in the solar cell when it is illuminated. Ex.1016-Komp, 7-9; Ex.1010-Holman-Thesis, 23-25.

46. An electron is a negatively charged particle and is part of an atom. Ex.1016-Komp, 7-9. An atom has one or more “valence” electrons, which are electrons on the outermost shell of an atom. Ex.1016-Komp, 7-9. Silicon has four valence electrons, and its outermost shell can hold up to eight. Ex.1033-Pierret, 26; Ex.1010-Holman-Thesis, 20. In a crystalline silicon solid, silicon atoms bond with four neighboring silicon atoms in a periodic arrangement or “lattice.” *See* Ex.1010-Holman-Thesis, 19-20 (showing two-dimensional crystalline lattice); Ex.1033-Pierret, 26. The silicon atoms share their valence electrons with the atoms to which they are bonded, resulting in each silicon atom perceiving that it has a filled valence shell of eight atoms. Ex.1018-Nelson, 44; Ex.1033-Pierret, 26. A simplified diagram of a silicon lattice is the following:



Ex.1010-Holman-Thesis, 20; *see also* Ex.1045-Green-1995, 5; Ex.1033-Pierret, 9-10.

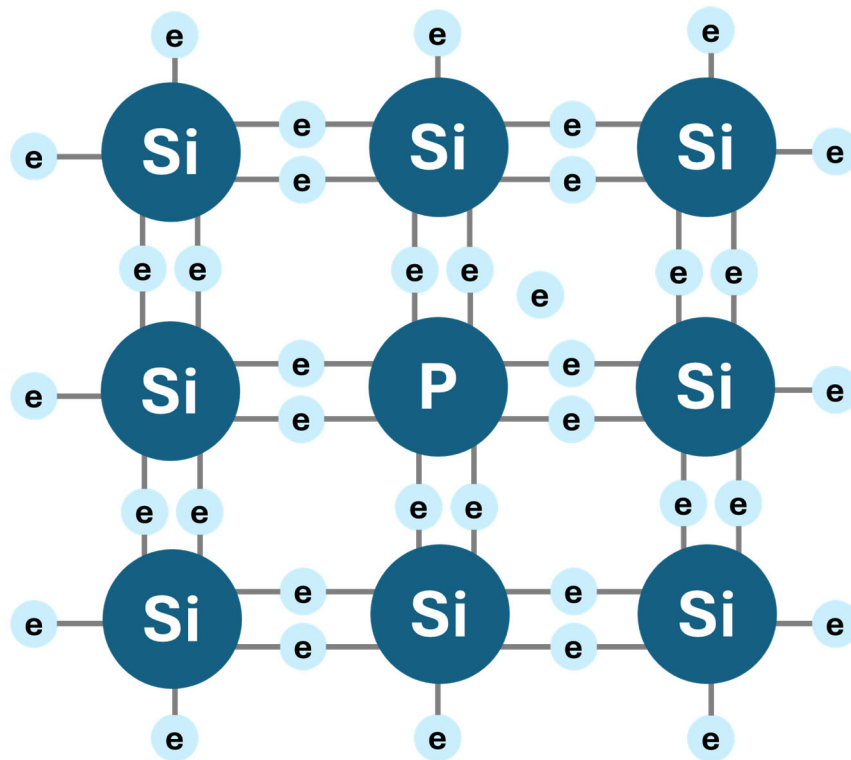
47. Once silicon atoms are bonded together in a solid, their valence electrons no longer reside in the individual shells of the isolated atoms, but instead populate a “valence band.” *See* Ex.1016-Komp, 13-18; Ex.1033-Pierret, 26-29; Ex.1010-Holman-Thesis, 6. The valence band is normally mostly full of electrons. Ex.1033-Pierret, 26-29. Silicon also has another band that is important to the function of solar cells, the “conduction band.” Ex.1033-Pierret, 29-32; Ex.1010-Holman-Thesis, 6. The conduction band is at a higher energy than the valence band and is thus normally mostly empty of electrons, but it may become (partially) populated either by the introduction of dopant atoms into the silicon crystal or by excitation of an electron from the valence band. Ex.1033-Pierret, 29-32. The

energetic distance between the top of the valence band and the bottom of the conduction band is the “bandgap energy.” Ex.1033-Pierret, 29-32; Ex.1010-Holman-Thesis, 6.

48. Introducing atoms with one more valence electron than silicon into the silicon crystal creates an extra electron that does not fit in the valence band. Ex.1033-Pierret, 35-39. Instead, at the temperatures at which solar cells normally operate, the extra electron resides in the conduction band. Ex.1033-Pierret, 35-39. The extra electron does not participate in bonding and is free to move around in the solid. Introducing such atoms is called doping, and in particular, n-type doping when extra electrons are introduced. Ex.1018-Nelson, 181-82; Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 23-24. In solar cells, n-type doping is used to create extra electrons in certain regions of the silicon wafer or layers of the solar cell. Ex.1018-Nelson, 181-82; *see also* Ex.1010-Holman-Thesis, 23-25.

49. It was well known prior to 2008 that phosphorous was commonly used as a dopant to create n-type regions or layers. As shown in the simplified diagram below, because phosphorus has five valence electrons (one more than silicon), an extra electron is introduced in the conduction band that can move through the lattice structure. Ex.1033-Pierret, 35-39; Ex.1016-Komp, 12-13 (“[I]f a small amount of phosphorus is added to the silicon crystal, the atoms of phosphorus (which have 5

valence electrons) will contribute 4 electrons and 4 levels to the valence band, and the extra electron will occupy a level near the bottom of the conduction band...It takes very little energy for the extra electron to jump to the conduction band from this donor level, so-called because it can donate conduction electrons to the system.”).



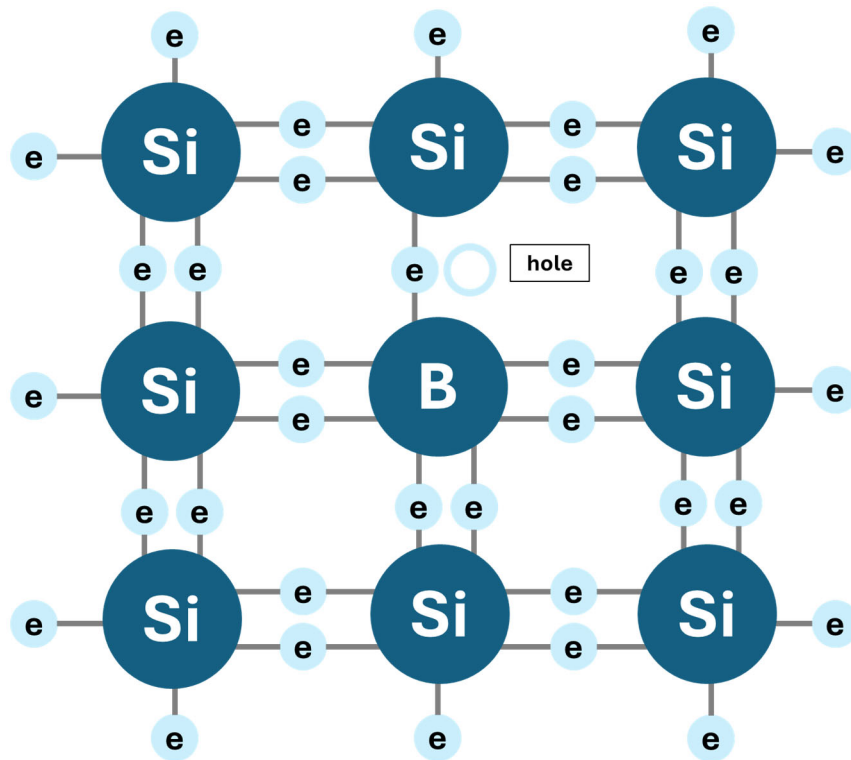
See Ex.1010-Holman-Thesis, 25; *see also* Ex.1033-Pierret, 36.

50. On the other hand, introducing atoms with one fewer valence electron than silicon into the silicon crystal creates a “hole” in the valence band. Ex.1033-Pierret, 35-39. A hole is not a physical object, like an electron, but rather a mathematical concept that represents an absence of an electron in the valence band.

Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 8. A hole in the valence band is mobile, much like an electron in the conduction band. Ex.1010-Holman-Thesis, 8. A hole does not physically move like an electron does, but because electrons move by filling holes, the science considers that holes also move, figuratively. Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 8. A moving electron carries a negative charge, and a moving hole carries a positive charge. Ex.1010-Holman-Thesis, 8. Thus, in the solar cell field, electrons and holes are both called “charge carriers” or simply “carriers” (of electricity). Ex.1016-Komp, 7-11.

51. Introducing atoms with one fewer valence electron than silicon is called p-type doping. Ex.1033-Pierret, 35-39; Ex.1018-Nelson, 181-182; Ex.1010-Holman-Thesis, 23-24. In solar cells, p-type doping is used to create extra holes in certain regions of the silicon wafer or layers of the solar cell. It was well known prior to 2008 that boron was commonly used as a dopant to create p-type regions or layers. Ex.1018-Nelson, 181-182. As shown in the simplified diagram below, because boron has three valence electrons (one fewer than silicon), a hole is introduced in the valence band that can move through the lattice structure. *See* Ex.1016-Komp, 11 (“[I]f an atom of boron (which has a valence of 3) is added to the crystal, it will contribute only 3 electrons to the system. It will also contribute 3 valence levels, plus 1 level which will be created in the band gap slightly above the

top of the valence band...These extra levels, called acceptor levels, are capable of accepting an electron from the valence band. Since the acceptor level is associated with a particular impurity atom, the electron that occupies it is trapped and cannot move. However, the hole created when the electron leaves the valence band can move.”).



See Ex.1010-Holman-Thesis, 25; *see also* Ex.1033-Pierret, 36.

52. Techniques for doping solar cell layers with phosphorous or boron were well-established by 2008. Ex.1016-Komp, 11 (“The process of deliberately adding a known impurity to a pure semiconductor is called doping.”). Silicon wafers were commonly purchased by solar cell manufacturers already uniformly doped (i.e., with

spatially uniform “background” dopant concentration). A wafer with uniform n-type doping was referred to as an “n-type wafer;” a wafer with uniform p-type doping was referred to as a “p-type wafer.” *See* Ex.1033-Pierret, 40; Ex.1010-Holman-Thesis, 22-23.

53. A common doping technique used in solar cell fabrication, called “diffusion,” involved driving dopant atoms from a dopant source—a gas, a liquid, or a solid containing dopant atoms—into a silicon wafer or a polysilicon layer at high temperatures in a furnace. Ex.1030-Benick, Abstract (“Emitter formation by in-line deposition of a PECVD PSG and subsequent diffusion in an in-line belt furnace”); Ex.1004-Froitzheim, [0011] (“diffusion from a p-type dopant from a liquid that is applied to the rear side”); Ex.1007-Smith (depositing boron-doped silicon dioxide (“BSG”) and phosphorus-doped silicon dioxide and diffusing dopants into a wafer). Diffusion was commonly used during solar cell fabrication to dope the region(s) near a surface of a wafer n-type or p-type, which either further enhanced the background doping of the wafer (if the diffused region had the same polarity as the wafer) or converted the polarity of the surface region of the wafer (if the diffused region had the opposite polarity as the wafer).

54. One well-known technique for diffusing phosphorus into a silicon wafer or polysilicon layer was known as phosphosilicate glass (PSG) diffusion. The

PSG diffusion technique involved forming a layer of PSG on the surface of the wafer (or a polysilicon layer on the wafer). One method to do this involved vaporizing phosphorus-containing liquid such as phosphorus oxychloride (POCl_3) into a furnace containing silicon wafers, where it reacted with the silicon atoms to form the PSG. Applying heat then drove the phosphorus from the PSG into the silicon or polysilicon via diffusion. *See, e.g.*, Ex.1018-Nelson, 187 (“Phosphorus may be deposited either from the vapour phase by exposure to nitrogen gas bearing POCl_3 ; from solid phase, for example by chemical vapour deposition of phosphorus oxide; or directly by ion implantation.”); Ex.1007-Smith, 3:56-57 (“atmosphere containing phosphorus oxychloride”); Ex.1004-Froitzheim, [0044] (“diffusion of Phosphorous from the gas phase”); Ex.1019-Krygowski, 1 (“ POCl_3 diffusion step is used to co-diffuse the emitter and pre-alloyed BSF”); Ex.1030-Benick (explaining POCl_3 diffusion).

55. Another known technique for diffusing boron into a silicon wafer or polysilicon layer was known as borosilicate glass (BSG) diffusion. This technique involved forming a layer of BSG on the surface of the wafer (or a polysilicon layer on the wafer) to form BSG. Ex.1007-Smith, 2:44-4:2; Ex.1004-Froitzheim, [0040]-[0041]. One method to do this involved vaporizing boron-containing liquid such as boron tribromide (BBr_3) into a furnace containing silicon wafers, where it reacted

with the silicon atoms to form the BSG. Ex.1043-Kerr, 153-155. Applying heat then drove the boron from the BSG into the silicon or polysilicon via diffusion. Ex.1007-Smith, 2:44-4:2; Ex.1004-Froitzheim, [0040]-[0041].

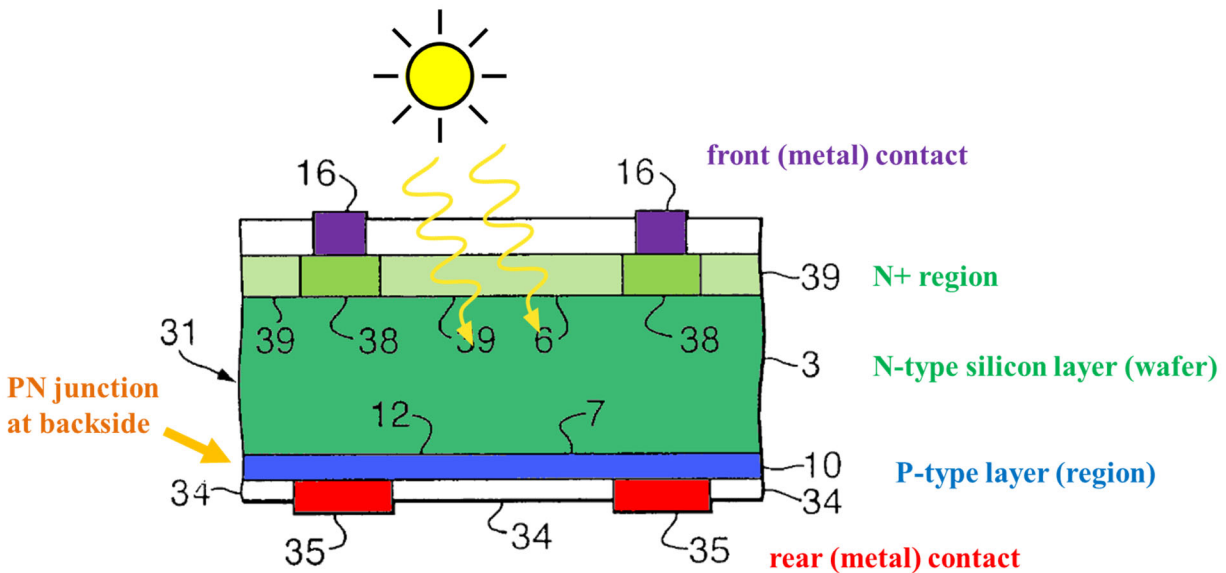
2. PN Junction

56. In a typical solar cell, an interface between n-type and p-type regions in a silicon wafer, or between an n-type wafer and a p-type layer added to that wafer (alternatively, a p-type wafer and an n-type layer added to it), is formed and is commonly known as the “PN junction.” Ex.1016-Komp, 5-18; Ex.1050-Tarr, 655-57. At the center of a PN junction is established an “electric field.” An electric field exerts a force on charge carriers that pushes them in the direction of the electric field or opposite the direction of the electric field, depending on the polarity of the charge carriers. Ex.1033-Pierret, 75-79. The PN junction—because of its built-in electric field—acts as the driving force to create electrical current when the solar cell is illuminated. Ex.1033-Pierret, 101; Ex.1010-Holman-Thesis, 26 (“The internal electric field separates the charges and pulls them towards the appropriate contacts. They flow through an external circuit, and—voilà!—electricity.”).

57. When solar radiation reaches a solar cell, and when the energy of the photons is greater than the bandgap energy of the silicon wafer, electrons in the valence band may be excited to the conduction band, absorbing the photons’ energy

to make the transition. *See* Ex.1016-Komp, 5-18, 10 (“The electron might be thermally excited by...a photon of light of sufficient energy might be absorbed by the crystal and cause the electron to jump. Once the electron is in the upper conduction band, it is free to move and can act as a carrier of electricity.”); Ex.1010-Holman-Thesis, 14-15. Each “photoexcited” electron leaves behind a hole in the valence band; light absorption creates an “electron-hole pair.” *See* Ex.1016-Komp, 5-18, 182 (defining “band gap energy” as “[t]he energy needed to raise an electron from the top of the valence band to the bottom of the conduction band”); Ex.1010-Holman-Thesis, 14-15. As discussed herein, the photoexcited electrons are mobile in the conduction band, and the photoexcited holes are mobile in the valence band. Ex.1010-Holman-Thesis, 14-15. A solar cell produces electricity when the photoexcited electrons are conveyed to one metal contact and the photoexcited holes are conveyed to a separate metal contact. Ex.1010-Holman-Thesis, 16. The PN junction facilitates this separation of the charge carriers. In particular, photoexcited electrons that encounter the PN junction are swept to the n-type region or layer by the PN junction’s electric field, and photoexcited holes that encounter the PN junction are swept to the p-type region or layer. *See* Ex.1016-Komp, 2-18; *see also* Ex.1010-Holman-Thesis, 24-25.

58. As an example, the below solar cell shown includes an **n-type silicon layer (wafer)** containing n-type dopants such as phosphorous. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. The wafer is often called a “substrate” because it is the base upon which other layers of the solar cell are built. It is also the thickest layer in the solar cell, commonly being 100-300 μm thick. The backside (also called a rear side in literature) of the solar cell below includes a **p-type layer (region)**, made by diffusing p-type dopants such as boron into the substrate’s backside. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. Diffused regions are thin relative to the wafer’s thickness, commonly extending 0.3-3 μm into the wafer’s surface. Ex.1004-Froitzheim, [0026]. At the interface of the n-type substrate and p-type region, the “PN junction” is formed. Ex.1004-Froitzheim, [0010], [0022], [0025]. Because the diffused region is thin and the wafer is thick, the PN junction is much closer to the backside of the solar cell than its middle or front. The p-type layer, in this case, as it is oppositely doped from the substrate, is called an “emitter.” In the field of solar cell technology, “emitter” usually refers to the region or layer that is oppositely doped from the substrate.



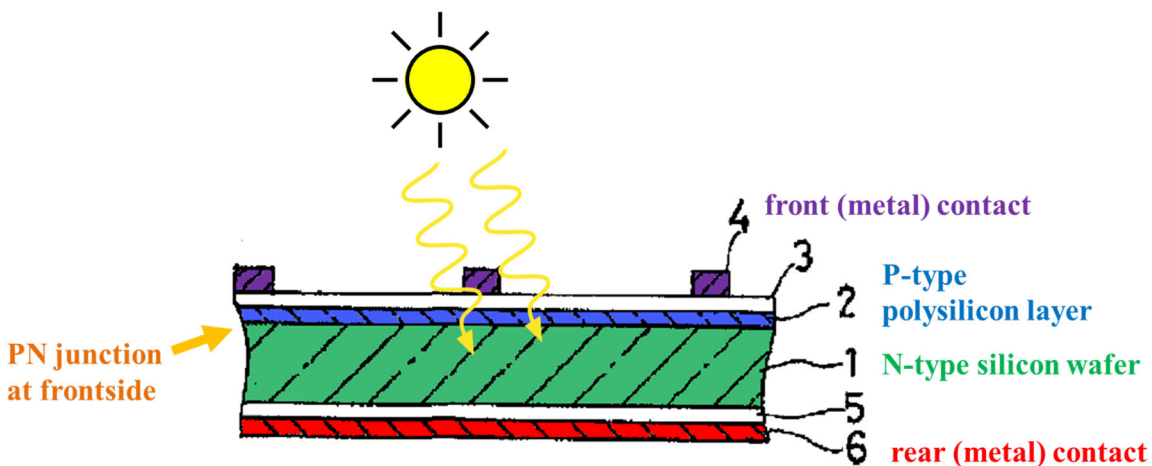
Ex.1004-Froitzheim, Fig.3.¹

59. Throughout the history of solar cells, many different arrangements of solar cell components have been developed. The placement of the PN junction, whether at the “backside” of the solar cell (formed by, e.g., a diffusion into the back of the wafer) or at the “frontside” of the solar cell (formed by, e.g., a diffusion into the front of the wafer), was one of the well-known arrangement options. *Compare* Ex.1018-Nelson, 188 (Fig. 7.7, frontside configuration); Ex.1004-Froitzheim, Fig.3 (backside configuration). In a “back-junction” (also called “backside junction”)

¹ All annotations and emphasis in figures and text throughout this Declaration are added unless otherwise noted.

configuration, in which the junction is at the solar cell's backside (as shown in Froitzheim above), the uniformly doped "bulk" of the wafer is closer to the sun than the oppositely doped emitter region or layer, and the sunlight hits the former first. *E.g.*, Ex.1004-Froitzheim, Fig.3. The PN junction is thus formed at the backside of the substrate, at the interface between the wafer bulk (n-type in the above figure) and the emitter (p-type in the above figure). Ex.1004-Froitzheim, Fig.1, Fig.3; Ex.1008-Li, Fig.1; Ex.1022-Meier, Fig.2, 4:27-65.

60. Alternatively, in a "front-junction" (also called "frontside junction") configuration, the emitter region or layer is located closer to the sun than the wafer bulk, and the sunlight hits the emitter first. *E.g.*, Ex.1031-Okayasu, Fig.1. The PN junction is formed at the frontside of the substrate, at the interface between the emitter (p-type in the below figure) and the wafer bulk (n-type in the below figure):



Ex.1031-Okayasu,² Fig.1.

61. A second method to form an emitter, in addition to dopant diffusion into a region near a surface of the wafer, as in Froitzheim above, is to “deposit” a layer onto the wafer surface that has the opposite doping polarity of the wafer. Deposition refers to a process to add such a layer, which is commonly built up atom by atom. Known processes include chemical vapor deposition and physical vapor deposition. Amorphous silicon and polycrystalline silicon emitter layers were well known by 2008. *E.g.*, Ex.1008-Li, Fig.1; Ex.1031-Okayasu, Fig.1. Okayasu above shows a polycrystalline silicon emitter.

62. It was well known that back-junctions were advantageous, especially for solar cells with high-quality silicon wafers (i.e., those with low rates of bulk recombination, as described below). For example, it was known that locating the emitter at the front of the solar cell can reduce solar cell efficiency because (i) diffused emitters can have high doping concentrations that can induce unwanted recombination if there is considerable absorption (i.e., parasitic absorption) within the emitter and (ii) most absorption in a solar cell occurs near the front of the solar cell. I explain recombination below in Section VII.B (Overview of Cell Efficiency).

² See 1032-Okayasu-Decl. (translator declaration for Okayasu translation).

Back-junction solar cells do not suffer from such parasitic absorption because locating the emitter at the rear of the solar cell ensures that most light is beneficially absorbed in the wafer before reaching the emitter. *See* Ex.1004-Froitzheim, [0025]-[0026] (“At the rear side 7, a p-doped layer 10 is arranged suitably such as discussed further below, and a p/n-junction 12 with the body layer is formed. The doping level of the p-region can be higher than what one would use at a front contact, since at the rear side that is away from the light-receiving front side there most of the light has already been absorbed and there is less risk for recombination.”).

63. Deposited silicon emitters were similarly known by 2008 to have higher absorption when they were located on the front side of a solar cell. For example, it was reported that a p-type amorphous silicon emitter deposited on an n-type wafer “act[ed] mainly as a ‘dead layer’ in which almost all the absorbed light [did] not generate photocurrent.” Ex.1061-Centurioni, 1818-1819. Similarly, it was reported that an n-type polycrystalline silicon emitter deposited on a p-type wafer caused a decrease in generated current due to optical losses (i.e., absorption) in the emitter. Ex.1062-Farrokh-Baroughi, 5-6.

64. Because polycrystalline silicon is a material that has optical properties very close to that of a monocrystalline or multicrystalline silicon wafer, it absorbs light of the same wavelengths as a wafer. Ex.1059-Lubberts, 6877 (explaining

absorption coefficient of doped polysilicon as a function of wavelength). Consequently, a polysilicon emitter at the front side absorbed light that would otherwise go to the substrate. *See* Ex.1062-Farrokh-Baroughi, 5-6; *see also* Ex.1060-Bordogna, 2:32-34 (“The use of Polysilicon leads to an intrinsic parasitic absorption of light that involves a consequent loss of a portion of the optical signal before it reaches the sensor”).

65. The manufacturing processes for front- and back-junction solar cells were functionally similar. For instance, they both involved a doped silicon wafer, diffusing dopants into the surface of the wafer or into polycrystalline silicon layers deposited on the wafer to form a PN junction, adding an anti-reflection coating, and adding metal contacts, among other standard manufacturing steps. *E.g., compare* Ex.1004-Froitzheim, [0038]-[0051] *with* Ex.1031-Okayasu, [0044].

3. Metal Contacts

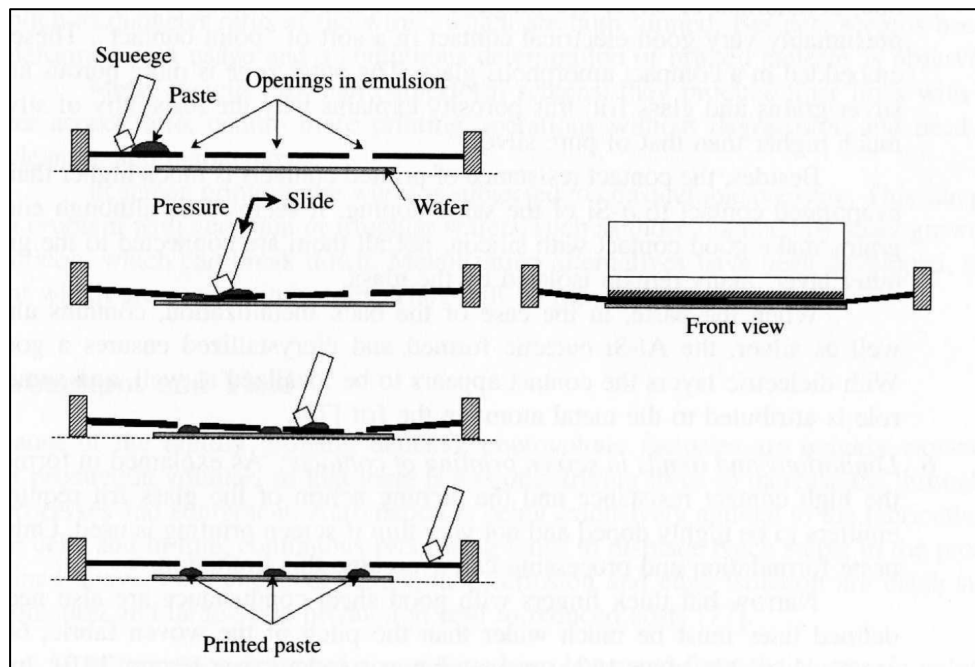
66. Solar cells have metal contacts (also called electrodes) at which photogenerated electrons and holes are collected and passed to external circuits. Ex.1016-Komp, 154-55. For example, the solar cells shown above (Froitzheim and Okayasu) each include at least one **front metal contact** (i.e., metal contact on the front side of the solar cell) and one **rear metal contact** (i.e., metal contact on the rear side of the solar cell). Ex.1004-Froitzheim, Fig.3; Ex.1031-Okayasu, Fig.1.

These metal contacts connect the solar cells to one another in solar modules, and the resulting “strings” of interconnected solar cells are connected to external circuits. Ex.1016-Komp, 13-14 (“The back contact and the top fingers shown are used to connect the solar cell to the external circuit”).

67. One well-known way to manufacture metal contacts was screen printing. Ex.1045-Green-1995, Chapter 11.2 (discussing “screen-printed” solar cells); Ex.1004-Froitzheim, [0020], [0049]. For instance, a 2001 publication described screen printing as being part of “[t]he most common fabrication approach” to reduce cell costs. Ex.1021-Gordon, 324. Screen-printed front and rear contacts were made from metal paste. Ex.1004-Froitzheim, [0020], [0049]; Ex.1045-Green-1995, 234-39; Ex.1018-Nelson, 188 (“In large scale production, AR coat, front and back contacts are usually deposited by screen printing and then fired.”). Screen-printed contacts were made of silver and/or aluminum. Ex.1004-Froitzheim, [0020], [0049]; Ex.1045-Green-1995, 234-39 (“addition of aluminum to the silver paste”), Ex.1022-Meier, 7:10-16 (“FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating. By way of example, a silver layer is screen-printed onto the n^+ layer 216, covering about 7% of the front surface in a grid pattern. Silver may be deposited by screen-printing to a thickness that is generally between about 5 μm and about 20 μm and preferably about

10 μm .”). Screen printing was favored in many applications because it was cheaper than other options. Ex.1018-Nelson, 188.

68. The basic steps of a typical screen-printing process are shown in the following illustrations:



Ex.1020-Luque, Fig.7.9, 277-78. As shown, first, a paste containing metal particles is deposited on a screen, which has openings where the contacts are desired to be formed on the underlying solar cell. Second, a squeegee is moved across the screen, dragging the paste with it. Ex.1020-Luque, Fig.7.9, 277-78. Once the paste reaches an opening in the screen, the squeegee's pressure deposits the paste through the opening onto the solar cell. Ex.1020-Luque, Fig.7.9, 277-78. After the paste is thus “printed” on the wafers, the structure is “fired.” Ex.1020-Luque, Fig.7.9, 277-78.

The firing process entails heating the structure under certain conditions. Ex.1020-Luque, Fig.7.9, 277-78. This solidifies the paste into the final contacts and makes electrical contact between the paste and an n-type or p-type region or layer (e.g., the emitter). Ex.1020-Luque, Fig.7.9, 277-78. In many cases, the paste was designed to “fire through” an anti-reflection coating located between the wafer and the paste. Ex.1020-Luque, 278 (“Higher temperatures are needed if an AR coating must be penetrated....”). Firing through refers to the paste etching (i.e., locally dissolving) the coating so that metal particles make contact to the underlying doped region or layer. Ex.1020-Luque, Fig.7.6, 278; Ex.1022-Meier, 7:10-12 (“FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating.”), Fig.3D.

4. Texturing and Anti-reflection Coating

69. It was well known by 2008 that the addition of texture and anti-reflection coatings to the front side of solar wafers would help maximize the amount of sunlight that a solar cell absorbs. Ex.1016-Komp, 20 (“To decrease reflection loss, most manufacturers etch the surface of the cell to roughen or ‘texturize’ it and apply antireflection coatings.”).

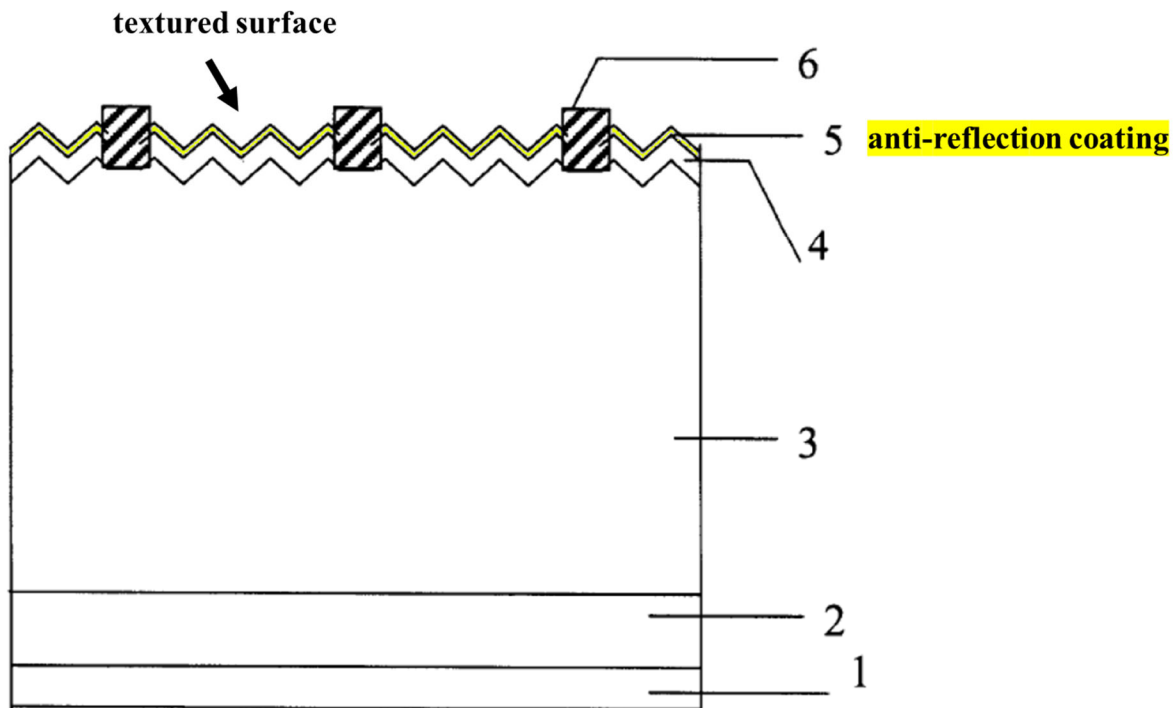
70. By 2008, texturing the surface of silicon had long been studied and implemented to increase a solar cell’s efficiency. Ex.1023-Yablonovitch, 2:49-55

(“front surface texturing...is essential for optical enhancement (light trapping)”); Ex.1045-Green-1995, 282 (“In the historical development of silicon cells...texturing accounted for the more than 10% relative performance advantage of black cells over violet cells.”). Texturing the surface of silicon increases a solar cell’s efficiency because some of the sunlight that reflects off the planar surface can be recaptured with a textured surface. Ex.1023-Yablonovitch, 1:60-62 (“The front of the cell may be textured to help trap the light internally and to reduce reflection losses.”); Ex.1018-Nelson, 188 (“textured to reduce reflectivity”). One well-known way to texture a surface was to etch the surface with chemicals. Ex.1004-Froitzheim, [0039] (“[E]tching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection.”), [0023], [0056] (“After etch removal, texture etching was applied to the [n-type] wafers.”), [0087]; Ex.1006-Borden-575, [0029] (discussing front surface textured solar cells); Ex.1024-Borden-578, [0023] (“[I]n step S302, the front surface of the n-type substrate is textured. This may be accomplished using conventional etching, such as isopropyl alcohol and KOH.”), Fig.3; Ex.1016-Komp, 20 (“To decrease reflection loss, most manufacturers etch the surface of the cell to roughen or ‘texturize’ it and apply antireflection coatings.”).

71. By 2008, anti-reflective coatings were also routinely applied to solar cells to increase their efficiency. Anti-reflection coatings, applied over the textured surface, minimize the amount of light that is reflected away from the cell and were well known. Ex.1004-Froitzheim, [0050] (“[A]ntireflection coating can be applied using known methods.”); Ex.1022-Meier, 1:30-35 (“Commercial embodiments of conventional solar cells typically include an optional anti reflective coating”), 4:45-47; Ex.1025-Sah, 3:52-55 (“front surface 12 ...[includes] antireflection coating”), Fig.1a (showing prior art); Ex.1023-Yablonovitch, 2:49-55 (“[A]n anti-reflection coating is desirable, and is assisted by the front surface texturing which is essential for optical enhancement (light trapping) in any case.”); Ex.1016-Komp, 20; Ex.1018-Nelson, 188.

72. One common material used for anti-reflection coating was silicon nitride. Ex.1004-Froitzheim, [0030], [0019], [0023], claim 7; Ex.1022-Meier, 6:20-25 (“An anti-reflective coating 214 may then be deposited on top of n^+ layer 216, as shown in Fig. 3B. By way of example, plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride...is carried out to form anti-reflective coating 214.”); Ex.1018-Nelson, 188 (“Suitable materials for silicon [AR coating include]...silicon nitride (Si_3Ni_4)”).

73. Li (below) provides one example of a solar cell with a textured front surface and anti-reflection coating. In two-dimensional images, such as Li, it was common to show surface texturing by depicting the surface of the solar cell as having jagged edges.



Ex.1008-Li, Fig.1. Froitzheim teaches another example of a solar cell with a textured front surface and anti-reflection coating. Although Froitzheim's figures do not depict a textured front surface, Froitzheim explains that the front surface is textured via etching. Ex.1004-Froitzheim, [0039] ("a short, alkaline crystal-oriented etching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection").

B. Overview of Solar Cell Efficiency

74. As discussed above, solar cells generate electricity when incident light excites electron-hole pairs that are separated and reach metal contacts connected to an external circuit. Solar cell efficiency is the ratio of power output from the cell to the power input from the sun under specific conditions, and solar cell efficiency is referred to as “power conversion efficiency.” Ex.1018-Nelson, 289. In other words, power conversion efficiency is a measure of the amount of electrical power extracted from the solar cell per amount of radiation power incident on the solar cell under particular conditions. For terrestrial solar cells, the conditions for evaluating efficiency are Air Mass 1.5 Global spectrum, 1000 W/cm^2 , and 25°C . Ex.1018-Nelson, 289.

75. Since the first modern solar cell was created in 1954 by Bell Laboratories (Ex.1026-Chapin), skilled artisans have worked continuously to improve cell efficiency. When the modern solar cell was initially created, the efficiency was about 6%. Ex.1026-Chapin. In 1961, a groundbreaking paper discussing the limit of solar cell efficiency was published by William Shockley and Hans Queisser. Ex1027-Shockley. It noted that a “theoretically justifiable upper limit” of efficiency exists in solar cells based on the laws of physics. Since then, the Shockley-Queisser limit for silicon-based solar cell (bandgap energy of 1.12eV)

efficiency has been known to be about 30%. Ex1027-Shockley, 510. Because of the physical limit on a cell's efficiency, even small efficiency gains were desirable. Ex.1025-Sah, 1:15-20 (patent filed in 1986 noting that "[s]ince about 1956, silicon solar cell conversion efficiency has been improved from about 5% to more than 16%"); Ex.1028-Metz (claiming 18.5% efficiency); Ex.1029-De-Ceuster (claiming 22% efficiency); Ex.1030-Benick (claiming 17.5% efficiency).

76. As I explained above, a solar cell generates electricity through the separation of photogenerated electrons and holes. One important goal of solar cell design is to maximize the number of electron-hole pairs that contribute to generating electricity by exiting through their respective metal contacts (i.e., electrodes). This is because the created electricity becomes usable only when it powers an external circuit. Ex.1016-Komp, 3-4, 121, 154-57.

77. A major factor decreasing solar cell efficiency is a phenomenon called "recombination." Ex.1016-Komp, 19-20; Ex.1051-Swanson-1986, 86 ("It has long been recognized that an important path to improved efficiency is through reducing carrier recombination."). Recombination was well studied by 2008 and occurs when electrons and holes "recombine" with each other before exiting the cell. Ex.1016-Komp, 19-20. When an electron that has been excited to the conduction band (via the absorption of light) encounters a hole in the valence band, there is a possibility

that the electron will return to the valence band and fill the hole—i.e., “recombine.” Ex.1010-Holman-Thesis, 15-16. While physics dictates that some types of recombination are inevitable, so-called “non-radiative recombination” is undesirable for cell efficiency because electrons and holes that recombine no longer contribute to the generated power of the solar cell. Ex.1016-Komp, 19-20; Ex.1018-Nelson, 81; Ex.1010-Holman-Thesis, 15-16.

78. By 2008, it was well known that (i) recombination occurs at several locations in a solar cell and (ii) non-radiative recombination should be reduced at such locations to achieve better efficiency. Ex.1045-Green-1995, 223 (“To obtain high cell performance, recombination throughout the cell has to be kept to a minimum.”), Ex.1051-Swanson-1986, 92 (“Carrier recombination can occur in four regions of the [point-contact solar cell]: (1) the bulk silicon (which is largely mediated through defects and impurities), (2) the surfaces of the silicon on the front and between the contact diffusions on the back (passivation with SiO₂ reduces this component), (3) the diffused junction regions and (4) the metal-silicon contacts. Research into improving the recombination related parameters of solar cells [] has resulted in cells where the recombination is dominated entirely by the diffused junction regions.”).

79. For example, it was well known that non-radiative recombination occurs in bulk regions (i.e., the silicon wafer) at defects in the crystalline lattice such as structural defects (e.g., grain boundaries), unintentional impurities (e.g., metal atoms), and intentional impurities (e.g., dopant atoms). Ex.1045-Green-1995, 223 (“Recombination in bulk regions can be minimized by choosing as high a quality starting material as possible”). It was also well known that recombination occurs at the surfaces of the wafer, where “surface” was commonly understood to mean the interface of the wafer with any other material, and surfaces were recognized to be extended crystalline defects. For example, it was well known that recombination occurs at the wafer interface with metal contacts. Ex.1045-Green-1995, 226 (“The regions where metal contact to the cell is made are regions of potentially very high recombination.”); Ex.1006-Borden-575, [0003].

80. Because recombination was an important factor in design considerations, ways to measure recombination were known in the art. This was beneficial because it allowed skilled artisans to compare whether different solar cell materials and configurations had decreased non-radiative recombination. A known way to evaluate recombination was to measure the emitter saturation current density (J_0). See Ex.1043-Kerr, 18-19. The emitter saturation current density represents the sum of the different recombination mechanisms that may incur inside of the emitter.

See Ex.1043-Kerr, 81-84 (“[R]ecombination due to the heavily doped emitter regions is characterised by a saturation current density....”). Lower emitter saturation current density indicates less recombination and thus the likelihood of a more efficient solar cell. *See* Ex.1043-Kerr, 18-19, 81-84.

81. Prior to 2008, different techniques to reduce non-radiative recombination were known. For example, it was well known that surfaces could be “passivated” to reduce recombination, i.e., reduce the density of electrons available to recombine with holes (or vice versa) or reduce the number of interfacial defect sites that facilitate such recombination. Ex.1043-Kerr, Abstract (“Surface recombination processes in silicon solar cells are becoming progressively more important as industry drives towards thinner substrates and higher cell efficiencies. The surface recombination properties of well-passivating SiN films on p-type and n-type silicon have been comprehensively studied, with S_{eff} values as low as 1cm/s being unambiguously determined.”); Ex.1004-Froitzheim, [0019] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”). One well-known surface passivation method was to heavily dope the surface region of a wafer—or a layer deposited on the wafer surface—so that there was primarily only one carrier type (i.e., electrons or holes) near the wafer surface. Ex.1049-Green-1986, 129 (“The heavily doped P^+

region at the rear of the cell blocks minority carrier flows, making the PP⁺ junction plane an effective low recombination-velocity surface.”). As recombination requires both an electron and a hole, having primarily only one carrier type reduces recombination. Ex.1049-Green-1986, 129, 151. An emitter, being doped and in the vicinity of a wafer surface, could provide such passivation.

82. Another well-known surface passivation method was to deposit a “passivation layer” on the wafer surface. A passivation layer either (i) removed defects at the wafer surface (“chemical passivation”) by advantageously bonding with the atoms on the silicon surface or (ii) contained immobile charge that repelled one carrier type (“field-effect passivation”). Ex.1004-Froitzheim, [0019] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”). Suitable passivation layers were known to include silicon nitride (which also commonly served as an anti-reflection coating, as I have described) and silicon oxide. Ex.1045-Green-1995, 224-226 (“Recombination in non-contacted areas of the surface can be minimized by the growth of a high-quality thermal oxide. Conditions for producing low interface state densities have been well documented for microelectronics”).

83. Numerous references throughout the history of solar cells taught passivating the surface of a silicon wafer by placing a very thin silicon oxide layer

between the wafer surface and a deposited layer, including a deposited emitter layer. In this case, the oxide layer is sandwiched in the PN junction and advantageously bonds with the atoms on the silicon surface to reduce recombination. For example, in the 1980s, Yablonovitch and Kwart taught the concept of a tunnel oxide layer. Ex.1036-Yablonovitch-1985, 1212-13 (discussing “tunneling” and a “thin [interfacial] oxide layer”); Ex.1023-Yablonovitch, 3:61-64 (“The interface 18 between the silicon ribbon 14 and the n⁺-SIPOS heterocontact contains a 20-40 Å interfacial layer of silicon dioxide which is so thin as to be permeable to electrons”); Ex.1046-Kwart, 1125 (“[b]oth poly-silicon and SIPOS emitters [can improve] performance through incorporating a thin, tunnelable interfacial oxide”). In 1990, Gan published a study on a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245. In 2008, Borden-575 taught a “tunnel oxide” that “provides passivation between the substrate and the polysilicon [emitter].” Ex.1006-Borden-575, [0022]; *see also* Ex.1016-Komp, 23 (“Current carriers pass through this insulator by a quantum mechanical process called tunneling. ... If the insulating layer is one of the proper thickness, around 20 Å, the open-circuit voltage of a cell can be increased without any significant loss in short-circuit current.”).

84. The teachings of oxide layers sandwiched in the PN junction also came from microelectronics technologies such as transistors. Ex.1034-Rahim, 2506 (“A considerable amount of work has been published in the literature on the effects of the interfacial oxide on the base current [] and emitter resistance [] of polysilicon emitter contacts”); Ex.1035-Parekh, 3167 (“a simple method for modifying the interfacial oxide thickness in a polysilicon emitter technology incorporated in a BiCMOS process [] allows an increase in the bipolar npn transistor current gain without adversely impacting other device parameters.”); Ex.1047-Wolstenholme, 232 (“there is a strong correlation between the high gain of polysilicon emitter bipolar transistors and the existence of a continuous, thin, interfacial oxide layer between the single-crystal silicon and the polysilicon.”). Since silicon-based solar cells and transistors are closely related in structure (e.g., both rely on PN junctions) and manufacturing, skilled artisans in solar cells frequently learned from and adopted transistor technologies. Ex.1045-Green-1995, 218 (“To achieve design objectives in [surface passivation,] full advantage had to be taken of developments in microelectronics”), 224 (stating that recombination and the usage of thermal oxide have been “well documented for microelectronics”).

85. In addition to recombination, skilled artisans also addressed contact resistance to increase solar cell efficiency. Contact resistance (ρ_c) is present in every

solar cell and is the resistance between the interface of two materials, or the resistance between the multiple interfaces of more than two materials. *See* Ex.1045-Green, 181-182 (“Metallic contacts to the cell are required to transfer the generated current to an external load. At the interface with silicon, it is known from experiment that metals induce a barrier to majority carriers.”); Ex.1020-Luque, 258, 263-264, 274-275 (“The requirements for the front metallization are low contact resistance to silicon.”). In the latter case of multiple interfaces, the resistance was sometimes called the “lumped contact resistance.” It was well known that contact resistance represents an opposition to current flow. *See* Ex.1045-Green, 182 (“The energy barrier to majority carrier flow gives rise to an undesirable contact resistance.”). Thus, it was well known that if an interface or a series of interfaces has higher resistance (i.e., there is higher contact resistance), it will be harder for current to flow and the power output of the solar cell would be lower. Ex.1045-Green, 182. As a result, skilled artisans sought to design for lower contact resistance because doing so would create a more efficient solar cell. Ex.1045-Green, 182; Ex.1005-Gan, 249.

86. It was well known that surface recombination and contact resistance were closely related, and that there were tradeoffs in achieving good (lower) surface recombination and good (lower) contact resistance. *E.g.*, Ex.1005-Gan, 248 (explaining that a decrease in contact resistance increases recombination in certain

cases). As a result, skilled artisans were familiar with techniques to balance recombination and contact resistance to improve overall efficiency. *E.g.*, Ex.1005-Gan, 249 (explaining that with polysilicon emitters, both low recombination and contact resistance are achievable with a very small fraction of interfacial oxide breakup because of “tunneling” through oxide resistance); Ex.1058-Swanson-1990, 473 (“In short, the criteria outlined above for an optimized single-diffusion front-side phosphorus emitter [include]...Surface dopant concentration $\leq 10^{20} \text{ cm}^{-3}$ to obtain low emitter saturation currents for the passivated emitter regions [and] Surface dopant concentration $\geq 10^{19} \text{ cm}^{-3}$ to insure good contact resistance.”).

VIII. OVERVIEW OF THE '053 PATENT

A. Summary of the '053 Patent

87. The '053 patent describes the manufacturing of a structure for a solar cell, which the '053 patent acknowledges was a “well known device[] for converting solar radiation to electrical energy.” Ex.1001-USP053, Abstract, 1:21-28, 2:12-14, 3:49-5:18. As depicted in Figure 1 below, the '053 patent's solar cell has an **N-type substrate 101 (green)** that includes “N-type doped regions 105 and 106 formed in the **substrate**.” Ex.1001-USP053, 2:28-56. The **N-type substrate 101** forms a “backside junction” with a **P-type emitter 108 (blue)** because the **P-type emitter** is

on the back side of the cell (i.e., the side facing away from the sun).³ Ex.1001-USP053, 2:35-43. (“In the example of FIG. 1, the solar cell 100 includes a backside junction formed by a P-type doped polysilicon emitter 108 serving as a P-type diffusion region and an N-type silicon substrate 101 serving as an N-type diffusion region.”); *see also* Ex.1001-USP053, 1:28-29 (“A solar cell includes P-type and N-type diffusion regions that form a junction.”). The front side of the **N-type substrate** may be textured (113) and include an anti-reflective coating 103. Ex.1001-USP053, 2:35-63, 4:36-46, 5:28-35.

³ As described in more detail below, I understand that the '053 patent's applicant represented to the Patent Office on multiple occasions that an emitter is oppositely doped from the substrate. *See* Sections VIII.B-C (Prosecution Histories).

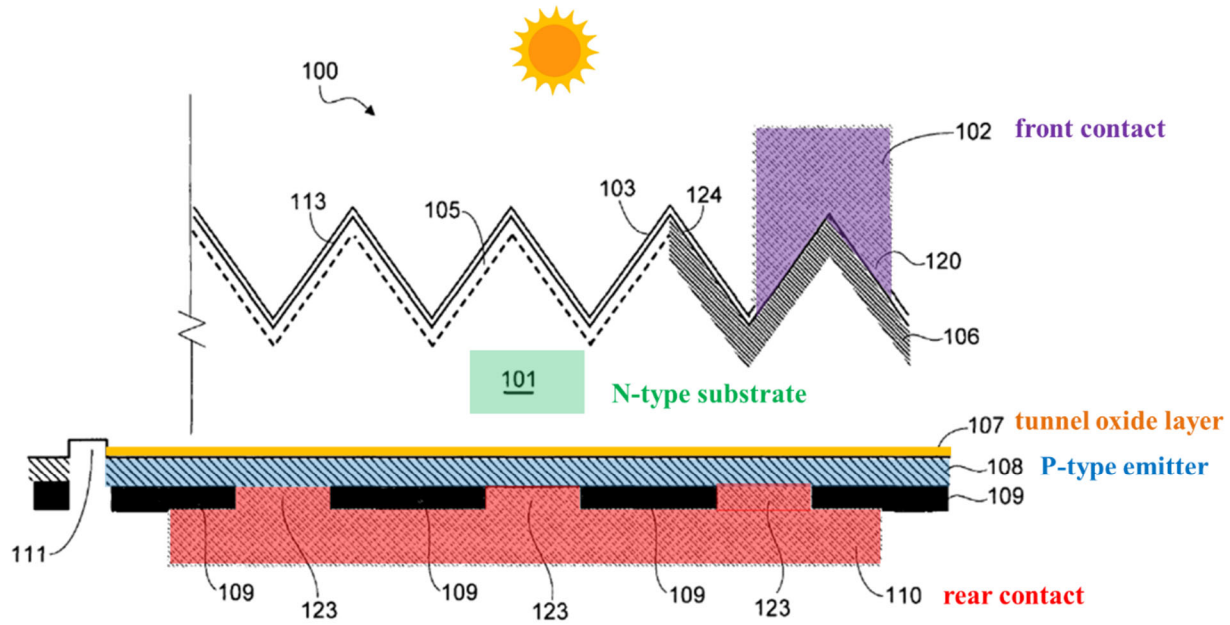


FIG. 1

Ex.1001-USP053, Fig.1.

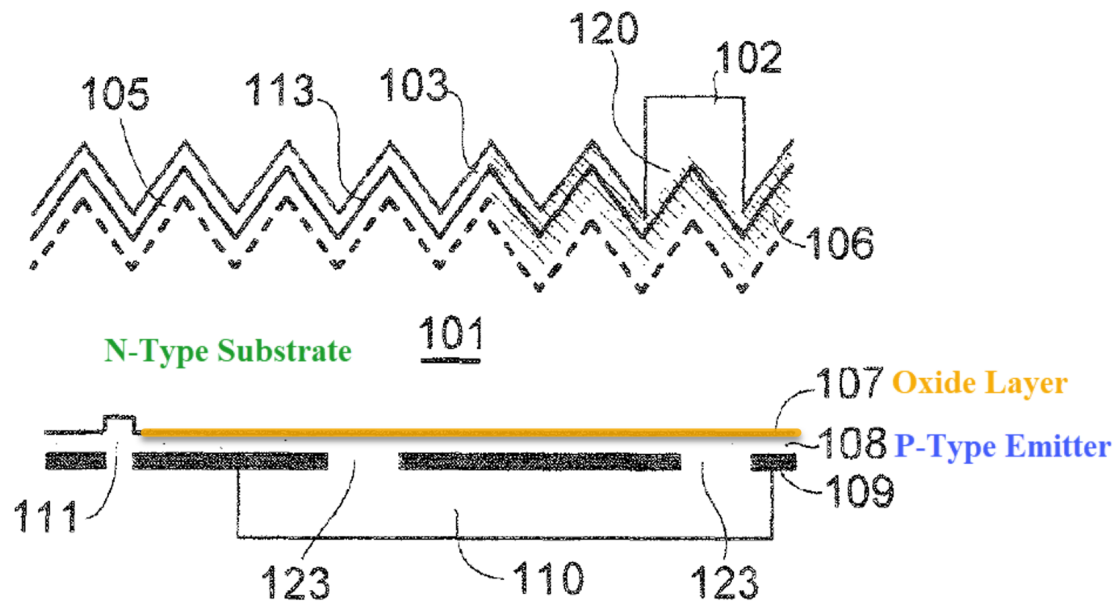
88. The '053 patent's solar cell is manufactured to have front and back metal contacts, which allows "an external electrical circuit to be coupled to and be powered by the solar cell." Ex.1001-USP053, 1:34-36. As shown in Figure 1, a **metal contact 102 (purple)** is electrically connected to the **N-type substrate** (via "N-type doped regions 105 and 106 formed in the [front of the] **substrate**"), and a **metal contact 110 (red)** is electrically connected to the **P-type emitter**. Ex.1001-USP053, 2:29-34, 3:6-29. The "**metal contact 110** electrically connects to the polysilicon emitter 108 through contact holes 123 formed through a dielectric comprising a silicon dioxide layer 109." Ex.1001-USP053, 3:6-9.

89. The '053 patent explains that a **tunnel oxide layer 107 (orange)** may be formed between the N-type substrate and P-type emitter. Ex.1001-USP053, 2:64-3:6. The '053 patent does not expressly identify the purpose or function of the **tunnel oxide layer**. *See generally* Ex.1001-USP053.

90. The '053 patent teaches and claims a method of manufacturing a solar cell with the structure described above in this section. I briefly highlight below nine manufacturing steps that are relevant to the '053 patent's claims. Ex.1001-USP053, 3:56-6:5, Figs.4A-4M, claims 1, 9, 16. **First**, "an N-type **silicon substrate 101**" is provided. Ex.1001-USP053, 3:59-4:3; Fig.4A. **Second**, a "**tunnel oxide 107**" is "formed on the...back surface[]...of the **substrate 101**." Ex.1001-USP053, 4:4-8; Fig.4B. **Third**, "[a] layer of polysilicon is...formed on the **tunnel oxide[] [107]** to form...the **polysilicon emitter 108**." Ex.1001-USP053, 4:8-13; Fig.4B. **Fourth**, "a P-type dopant source [] is formed on the **polysilicon emitter**," and "[a] dielectric capping layer [] is formed on the P-type dopant source [] to prevent dopants from escaping." Ex.1001-USP053, 4:14-27; Fig.4C. **Fifth**, "exposed regions on the front surface of the **substrate 101** are randomly textured" to increase light absorption. Ex.1001-USP053, 4:36-41, 2:57-63; Fig.4E.

91. **Sixth**, "an N-type dopant source... is formed on regions of the textured surface." Ex.1001-USP053, 4:51-59. **Seventh**, the cell is heated (i.e., "a dopant

drive-in step”) to diffuse the dopants previously placed on the substrate and emitter. Ex.1001-USP053, 4:60-5:8; Fig.4G. The drive-in step may be formed “in-situ,” meaning “a **single manual...loading** of the **substrate 101** in a furnace” or other tool, “which advantageously helps in lowering fabrication cost.” Ex.1001-USP053, 5:9-18. **Eighth**, an “antireflective coating of silicon nitride layer 103 is formed over the textured surface 113.” Ex.1001-USP053, 5:28-35. **Ninth and finally**, metal contacts 110 (rear) and 102 (front) are formed so solar energy can be harvested as usable electricity. Ex.1001-USP053, 1:25-49, 5:45-5; Figs.4L-4M. The result of this method is shown in the following figure:



Ex.1001-USP053, Fig.4M.

B. Prosecution History

92. I have reviewed the full file history for the '053 patent. Based on my review, I understand that application No. 13/495,577 was filed on June 13, 2012, and issued as the '053 patent. I understand that the '053 patent was filed as a divisional application of Application No. 12/070,742, which issued as the '516 patent. Ex.1001-USP053, Cover.

93. I understand that the applicant had to distinguish its claims during prosecution and made several arguments regarding the scope of the '053 claims. In particular, the pending claims recited a “backside junction,” and the applicant argued that the cited prior art did not disclose a “backside junction” because the prior art instead taught polysilicon back surface field (“BSF”) solar cells (i.e., cells where the substrate and backside polysilicon are similarly doped). Although the claims were allowed by the Examiner, the prosecution record does not reflect that the Examiner found that the recited method steps were novel or not obvious. Instead, the prosecution record reflects that the claims were allowed due to the structure resulting from the method steps recited in the claims.

94. For example, I understand that during prosecution of the '053 patent, pending claim 21 (which issued as claim 9) recited the following:

A method of fabricating a solar cell comprising:

forming a layer of polysilicon over a back surface of a silicon substrate;
forming a first dopant source layer over the layer of polysilicon;
diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate;
and
diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.

Ex.1002-FH053, 5. The claims were subsequently rejected over various references, including over combinations including Smith (Ex.1007) and Meier (Ex.1022). *See* Ex.1002-USP053FH, 89-91, 141-146.

95. Following this rejection, the Applicant submitted a “First Action Interview” document where it amended the independent claims to add the step of “forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.” *See* Ex.1002-USP053FH, 124-131. In the corresponding remarks, the Applicant argued Smith and Meier did not disclose the structure resulting from the recited methods. *See* Ex.1002-USP053FH, 124-131.

96. After this submission, the Examiner issued an interview summary indicating that the claims remain rejected, including over a combination including Smith (Ex.1007). Ex.1002-USP053FH, 141-147. Following this interview summary, the applicant repeated its amendment to the independent claims to add the

step of “forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.” *See* Ex.1002-USP053FH, 148-156. In the remarks, the applicant did not argue that Smith did not disclose “a [*front side*] metal contact.” Ex.1002-USP053FH, 155-56.

97. The Examiner subsequently rejected the claims (again) as obvious over prior art, including Smith as a secondary reference. *See* Ex.1002-USP053FH, 162-169. In response to this rejection, the applicant did not amend the claims and instead argued the claims were patentable over the cited prior art. In particular, the applicant explained that the pending claims recited “that the layer of polysilicon forms a backside junction with the silicon substrate.” Ex.1002-FH053, 217-218. The applicant argued that the cited prior art “discloses a solar cell with a polysilicon back surface field (BSF), and “[a]s is well known, a BSF has the same dopant type as the substrate, but at a higher concentration to keep minority charge carriers away from the back surface.” Ex.1002-FH053, 217-218. Because the back surface field was the same dopant type as the substrate (i.e., the back surface field was not an emitter), the applicant argued that the cited prior art did not disclose the recited backside junction. Ex.1002-FH053, 217-218. Thus, the applicant of the ’053 patent represented to the Patent Office during prosecution that an emitter is a layer that is oppositely doped from the substrate. Importantly, in its response to the latest office

action, the applicant did not submit specific arguments relating to Smith. *See* Ex.1002-USP053FH, 162-169.

98. Following these arguments, the Examiner issued an advisory action repeating its rejections that the claims were obvious. Ex.1002-USP053FH, 229 (Advisory Action (Apr. 24, 2014)). The Examiner found that the references described a polysilicon layer that could be oppositely doped from the base (i.e., the emitter is “oppositely doped to the solar cell substrate which would form the claimed junction”). Ex.1002-USP053FH, 230. The applicant subsequently filed a pre-appeal brief conference request, where it repeated its arguments. Ex.1002-USP053FH, 232-237 (applicant’s appeal brief arguing that an emitter is the layer that is oppositely doped from the substrate).

99. Thereafter, I understand that the Examiner allowed the claims. Ex.1002-USP053FH, 245. In the Reasons for Allowance, the Examiner stated that the invention was patentable because “[t]he prior art of record lacks the instantly claimed backside junction formed at the interface of a first material of a silicon substrate comprising one dopant type and a second material of a polysilicon layer of an opposite dopant type.” Ex.1002-USP053FH, 250. Thus, the Examiner allowed the ’053 patent because the record did not include the claimed “backside junction”

solar cell configuration; the Examiner did not issue the claims because the recited manufacturing steps were novel or not obvious.

C. Prosecution History of Related Application

100. I understand that the applicant of the '053 patent filed an application that claims priority to the '053 patent. I have reviewed this application. I understand that the application that claims priority to the '053 patent is Application No. 14/504,771 ("771 Application"), which was filed on October 2, 2014 and ultimately abandoned by the applicant. Ex.1039-771FH, 28-33, 465-466. Similar to the '053 patent, the '771 Application claims priority to the '516 patent and shares the same specification and figures as the '516 and '053 patents. Ex.1039-771FH, 3-25, 28-33; Ex.1040-USP516. I understand that the applicant of the '516 and '053 patents represented to the Patent Office during prosecution of the '771 Application that an emitter is the layer that is oppositely doped from the substrate.

101. Specifically, I understand that during prosecution of the '771 Application, pending claim 1 recited the following:

A solar cell, comprising:
a substrate having a front surface that faces the sun to collect solar radiation
during normal operation and a back surface opposite the front surface;
an oxide layer disposed on the front surface of the substrate;
an anti-reflective coating on the oxide layer;
a tunnel dielectric disposed over the back surface of the substrate;

an emitter disposed over the tunnel dielectric, the emitter forming a backside junction with the substrate;
a doped diffusion region in the substrate;
a front electrode that is coupled to the doped diffusion region on the front surface of the substrate; and
a back electrode that is coupled to the emitter on the back surface of the substrate.

Ex.1039-771FH, 408-421. In a brief to the Patent Trial and Appeal Board, the applicant argued that the cited prior art “discloses a manufacturing method for a [back surface field (BSF)] type solar cell,” and “[a]s is well known, a BSF layer is a backside layer that has the same polarity as the substrate.” Ex.1039-771FH, 416. The applicant emphasized that “a BSF layer cannot form a backside junction with the substrate because it has the same polarity as the substrate.” Ex.1039-771FH, 416. Thus, the applicant of the ’053 patent represented to the Patent Office during prosecution of the ’771 Application that an emitter is the layer that is oppositely doped from the substrate. *See also* Ex.1039-771FH, 262-268 (applicant response arguing that an emitter is the layer that is oppositely doped from the substrate), 279-282 (applicant pre-appeal brief arguing the same), 312-317 (applicant pre-appeal brief arguing the same), 387-392 (applicant’s response arguing the same).

IX. CLAIM CONSTRUCTION

102. I was informed and I understand that I should give claim terms their ordinary and customary meaning as understood by a person of ordinary skill in the

art at the time of the invention. I was informed and I understand that the words used in the patent's claims and the context in which the words are used in the claims are highly relevant to determine a word's meaning. I also understand that the words of a claim are to be interpreted in the context of the entire patent. This includes the patent's claims, its specification, and its figures.

103. I have been further instructed that a patent's prosecution history (also called the file history) may provide helpful evidence about how the U.S. Patent and Trademark Office and the applicant understood the patent and its claims. Therefore, I have been instructed that claims should also be interpreted with the patent's prosecution history in mind.

104. I have also been instructed that "extrinsic evidence" (such as pertinent scientific or technical references or dictionaries) may also help inform how a person of ordinary skill in the art would have understood a claim term. I have been instructed that extrinsic evidence must always be considered with intrinsic evidence.

105. I have applied these instructions in this declaration. I give the claim terms their plain and ordinary meaning, including as would have been understood by a person of ordinary skill in the art. However, if Patent Owner proposes an express claim construction in this proceeding or in another proceeding involving the patent, I reserve the right to respond to that construction. I also reserve the right to

propose an express construction consistent with the term's plain and ordinary meaning, if one is needed.

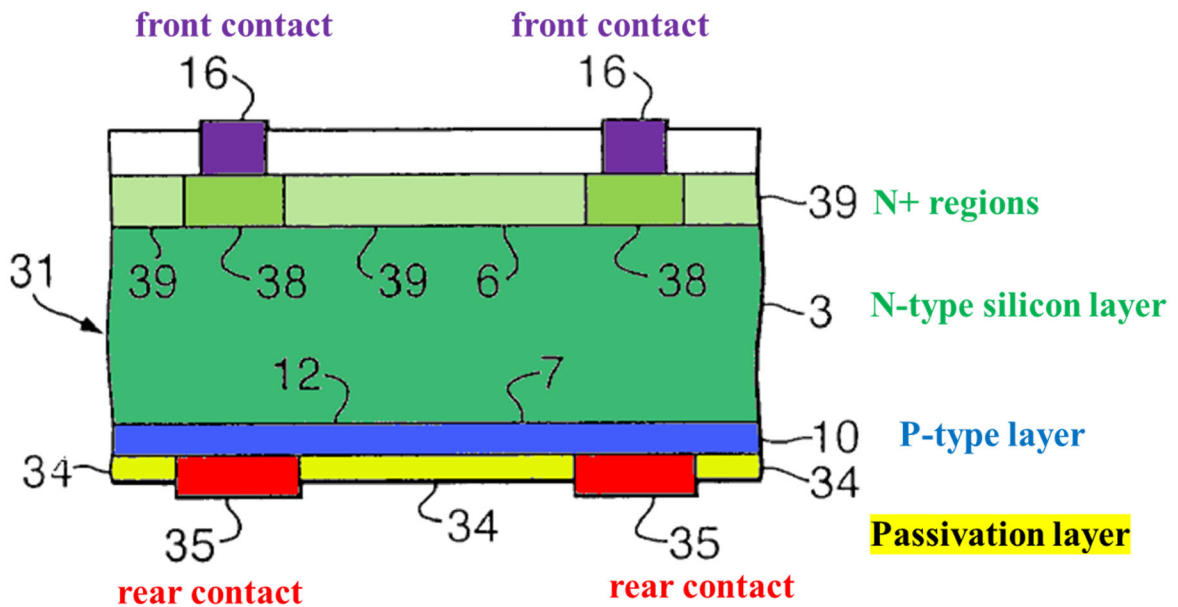
X. OVERVIEW OF THE PRIOR ART

A. Froitzheim

106. I understand that EP 1,732,142A1 to Froitzheim ("Froitzheim," Ex.1004) was published on December 13, 2006, i.e., before the '053 patent's parent was filed on February 20, 2008. Ex.1004-Froitzheim, Cover; Ex.1001-USP053, Cover. Froitzheim teaches manufacturing a rear junction (i.e., back-junction) solar cell. Froitzheim's solar cell (shown below) includes a **silicon body layer 3 (green)** with a front side that faces the sun and a rear side that faces away from the sun. Ex.1004-Froitzheim, [0010]-[0011]. The **silicon body layer** includes **n+ doped regions 38 and 39 (light green)**. Ex.1004-Froitzheim, [0034]. The rear side of Froitzheim's solar cell has a diffused **p-type layer (blue)**. The diffused **p-type layer** forms a PN junction with the substrate's backside, i.e., a back-junction. Ex.1004-Froitzheim, [0010] ("a non-alloyed p-type doped region at the rear side of the body layer and forming a p/n-junction therewith"), [0011].

107. Froitzheim teaches that its solar cell further has a **passivation layer 34 (yellow)** on the back side of the cell. Ex.1004-Froitzheim, [0019]. Froitzheim explains that the **passivation layer 34** "minimize[s] recombination losses" and is an

oxide such as silicon oxide (SiO₂). Ex.1004-Froitzheim, [0019]. As also shown below, Froitzheim's solar cell also includes **front contacts 16 (purple)** that are electrically coupled to the **silicon body layer** (via the **n+ doped region 38**) and **rear contacts 35 (red)** that are electrically coupled to the **p-type layer**. Ex.1004-Froitzheim, [0033].



Ex.1004-Froitzheim, Fig.3,⁴ [0024]-[0032], Fig.1.

⁴ Froitzheim's Figure 1 is similar to its Figure 3, but Figure 3 also contains other layers and contacts as compared to Figure 1. Ex.1004-Froitzheim, [0033]-[0034]. Froitzheim teaches that the top layer in Figure 1 is also a passivation layer. Ex.1004-

108. In addition, Froitzheim describes that “etching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection.” Ex.1004-Froitzheim, [0039]. Froitzheim further explains that an “antireflection coating can be applied using known methods.” Ex.1004-Froitzheim, [0050].

B. Gan

109. I understand that Gan is an article that was published in 1990, i.e., before the '053 patent's parent was filed on February 20, 2008. Ex.1005-Gan, 246; Ex.1001-USP053, Cover. Gan explains that solar “cell performance can be improved if [a] diffused-emitter is replaced with [a] polysilicon emitter....” Ex.1005-Gan, 245. Gan notes that “a very thin oxide (interfacial oxide)” “always exists” between the “polysilicon [emitter] and the substrate.” Ex.1005-Gan, 245. This oxide “can be as a by-product of the cleaning process or is grown intentionally.” Ex.1005-Gan, 245. Gan analyzes and evaluates a solar cell test structure with a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245-246. One polysilicon emitter evaluated by Gan is a p-

Froitzheim, [0030]. As a result, a person of ordinary skill in the art would have understood that the top layer in Figure 3 is a **passivation layer**.

type emitter, and Gan's grown oxide layer has a thickness below 20 Angstroms. Ex.1005-Gan, 245, 246, 249, Figs.4-5.

110. Gan teaches that two important factors for cell efficiency, lower recombination (J_o) and contact resistance (ρ_c), are improved when a solar cell has a polysilicon emitter and also a thin oxide layer between the polysilicon emitter and substrate. Ex.1005-Gan, 245. Gan specifically discusses two metrics: (i) J_o , which is the emitter saturation current density, and (ii) ρ_c , which is the contact resistivity. See Ex.1005-Gan, 249. It was well known that lower J_o indicates less recombination, and lower ρ_c indicates less contact resistance. Lower J_o and ρ_c values therefore provide for a solar cell to have higher efficiency. Ex.1005-Gan, 245; Ex.1043-Kerr, 18-19, 81-84; Ex.1020-Luque, 274-275.

111. Gan determined J_o and ρ_c measurements for the solar cell test structures it was evaluating, and it observed "that the J_o of the p-type polysilicon emitter" with a "thermal oxide layer as the interfacial layer" "appeared to be much lower than [was] previously reported." Ex.1005-Gan, 248. Based on these measurements, Gan also observed that a polysilicon emitter with thin interfacial oxide layer had lower J_o and ρ_c , relative to diffused emitters. Ex.1005-Gan, 249 ("First, most of J_o are below 5×10^{-14} A/cm² which is about one order magnitude lower than that of diffused emitters. Second, most of ρ_c are also lower than 5×10^{-5} Ω -cm²").

112. In view of these observations, Gan concludes that polysilicon emitters with interfacial oxide layers are “quite useful for silicon concentrator solar cells.” Ex.1005-Gan, 249.⁵ Gan further determined “more than one absolute percent of the cell efficiency is obtained for a **backside contact solar cell** with polysilicon emitters with characteristics shown here.” Ex.1005-Gan, 249 (“It is interesting to see how much of the cell efficiency can be improved with polysilicon emitters of characteristics given here.”). By 2008, it was well known that “backside contact” solar cells included PN junctions on the rear side of the cell. *See* Ex.1015-Swanson-485, 1:20-26 (“In a back side contact solar cell, **the p-type and n-type regions are coupled to metal contacts on the back side of the solar cell** to allow an external electrical circuit or device to be coupled to and be powered by the solar cell.”); Ex.1051-Swanson-1986, 85 (“In this [interdigitated back-contact] cell both the n- and p-type diffusions are interleaved **on the back surface** and contacted with two interdigitated comb-shaped metal bus systems.”).

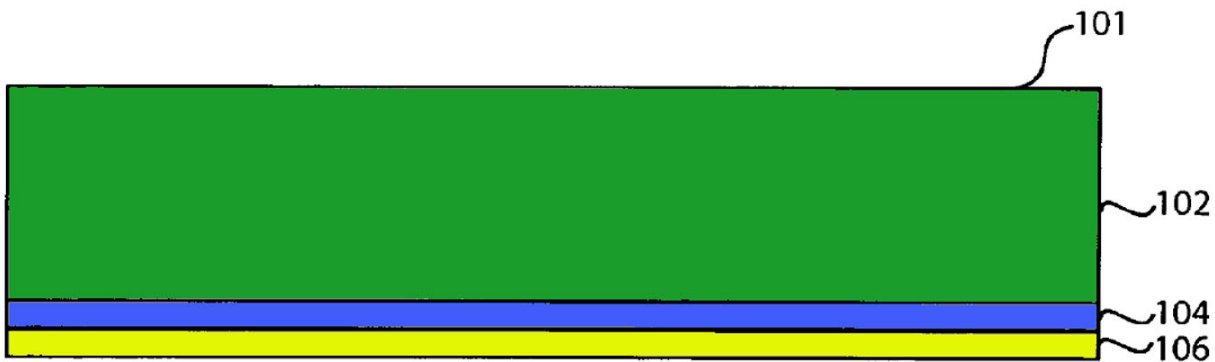
⁵ Concentrator solar cells are a category of solar cells that use lenses, mirrors, etc. to focus (i.e., concentrate) sunlight onto the cell. Ex.1016-Komp, 56-58. Non-concentrator solar cells are solar cells that do not have these features (i.e., sunlight is not focused onto the cell). Ex.1016-Komp, 56-58.

C. Smith

113. I understand U.S. Patent No. 6,998,288 to Smith (“Smith,” Ex.1007), issued on February 14, 2006, i.e., before the ’053 patent’s parent was filed on February 20, 2008. Ex.1007-Smith, Cover; Ex.1001-USP053, Cover. I understand that Smith was cited during prosecution as disclosing several of the routine manufacturing steps recited in the ’053 patent’s claims. *See* Section VIII.B (Overview of the ’053 Patent – Prosecution History). Smith teaches “techniques for simplifying the fabrication of solar cells.” Ex.1007-Smith, 1:36-40 (“Just like in most manufacturing processes, each step employed in the manufacture of solar cells has an associated cost. Thus, techniques for simplifying the fabrication of solar cells are generally desirable.”); *see also* Abstract, Figs.1-7, claims 1-20. In an example that describes manufacturing a back side contact⁶ (i.e., back-contact) solar cell, Smith teaches depositing “**boron-doped silicon dioxide (SiO₂) (‘BSG’) 104**...on the back side of **wafer 102**...using an atmospheric pressure chemical vapor deposition process (APCVD).” Ex.1007-Smith, 2:44-49. APCVD is then used to

⁶ Smith explains, “[i]n a back side contact solar cell, the doped regions are coupled to metal contacts on the back side of the solar cell to allow an external electrical circuit to be coupled to and be powered by the solar cell.” Ex.1007-Smith, 1:29-32.

deposit “**an undoped silicon dioxide 106**” layer. Ex.1007-Smith, 2:53-60. Smith teaches that the combination of APCVD and undoped silicon dioxide are used because it “advantageously allows for one sided deposition.” Ex.1007-Smith, 2:55-60.

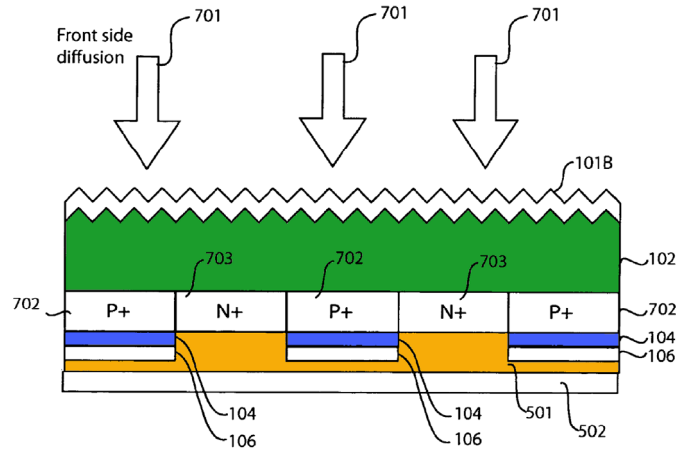


Ex.1007-Smith, Fig.2.

114. Smith also teaches “in-situ [manufacturing] steps,” which “simplif[y] the fabrication process,” to diffuse dopants from their respective layers. Ex.1007-Smith, 3:40-4:2. Smith describes in-situ diffusion as diffusion steps “performed in one loading of wafer [] into the wafer processing tool.” Ex.1007-Smith, 3:40-42.

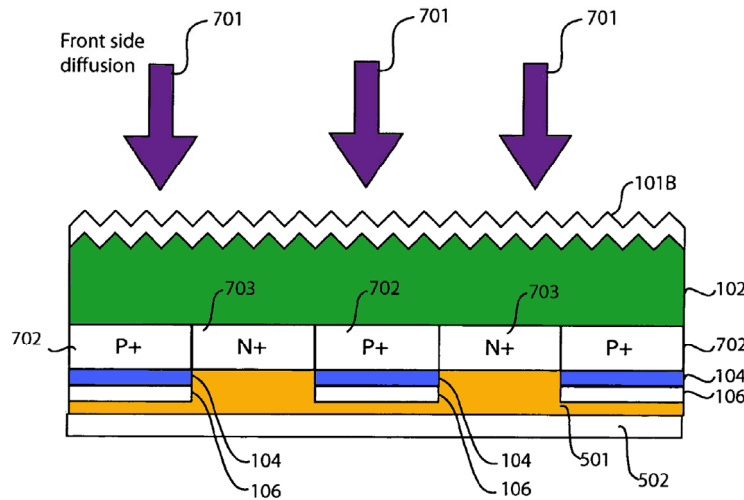
115. For example, Smith describes its in-situ diffusion with two diffusion steps that are performed after a wafer is loaded in a furnace. The “first in-situ step” is to diffuse **p-type dopants 104** and **n-type dopants 501** into the backside (i.e., side away from the sun) of the substrate. Ex.1007-Smith, 3:40-55. Specifically, “**wafer 102** is heated to about 1000° C. for one hour to diffuse dopants from **boron-**

doped silicon dioxide 104 and phosphorus-doped silicon dioxide 501 into wafer 102.” Ex.1007-Smith, 3:43-55. This process is shown in the following modified Smith Figure 7:



Ex.1007-Smith, Fig.7.

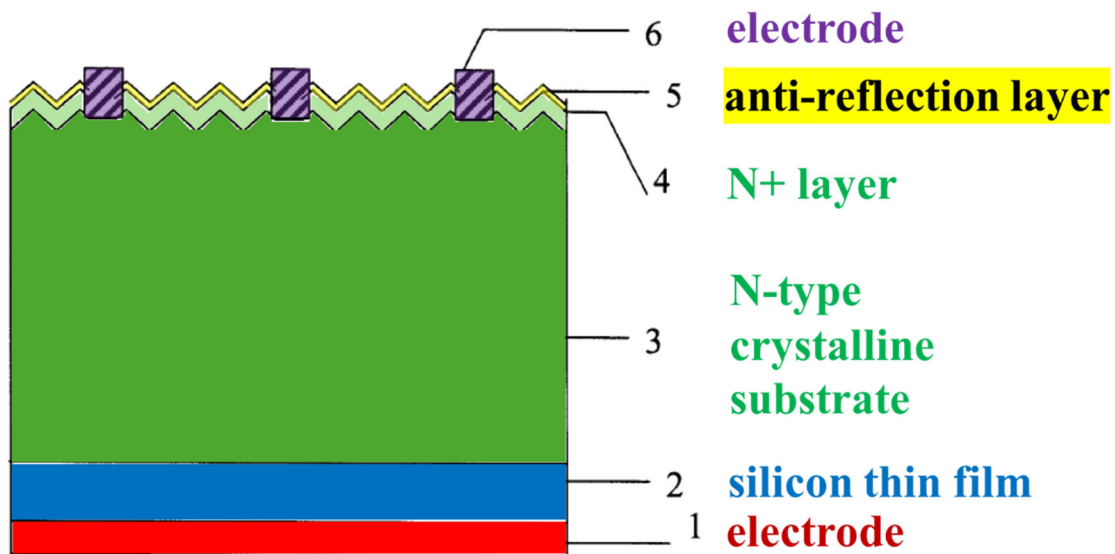
116. The “second in-situ step” is where “the furnace conditions are changed to about 750° C. with an atmosphere containing phosphorus oxychloride, then to about 975° C. with an atmosphere containing oxygen to diffuse phosphorus as an N-type dopant into wafer 102 from its front side.” Ex.1007-Smith, 3:56-67. This is shown in the following modified figure of Smith:



Ex.1007-Smith, Fig.7, claims 1-2, 9, 10, 20. In addition, Smith explains that “persons of ordinary skill in the art” would recognize that its teachings could be applied in different applications. *See, e.g.*, Ex.1007-Smith, 2:7-13 (“In the present disclosure, numerous specific details are provided such as examples of apparatus, process parameters, materials, process steps, and structures to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details.”), 4:11-16 (“While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.”), claim 9 (“A method of fabricating a solar cell...”), claim 17.

D. Li

117. I understand that CN 1949545A to Li (“Li,” Ex.1008)⁷ was published on April 18, 2007, i.e., before the ’053 patent’s parent was filed February 20, 2008. Ex.1008-Li, Cover; Ex.1001-USP053, Cover. Li teaches manufacturing a crystalline silicon solar cell with a thin-film silicon emitting region (i.e., emitter) on its back surface. Ex.1008-Li, 2. Specifically, Li teaches a solar cell (shown below) that includes a back **electrode 1 (red)**; a **silicon thin film 2 (blue)**; an **N-type crystalline silicon substrate 3 (darker green)**; a **highly doped N+ layer 4 (lighter green)**; an **anti-reflection layer 5 (yellow)**; and a **positive electrode 6 (purple)**. Ex.1008-Li, Abstract, 3.



⁷See 1009-Li-Decl. (translator declaration for Li translation).

Ex.1008-Li, Fig.1.⁸

118. Li explains the **silicon thin film 2** (P-type emitter) is prepared by a deposition method. Ex.1008-Li, 3. It can be made of a material such as amorphous silicon, microcrystalline silicon, or nanocrystalline silicon. Ex.1008-Li, 2. The cell also has **anti-reflection layer 5**, which can be a material such as SiN (silicon nitride) or SiO₂ (silicon oxide). Ex.1008-Li, 4. The solar cell implements a **highly doped N+ layer 4**, used “for passivating the front surface of a cell by using changes in doping concentration and for providing good ohmic contact to a front surface electrode.” Ex.1008-Li, 4.

119. Li explains that its solar cell is constructed such that it “avoids light loss caused by the amorphous silicon layer and the transparent conductive thin film on the front surface, such that the cell efficiency can be improved by 10% or above,” compared to “an amorphous silicon/crystalline silicon heterojunction solar [‘HIT’] cell.” Ex.1008-Li, 4. In addition, Li explains that the “improvement of the cell efficiency and simplification of processes can make up for adverse influence caused by increase of material costs” to implement Li’s design. Ex.1008-Li, 3-4.

⁸ Li only includes one figure. *See generally* Ex.1008-Li. For simplicity, I refer to this Figure as “Figure 1.”

XI. GROUNDS FOR FINDING THE CHALLENGED CLAIMS INVALID

120. It is my opinion that the Challenged Claims are unpatentable on the following grounds.

- **Ground I:** Claims 9-12, 14, and 16-20 are invalid as obvious over Froitzheim and Gan.
- **Ground II:** Claims 1-20 are invalid as obvious over Froitzheim, Gan, and Smith
- **Ground III:** Claims 9-20 are invalid as obvious over Li, Gan, and Smith

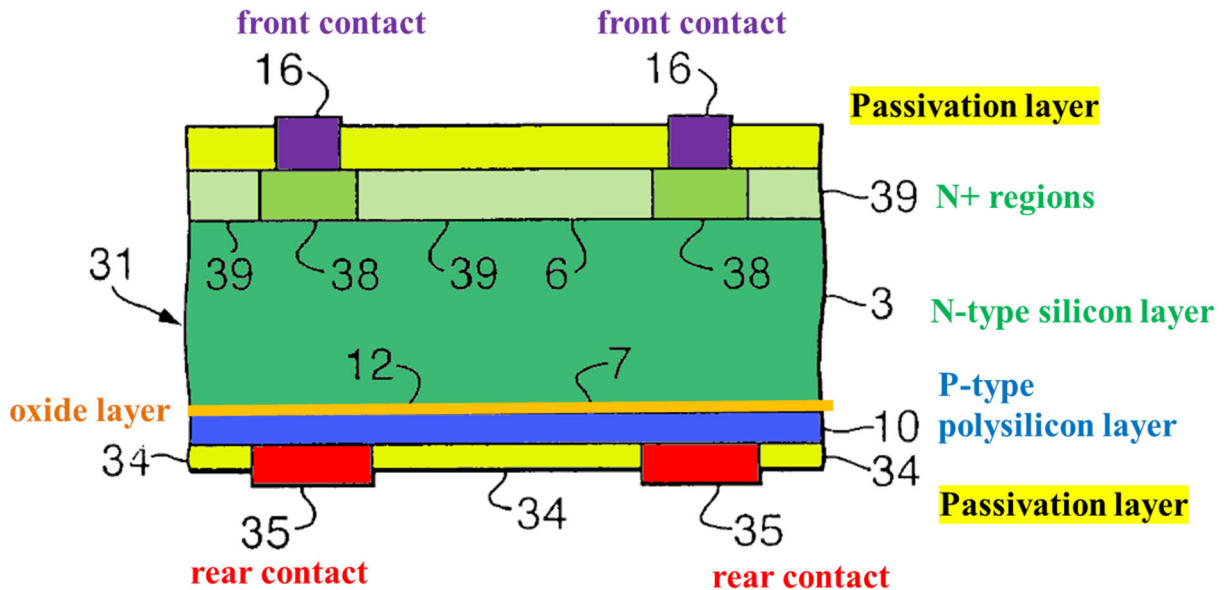
The below discussion demonstrates in detail that claims 1-20 of the '053 patent are unpatentable as obvious. A copy of the Challenged Claims are attached as **Appendix C**.

A. Ground I: Claims 9-12, 14, and 16-20 Are Invalid as Obvious over Froitzheim and Gan

1. Motivation to Combine

121. I understand that for a patent to be obvious in view of multiple references, the references must be analogous to the claims being challenged. *See* Section III (Legal Principles). In addition, I understand that a person of ordinary skill in the art must have been motivated to combine the references with a reasonable expectation of success. *See* Section III (Legal Principles). It is my opinion that each requirement is met for the combination of Froitzheim and Gan.

122. The combination of Froitzheim's manufacturing of a back-junction solar cell and Gan's manufacturing of a polysilicon emitter and oxide layer structure simply amounts to using a known structural feature—polysilicon emitter and oxide layer on a silicon wafer as taught by Gan—to improve a similar apparatus—Froitzheim's back-junction solar cell. The combination of Froitzheim and Gan achieves goals common to both references and the industry—increasing a solar cell's efficiency to thereby increase its power output. The combination of Froitzheim's back-junction solar cell and Gan's polysilicon emitter and oxide layer structure would have also been a simple modification because it would have simply involved implementing Gan's oxide layer and polysilicon emitter on the backside of Froitzheim's n-type silicon layer. The implementation of Gan's oxide layer and polysilicon emitter into Froitzheim's back-junction solar cell is shown in the below figure, which depicts the oxide layer implemented on the backside of Froitzheim's n-type silicon layer and the polysilicon emitter implemented on the backside of the oxide layer to form a PN junction on the backside of the solar cell.



Ex.1004-Froitzheim, Fig.3; Ex.1005-Gan, 245, 249.

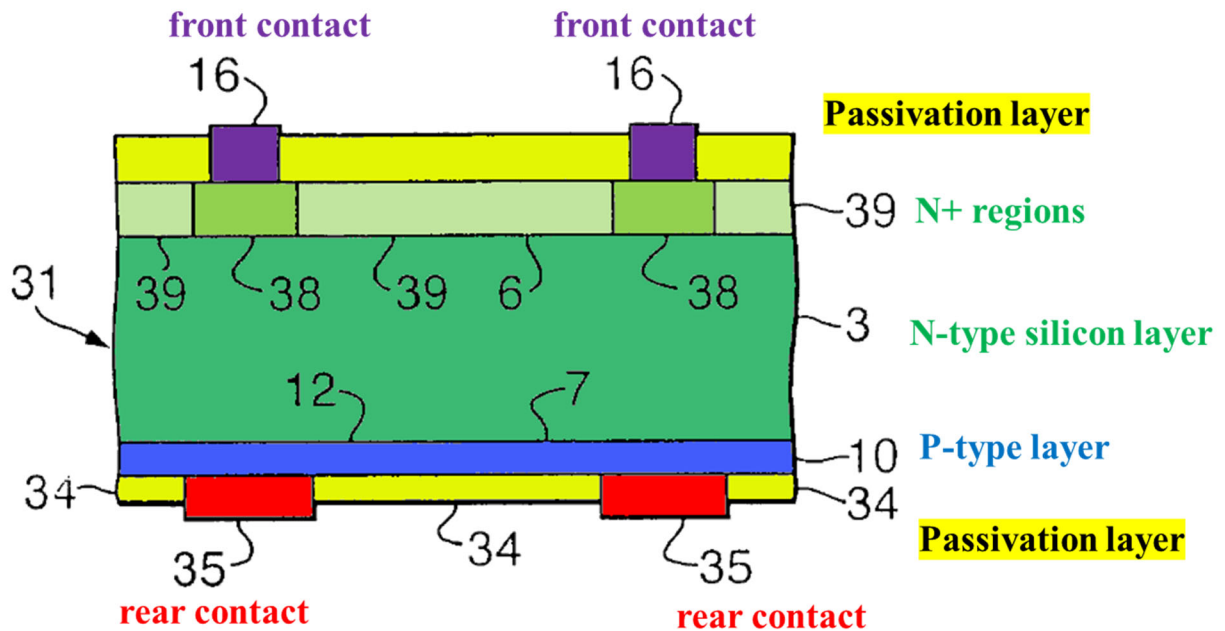
123. **First**, Froitzheim and Gan are in the same field as the Challenged Claims—solar cells. Both references are focused on increasing efficiency, one of the main problems addressed in the Challenged Claims. Both references also offer the same types of solutions for increasing efficiency—optimized solar cell configurations. Ex.1004-Froitzheim, [0001]-[0009] (“It is an object of the present invention to provide a new type of Si solar cell that shows improved stability and good efficiency.”); Ex.1005-Gan, 245-49 (“more than one absolute percent of the cell efficiency is obtained for a backside contact solar cell with polysilicon emitters with characteristics shown here”). Therefore, Froitzheim and Gan are analogous art to the Challenged Claims.

124. **Second**, a person of ordinary skill would have been motivated to implement manufacturing steps to incorporate Gan's oxide layer and polysilicon emitter in Froitzheim's back-junction solar cell to create a more efficient solar cell that would result in greater power output.

125. Froitzheim and Gan each teach manufacturing solar cell structures that are intended to improve a solar cell's efficiency, meaning that they can convert more sunlight to usable energy. Froitzheim teaches manufacturing a solar cell that has multiple features that are directed to improving a cell's efficiency. Froitzheim teaches manufacturing a solar cell that is a rear (back) junction solar cell. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. Specifically, Froitzheim teaches manufacturing a "rear junction solar cell" (i.e., back-junction solar cell) with an **n-type silicon layer** and **p-type emitter**. Ex.1004-Froitzheim, [0022], [0024] ("The solar cell 1 comprises a silicon body layer 3 of n-type bulk doping having a front side 6 and a rear side 7."), [0027] ("At the rear side 7, a p-doped layer 10 is arranged suitably such as discussed further below, and a p/n-junction 12 with the body layer is formed"), [0038]-[0051], Fig.1, Fig.3. The **n-type silicon layer** and **p-type emitter** form a PN junction on the cell's back side, as shown below. Ex.1004-Froitzheim, [0022], [0027]. As I explained in Section VII.A.2 (Overview of Solar Cells – PN Junction), Froitzheim explains that this configuration is advantageous because it

minimizes the amount of light absorbed by the emitter before it reaches the substrate. Ex.1004-Froitzheim, [0013] (“The placement of the p/n-junction at the rear side of the cell has the further advantage that the photocurrent maximised since light cannot be unproductively absorbed in a front-side emitter, in particular in the so-called dead zone of such an emitter.”).

126. Froitzheim’s solar cell also teaches and implements **passivation layers** to minimize recombination at the silicon wafer surfaces. In particular, Froitzheim explains that its solar cell includes **passivation layers** at the front and back sides of its cell. Ex.1004-Froitzheim, [0010]-[0011], [0017]-[0021] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”), [0033] (“Between the fingers a passivation layer 34 is arranged, for which the same type of layers can be used as for the front side.”).



Ex.1004-Froitzheim, Fig.3. After studying this configuration, Froitzheim found it had “improved stability and good efficiency.” Ex.1004-Froitzheim, [0009].

127. Gan similarly focuses on solar cell efficiency, and a person of ordinary skill in the art would have been motivated to improve the efficiency of Froitzheim’s back-junction solar cell by implementing a polysilicon emitter and oxide layer to form the PN junction, as taught by Gan. As detailed below, Gan teaches that replacing a diffused emitter with a polysilicon emitter and an oxide layer placed between the polysilicon emitter and silicon substrate would result in improved performance. Ex.1005-Gan, 245-246.

128. As I explained in Section X.B (Overview of the Prior Art – Gan), Gan studies a solar cell that has a **p-type polysilicon emitter** and an **oxide layer** between

the polysilicon emitter and silicon substrate. Ex.1005-Gan, 245. Gan specifically teaches the emitter saturation current density (J_o) and contact resistance (ρ_c) of this emitter design. As I explained in Section VII.B (Overview of Solar Cell Efficiency), emitter saturation current density (J_o) indicates the amount of recombination that is occurring within the emitter, and lower emitter saturation current density (J_o) indicates lower recombination and the potential for a more efficient solar cell. As I also explained in Section VII.B (Overview of Solar Cell Efficiency), contact resistance (ρ_c) indicates how much power is lost at one or more interfaces between the wafer and metal contacts, and lower contact resistance (ρ_c) indicates less power loss and thus the potential for a more efficient solar cell. Thus, all else being equal, these two metrics are indicative of solar cell efficiency, and as these two metrics decrease, solar cell efficiency increases.

129. The emitter saturation current density (J_o) and contact resistance (ρ_c) for Gan's analyzed solar cell test structures are reported in Figure 6. As shown in Figure 6 below, the contact resistance (ρ_c) is on the vertical axis and the emitter saturation current density (J_o) is on the horizontal axis.

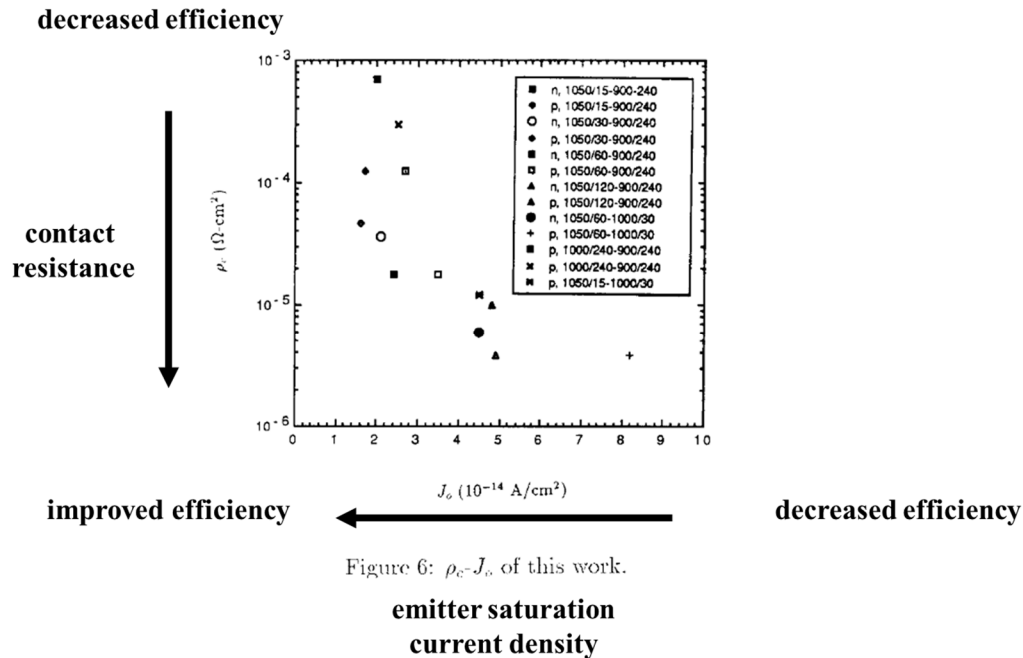


Figure 6: ρ_c - J_o of this work.

Ex.1005-Gan, 245. Gan found that its analyzed **p-type polysilicon emitter** and **oxide layer** structure demonstrated improved performance over prior emitters. Specifically, Gan found “that the J_o of the p-type polysilicon emitter” with a “thermal oxide layer as the interfacial layer” was “much lower than [was] previously reported.” Ex.1005-Gan, 248. Gan noted that this combination—**polysilicon emitter** and **oxide layer** on the wafer surface—had less recombination and lower contact resistance as compared to that of diffused emitters. Ex.1005-Gan, 249 (“[M]ost of J_o [in Figure 6] are...about one order magnitude lower than that of diffused emitters [and] most of ρ_c [in Figure 6] are also lower”). Based on this data, Gan concludes that a polysilicon emitter and oxide layer structure is “quite useful for silicon solar cells,” and teaches that “cell performance can be improved if the

diffused-emitter is replaced with the polysilicon emitter.” Ex.1005-Gan, 245, 249 (“To conclude, we showed that polysilicon emitters with low [emitter saturation current density (J_o) and contact resistance (ρ_c)] can be obtained with a very small fraction of interfacial oxide breakup.”).

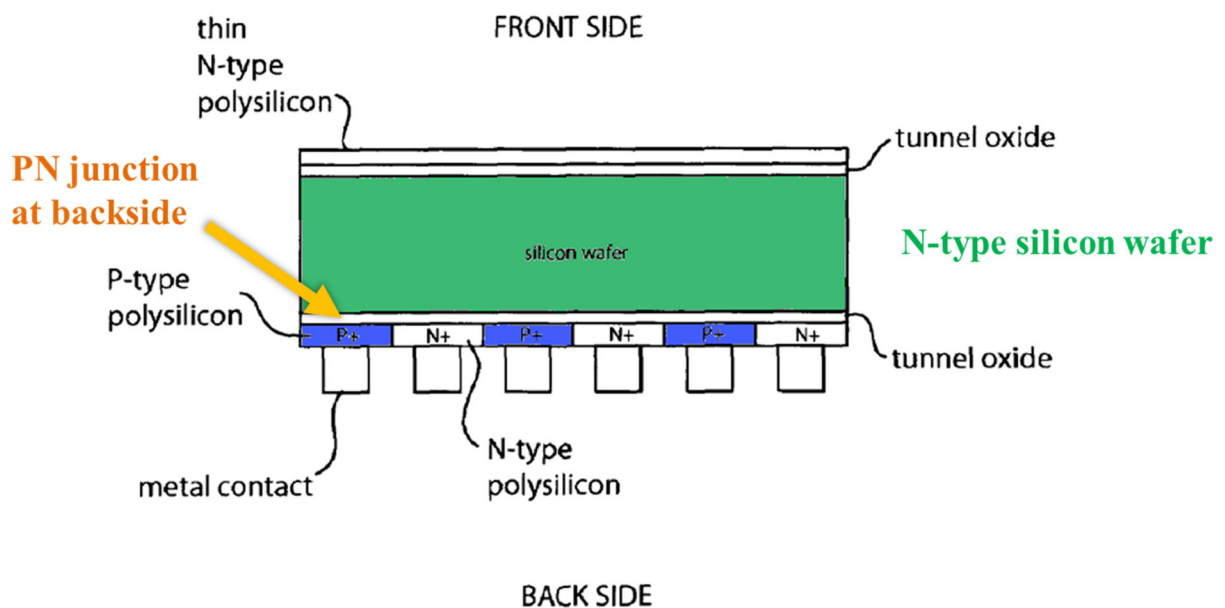
130. A person of ordinary skill in the art would have been motivated to apply Gan’s teachings to Froitzheim’s solar cell to improve the efficiency of Froitzheim’s solar cell. A person of ordinary skill in the art would have understood that Gan’s teachings are directly applicable to Froitzheim. As discussed above, Froitzheim teaches a diffused emitter, and Gan specifically teaches replacing a diffused emitter with a polysilicon emitter and oxide layer structure to improve the efficiency of a solar cell. *See* Ex.1005-Gan, 245, 249. Significantly, Gan explains that its overall structure is beneficial to p-type emitters and silicon substrates, and Froitzheim teaches a p-type emitter and a silicon substrate. *E.g.*, Ex.1004-Froitzheim, [0010]-[0011]. Thus, a person of ordinary skill in the art would have understood that Froitzheim’s solar cell would obtain Gan’s benefits by implementing Gan’s disclosed structure.

131. Moreover, although Gan references a concentrator solar cell—a category of solar cells that uses lenses, mirrors, and other components to focus (i.e., concentrate) sunlight on a cell (Ex.1016-Komp, 56-58)—a person of ordinary skill

in the art would have understood that Gan's teachings are equally applicable to non-concentrator solar cells. Importantly, Gan explains that its disclosed polysilicon emitter and oxide layer structure is "useful for silicon solar cells" generally and does not state that its teachings are limited to concentrator solar cells. Ex.1005-Gan, 249. As a result, a person of ordinary skill in the art would have understood that Gan's teachings are equally relevant for non-concentrator cells, even if Froitzheim does not expressly teach light concentration structures (such as a lens) for use with its solar cell. Persons of ordinary skill in the art frequently looked at various solar cell designs and related technologies when evaluating how to improve a solar cell's efficiency, which is exactly what Gan did when evaluating how to improve a cell's design. *E.g.*, Ex.1005-Gan (explaining that "[p]olysilicon emitters, because of their important applications in high speed bipolar transistors, have been widely studied" and applying those learnings to solar cells).

132. Additionally, Gan teaches that its structure is useful for solar cells manufactured to have PN junctions on the backside of the solar cell, as in Froitzheim. Gan specifically estimates that this structure on "backside contact solar cells" would achieve an improvement of "more than one absolute percent of the cell efficiency." Ex.1005-Gan, 249. As I explained in Section X.B (Overview of the Prior Art – Gan), it was well known prior to 2008 that "backside contact" solar cells (i.e., solar cells

with the metal contacts just on the backside) included PN junctions on the back side of the cell—they are a type of back-junction solar cells. For example, Swanson-458 (patent filed in 2005) explained that “[i]n a back side contact solar cell, **the p-type and n-type regions are coupled to metal contacts on the back side of the solar cell** to allow an external electrical circuit or device to be coupled to and be powered by the solar cell.” Ex.1015-Swanson-485, 1:20-26. This is shown in Figure 1 of Swanson (below), where the PN junction is on the rear side of the cell.



Ex.1015-Swanson, Fig.1. As a result, a person of ordinary skill in the art would have understood that Gan’s teachings were applicable to Froitzheim because Gan’s teachings were directly applicable to solar cells manufactured with PN junctions on the back side of the cell. In other words, a person of ordinary skill in the art would have understood that implementing a polysilicon emitter and oxide layer, as taught

by Gan, in Froitzheim's back-junction solar cell was merely applying a known technique (Gan) to a similar device (Froitzheim) that is ready for improvement to yield predictable results (a more efficient solar cell) and was a predictable variation of the prior art.

133. A person of ordinary skill in the art would have also been motivated to implement a polysilicon emitter, as taught by Gan, on the back side of Froitzheim's solar cell. For example, Froitzheim specifically teaches that a backside emitter is beneficial. As I explained in VII.A.2 (Overview of Solar Cells – PN Junction), absorption within a heavily doped region—such as an emitter—reduces the amount of electricity generated by a solar cell. Froitzheim explains that a backside emitter is beneficial because it optimally reduces the amount of sunlight that could be parasitically absorbed by the emitter since light is instead absorbed by the wafer before reaching the emitter at its backside. Ex.1004-Froitzheim, [0013] (“The placement of the p/n-junction at the rear side of the cell has the further advantage that the photocurrent maximised since light cannot be unproductively absorbed in a front-side emitter, in particular in the so-called dead zone of such an emitter. This maximises in particular the contribution of short wavelength light to the photocurrent, because such light is predominantly absorbed close to the front side, whereas longer wavelength light penetrates deeper into the cell.”).

134. Significantly, it was known that if a polysilicon emitter is placed on the front side of the cell, the polysilicon emitter would absorb light that otherwise would have gone to the active region of the solar cell (i.e., the region where usable electron-hole pairs are generated), thereby decreasing the amount of electricity that could be produced by the cell. *See* Section VII.A.2 (Overview of Solar Cells – PN Junction); Ex.1062-Farrokh-Baroughi, 5-6; Ex.1059-Lubberts, 6877. As a result, a person of ordinary skill in the art would have understood implementing Gan's polysilicon emitter in Froitzheim's back-junction solar cell would improve the efficiency of the cell (as taught by Gan) while also accounting for the potential drawbacks of polysilicon emitters (parasitic absorption). In other words, implementing a polysilicon emitter in Froitzheim's back-junction solar cell would improve the cell's efficiency and ensure sunlight would not be absorbed by the polysilicon emitter before reaching the active region (i.e., wafer).

135. A person of ordinary skill in the art would have also been motivated to modify Froitzheim's back-junction solar cell to incorporate a polysilicon emitter and oxide layer structure, as taught by Gan, because each reference teaches similar and compatible solar cell structures. Froitzheim and Gan each teach solar cells manufactured to have the same basic configuration of a silicon wafer substrate, p-type emitter, and metal contacts. Ex.1004-Froitzheim, Abstract, [0010]-[0013],

Fig.1, Fig.3; Ex.1005-Gan, 245-249. Froitzheim and Gan also teach solar cell structures that are made with similar manufacturing processes. In particular, each teach common manufacturing processes, such as diffusion from a dopant source to form the emitter, including overlapping temperature ranges for said diffusion. Ex.1004-Froitzheim, [0042] (teaching a temperature range between 900-1200 °C); Ex.1005-Gan, 246 (teaching a temperature range between 900-1000°C). Thus, a person of ordinary skill in the art would have understood that Froitzheim's solar cell and Gan's solar cell have compatible manufacturing processes, especially because new equipment—e.g., a furnace for diffusion—would have been unnecessary.

136. A person of ordinary skill in the art would have known how to add oxide layers to silicon surfaces, as doing so was well-known and routine by 2008. *E.g.*, Ex.1005-Gan, 246; Ex.1006-Borden-575, [0026]; Ex.1004-Froitzheim, [0030]; Ex.1015-Swanson, 1:50-2:61; *see also* Section VII.B (Overview of Solar Cell Efficiency). A person of ordinary skill in the art would have also readily understood how to manufacture a polysilicon emitter. Manufacturing polysilicon emitters was well-known and routine by 2008. Ex.1050-Tarr, 655 (“It has been known for over a decade that polysilicon emitter contacts can reduce the back-injection current and thereby improve the performance of bipolar transistors[. It is, therefore, somewhat surprising that[, as of 1985,] consideration has only recently been given to the use

of polysilicon contacts in the production of high-efficiency solar cells.”). Moreover, the ’053 patent itself assumes (correctly) that a person of ordinary skill in the art would have understood how to manufacture solar cell layers. The ’053 patent generically describes manufacturing an oxide layer and doped polysilicon layer but does not provide specific implementation details. *See generally* Ex.1001-USP053. Thus, a person of ordinary skill in the art would have been motivated to modify Froitzheim to include a polysilicon emitter and oxide layer because doing so would simply involve substituting one known element (diffused emitter) for another (polysilicon emitter and oxide layer) to obtain predictable results (a more efficient solar cell).

137. Also, a person of ordinary skill in that art would have understood that adding Gan’s configuration to Froitzheim’s solar cell was a simple design choice. Because efficiency is an important design consideration, a person of ordinary skill in the art would have been motivated to seek a more efficient solar cell even if doing so resulted in additional manufacturing steps or components. In fact, as I explained in Section VII.B (Overview of Solar Cell Efficiency), over the past 50 years, solar cell designers have continued to prioritize gains in efficiency when evaluating potential designs. Thus, even if implementing Gan’s configuration to Froitzheim’s solar cell resulted in additional costs due to manufacturing steps or components, a

person of ordinary skill in that art would have nevertheless been motivated to make such a design change to achieve a more efficient solar cell.

138. Finally, a person of ordinary skill in the art would have been aware of the plethora of teachings explaining the use and benefits of polysilicon emitters, including with interfacial oxide layers and including for solar cells and transistors. Section VII.B (Overview of Solar Cell Efficiency). For example, Foglietti disclosed forming an interfacial oxide between a substrate and polysilicon emitter. Ex.1042-Foglietti, [0046] (“the wafer has the single crystal substrate 250 and an interfacial oxide 260 formed thereon in accordance with the present invention and a polysilicon layer 262 lies thereover”). Also, I understand that during prosecution of the ’771 Application, which claims priority to the ’516 patent, the Board affirmed that Foglietti teaches an interfacial oxide and that “it would have been obvious to one of ordinary skill in the art to modify the interface between the doped polysilicon regions and the monocrystalline substrate by adding an interfacial oxide as disclosed by Foglietti and Gan to allow for optimal growth of the polysilicon region and result in recombination occurring primarily at the oxide interface.” Ex.1039-FH771, 462-463. Thus, the Board affirmed that Foglietti teaches an interfacial oxide between a substrate and polysilicon emitter and that a person of ordinary skill in the art would be motivated to implement these features in a solar cell.

139. Borden-575 is another example of a reference that teaches an interfacial oxide between a polysilicon emitter and silicon substrate without inhibiting current flow. Ex.1006-Borden-575, [0022] (“This oxide – typically 8 to 15 Å thick – provides passivation between the substrate and the polysilicon, while allowing for tunnel current flow”). Other publications such as Kwark and Yablonovitch also contain similar teachings. Ex.1046-Kwark, 1125 (“poly-silicon contacts and SIPOS contacts...both obtain their improved performance through incorporating a thin, tunnelable interfacial oxide that impedes the flow of holes”); Ex.1023-Yablonovitch, 3:61-64 (“The interface 18 between the silicon ribbon 14 and the n⁺-SIPOS heterocontact contains a 20-40 Å interfacial layer of silicon dioxide which is so thin as to be permeable to electrons”).

140. It was also well-known in transistor art to use an interfacial oxide between a polysilicon emitter and substrate. For example, Rahim taught that a “well controlled interfacial oxide [] gives low values of emitter resistance” and there was “a considerable amount of work...published in the literature on the effects of the interfacial oxide on the base current [] and emitter resistance [] of polysilicon emitter contacts.” Ex.1034-Rahim, 2506. Gan also explains that polysilicon emitters and oxide layers were previously implemented on transistors and such improvements were applicable to solar cells. Ex.1005-Gan, 245 (“Polysilicon emitters, because of

their important applications in high speed bipolar transistors, have been widely studied. It was [previously] found that...[an interfacial oxide] can be...grown intentionally[.]”). The underlying physics for transistors and solar cells are similar (both rely on current flow at PN junctions), and therefore persons of skill in the art developing new solar cells often looked to teachings from transistors and often had success porting over transistor technology into solar cells. Ex.1023-Yablonvitch, 1:27-44, 2:10-12 (teaching implementing a material known for transistors into a solar cell). A person of ordinary skill in the art would have thus been motivated to combine Froitzheim and Gan because the combination would have merely involved the use of known techniques (polysilicon emitter and oxide layer) to improve similar devices (solar cells) in the same way (applying the learnings from transistors to solar cells).

141. Accordingly, a person of ordinary skill in the art would have been motivated to replace Froitzheim’s diffused emitter with Gan’s polysilicon emitter and oxide layer.

142. **Third**, a person of ordinary skill in the art would have had a reasonable expectation of success in implementing Gan’s polysilicon emitter and oxide layer in Froitzheim’s back-junction solar cell. Including a polysilicon emitter and oxide layer was well known in the art, and Gan specifically describes steps for

implementing a polysilicon emitter and oxide layer on a silicon substrate. Ex.1005-Gan, 246; Ex.1006-Borden-575, [0022]; Ex.1046-Kwark, Abstract, 1121. Therefore, a person of ordinary skill in the art would have known that modifying Froitzheim's manufacturing processes to incorporate Gan's processes for forming a polysilicon emitter and oxide layer was simply substituting one known structural feature (i.e., Gan's polysilicon emitter and oxide layer) for another structural feature (i.e., Froitzheim's diffused emitter) to obtain the predictable result of a more efficient solar cell.

143. Furthermore, as I discussed above, a person of ordinary skill in the art would have appreciated that the references have compatible structures and manufacturing steps. For example, each reference teaches thermal diffusion processes to drive dopants into the emitter, and they disclose overlapping temperature ranges. Ex.1004-Froitzheim, [0042]; Ex.1005-Gan, 246. Thus, as I explained above, a person of ordinary skill in the art would have understood that Froitzheim's solar cell and Gan's solar cell have compatible manufacturing processes, especially because new equipment—e.g., a furnace for diffusion—would not be needed. That is, a person of ordinary skill in the art would have had a reasonable expectation of success at implementing an oxide layer and polysilicon

emitter in Froitzheim, as taught by Gan, because doing so would be a simple substitution of one element for another.

144. As I also discussed above, a person of ordinary skill in the art would also have easily been able to replace a diffused emitter with a polysilicon emitter and oxide layer. Manufacturing techniques for solar cells were well-known by 2008, including manufacturing polysilicon emitters and oxide layers. *E.g.*, Ex.1005-Gan (polysilicon emitter, oxide layer); Ex.1006-Borden-575 (polysilicon emitter, oxide layer); Ex.1046-Kwark (polysilicon emitter, oxide layer); Ex.1023-Yablonovitch (oxide layer); Ex.1031-Okayasu (polysilicon emitter); Ex.1050-Tarr (polysilicon emitter). In fact, the '053 patent itself assumes (correctly) that a person of ordinary skill in the art would have understood how to manufacture a solar cell. The '053 patent generically describes manufacturing an oxide layer and doped polysilicon layer but does not provide specific implementation details. *See generally* Ex.1001-USP053. Thus, a person of ordinary skill in the art would have readily understood that replacing Froitzheim's back side emitter, which Froitzheim teaches is made by diffusing boron into the back side of the substrate, with Gan's deposited polysilicon emitter would easily be accomplished, especially since Gan teaches the well-known manufacturing steps to do so. *See* Ex.1005-Gan, 246 (describing manufacturing steps). In other words, a person of ordinary skill in the art would have understood

that replacing Froitzheim's back side emitter with Gan's polysilicon emitter and oxide layer would have simply involved using Gan's known technique of a polysilicon emitter and oxide layer with Froitzheim's known solar cell to improve Froitzheim's solar cell in a similar way.

145. Finally, as discussed, a person of ordinary skill in the art would have reasonably expected success because tunnel oxide layers and polysilicon emitters had been successfully implemented in multiple instances, including for transistors and solar cells. Ex.1005-Gan, 246; Ex.1006-Borden-575, [0022]; Ex.1046-Kwark, Abstract, 1121. As a result, a person of ordinary skill in the art would have expected that Gan's known technique of a polysilicon emitter and oxide layer was a known, successful technique for solar cells and transistors, and would expect that this known technique would be successful when applied to Froitzheim's back-junction solar cell. Accordingly, it is my opinion that a person of ordinary skill in the art would have been motivated to modify Froitzheim's manufacturing of a back-junction solar cell to implement the manufacturing of a polysilicon emitter and oxide layer, as taught by Gan, with a reasonable expectation of success.

2. Claim 9

a. Element 9[pre]: A method of fabricating a solar cell.

146. Froitzheim teaches *a method of fabricating a solar cell*.⁹ Ex.1004-Froitzheim, Title, Abstract, [0022], [0024], [0038] (“The method of manufacturing a solar cell according to the invention will now be discussed.”), [0039]-[0051], Fig.1, Fig.3, claims 1-11.

147. In addition, Gan teaches *a method of fabricating a structure for a solar cell*. In particular, Gan teaches a twelve-step “process sequence” for *fabricating a structure for a solar cell*

1. Field oxidation (2000 Å)*.
2. Polysilicon-substrate contact opening*.
3. Thin thermal oxide growth at 800 °C*. (10-minute oxygen flow)
4. Polysilicon deposition (6000 Å) and first-step anneal (1050 °C)*.
5. First-step anneal *.
6. Polysilicon finger definition.
7. Undoped glass deposition (2000 Å).
8. Metal-polysilicon and metal-substrate contact opening.
9. Doped glass deposition on both sides of the wafer*.
10. Drive-in; 900-1000 °C*.
11. Doped glass stripping and Al-1% Si alloy deposition.
12. Metal finger definition.

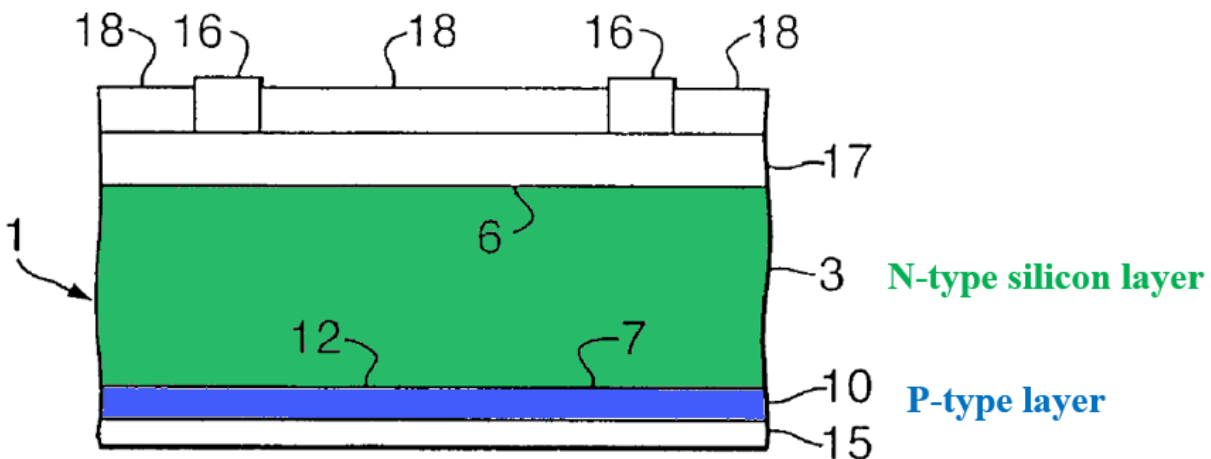
Ex.1005-Gan, 246, 245-249.

⁹ Italicized text is used to indicate claim language unless otherwise noted.

b. Element 9[a]: forming a layer of polysilicon over a back surface of a silicon substrate.

148. The combination of Froitzheim and Gan teaches *forming a layer of polysilicon over a back surface of a silicon substrate.*

149. Froitzheim teaches manufacturing “a rear junction solar cell” “by arranging [i.e., *forming*] a non-alloyed **p-type doped region** at the rear side [i.e., on a *back surface*] of an **n-type Silicon body layer** [i.e., *silicon substrate*].” Ex.1004-Froitzheim, [0011], [0038]-[0048]. A person of ordinary skill in the art would have understood that the **p-type doped region** is an emitter, which is what the “*layer of polysilicon*” is in claim 9. This is because the **p-type doped region** is oppositely doped from the **n-type silicon layer**, forming “a p/n-junction.” Ex.1004-Froitzheim, Abstract, [0024]-[0026], claim 1. This is shown in Figures 1 and 3 of Froitzheim:



Ex.1004-Froitzheim, Fig.1.

150. Gan teaches *forming a layer of polysilicon over a surface of a silicon substrate* because it teaches a “[p]olysilicon deposition” step on a *silicon* wafer. Ex.1005-Gan, 246 (step four). Gan specifically teaches depositing a layer of polysilicon over a silicon wafer, and the polysilicon layer becomes a **P-type polysilicon emitter** after the polysilicon layer is doped with boron. Ex.1005-Gan, 245-246.

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performance benefits, as I described in Section X.B (Overview of the Prior Art – Gan). Ex.1005-Gan, 245 (discussing and analyzing “both n- and **p-type polysilicon emitters**” and explaining that “cell performance can be improved if **the diffused-emitter is replaced with the polysilicon emitter**”).

152. As also discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s solar cell to implement Gan’s **P-type polysilicon emitter** and would have had a reasonable expectation of success in doing so. In particular, a person of ordinary skill in the art would have been motivated to follow Gan’s manufacturing steps to implement the polysilicon emitter in Froitzheim, which would involve depositing the layer of polysilicon over the backside of Froitzheim’s **n-type silicon layer** (i.e., *silicon substrate*). Accordingly, the combination of Froitzheim and Gan teaches *forming a layer of polysilicon over a back surface of a silicon substrate*.

c. Element 9[b]: forming a first dopant source layer over the layer of polysilicon.

153. The combination of Froitzheim and Gan teaches *forming a first dopant source layer over the layer of polysilicon*.

154. Froitzheim teaches that “a diffusion source layer that contains boron as a dopant is applied, e.g., spun, only onto the back of the **n-doped silicon wafer**.” Ex.1004-Froitzheim, [0040]-[0041], Fig.3. Froitzheim explains that the boron

doping process is further described in the incorporated reference U.S. Patent No. 5,899,704 to Schlosser. Ex.1004-Froitzheim, [0040]; Ex.1053-Schlosser, 2:17-23 (applying “a diffusion source layer that contains boron as a dopant” and “driv[ing] in the dopant”). Also, as I explained in VII.A.1 (Technology Background – Doping), a person of ordinary skill in the art would have understood that Froitzheim is referring to a common “spin-on glass” (SOG) technique that forms a borosilicate glass layer (BSG), which is *a first dopant source layer*. E.g., Ex.1054-Gee, 16:63-17:28 (explaining use of spin-on glasses such as PSG and BSG as dopant sources). Thus, Froitzheim teaches *forming a first dopant source layer*. This process is used to create the **p-doped layer** (i.e., diffused **emitter**). Ex.1004-Froitzheim, [0022].

155. Gan teaches *forming a dopant source layer over the layer of polysilicon*. For instance, in step 4 of its twelve-step “process sequence,” Gan deposits a “[p]olysilicon” layer on the substrate, and in step 9, deposits “[d]oped glass” on “both sides of the wafer,” thus “*over*” the deposited polysilicon. Ex.1005-Gan, 246, 248. The doped glass contains p-type dopants to create a “p-type polysilicon emitter” in step 10. Ex.1005-Gan, 246, 248.

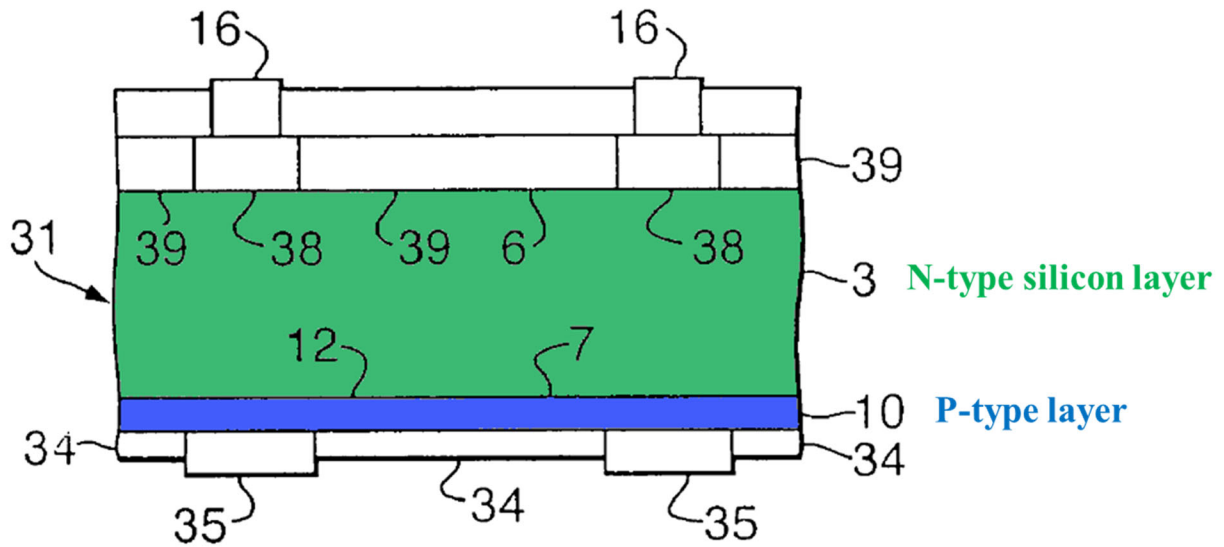
156. As discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s methods to implement Gan’s **P-type polysilicon emitter** and also would have had a

reasonable expectation of success in doing so. In particular, a person of ordinary skill in the art would have been motivated to follow Gan's manufacturing steps to implement the polysilicon emitter in Froitzheim, which would involve depositing the layer of polysilicon over the backside of Froitzheim's **n-type silicon layer** and *forming a dopant source layer over the layer of polysilicon* to dope the polysilicon layer such that the polysilicon layer becomes a **P-type polysilicon emitter**. Thus, the combination of Froitzheim and Gan teaches *forming a first dopant source layer over the layer of polysilicon*.

d. Element 9[c]: diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate.

157. The combination of Froitzheim and Gan teaches *diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate*.

158. Froitzheim teaches manufacturing a "rear junction" solar cell, which entails *forming a backside junction with the silicon substrate*. Specifically, Froitzheim teaches forming a "**p-doped layer 10**" on the rear side (backside) of the **n-type silicon layer 3**, which forms "a p/n-junction" with the n-type silicon substrate. Ex.1004-Froitzheim, [0025]; *see also* Abstract, [0010]-[0013], [0024], Fig.1, Fig.3.



Ex.1004-Froitzheim, Fig.3; *see also* Ex.1004-Froitzheim, Fig.1, [0033].

159. A person of ordinary skill in the art would have known the **p-type doped region** to be the emitter because it is oppositely doped from the **n-type silicon layer** and thus forms “a p/n-junction.” Ex.1004-Froitzheim, Abstract, [0024]-[0026], claim 1. The '053 patent explains that a “backside junction” exists because an emitter oppositely doped from the substrate is located on the backside of the solar cell. Ex.1001-USP053, 1:53-55. Thus, because Froitzheim teaches forming a **P-type layer** on the back or rear side of an **n-type silicon layer** to create a rear “p/n” junction, Froitzheim teaches *forming a backside junction with the silicon substrate*.

160. To make this “rear junction solar cell” configuration, Froitzheim teaches *diffusing dopants from a first dopant source layer* into the back of the **n-doped silicon wafer (substrate)**. Froitzheim teaches, for example, that after

depositing the “diffusion source layer,” “the wafer is treated in an atmosphere that contains oxygen at a temperature of 900 to 1200 degree centigrade, preferably between 1000 and 1100 degree C, to generate an oxide layer **and to drive in the dopant.**” Ex.1004-Froitzheim, [0041]-[0042]. A person of ordinary skill in the art would have known “drive in the dopant” meant diffusing the dopants from the *dopant source layer* into the substrate, in this case, forming a diffused emitter. *E.g.*, Ex.1053-Schlosser, 2:17-23 (applying “a diffusion source layer that contains boron as a dopant” and “driv[ing] in the dopant”).

161. Gan teaches driving-in dopants from *a first dopant source layer to the layer of polysilicon*. Specifically, Gan teaches that after the doped glass is deposited on the polysilicon layer, dopants from the doped glass are “[d]rive[n]-in [at] 900-1000 °C,” to the target layer, which is the *polysilicon* layer in Gan. Ex.1005-Gan, 246. A person of ordinary skill in the art would have known “driv[ing]-in” means diffusing dopants from the doped glass into the layer of polysilicon, as this was common usage. Ex.1005-Gan, 246.

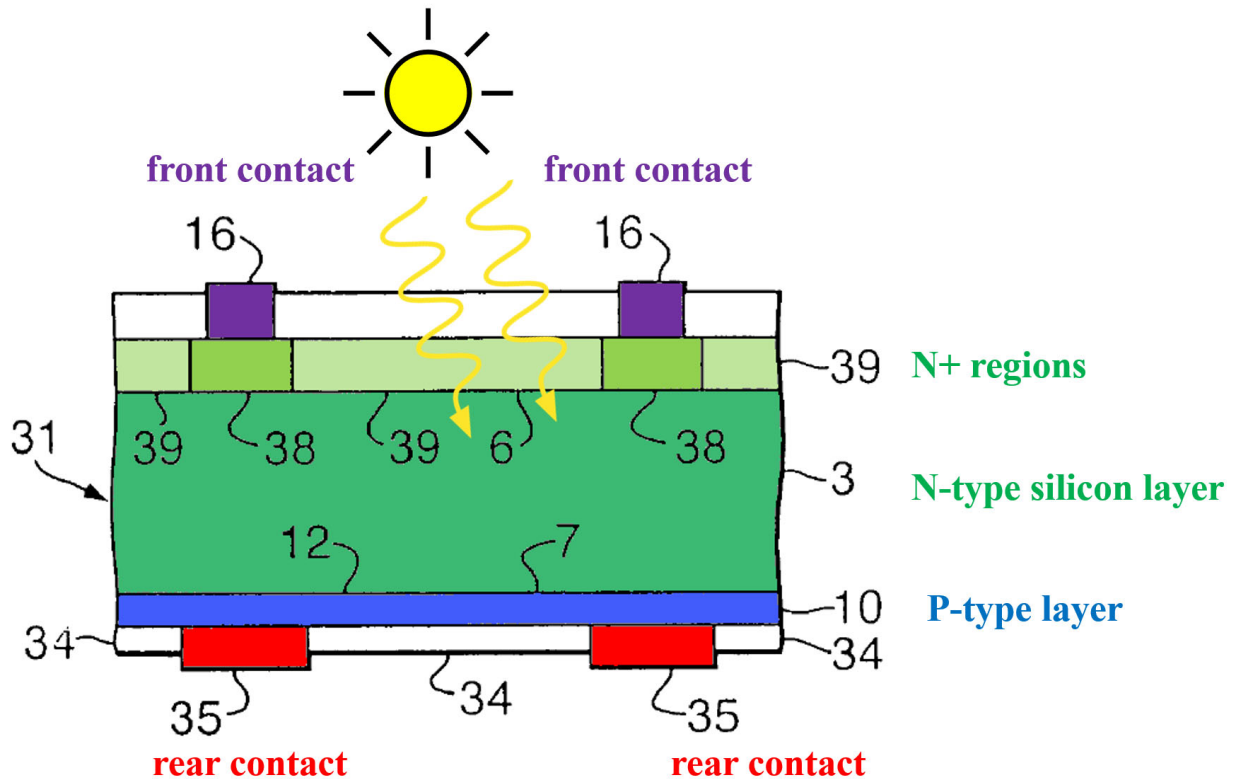
162. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s methods to implement Gan’s **P-type polysilicon emitter** and also would have had a reasonable expectation of success in doing so. In particular, a person of ordinary

skill in the art would have been motivated to follow Gan's manufacturing steps to implement the polysilicon emitter in Froitzheim, which would involve depositing the layer of polysilicon over the backside of Froitzheim's **n-type silicon layer**, forming a dopant source layer over the layer of polysilicon, and then *diffusing dopants from the first dopant source layer to the layer of polysilicon* to form a **P-type polysilicon emitter** which would thus *form a backside junction with the silicon substrate*.

- e. **Element 9[d]: diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.**

163. Froitzheim teaches *diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation*.

164. Froitzheim teaches the fabrication of a solar cell that has front and rear sides. Ex.1004-Froitzheim, Abstract, [0024], [0032]-[0033], Fig.1, Fig. 3, claim 1. Froitzheim teaches, “[d]uring normal operation of the solar cell 1 the front side 6 faces the sun.” Ex.1004-Froitzheim, [0032]. The modified Froitzheim Figure 3 below depicts this:



Ex.1004-Froitzheim, Fig.3.

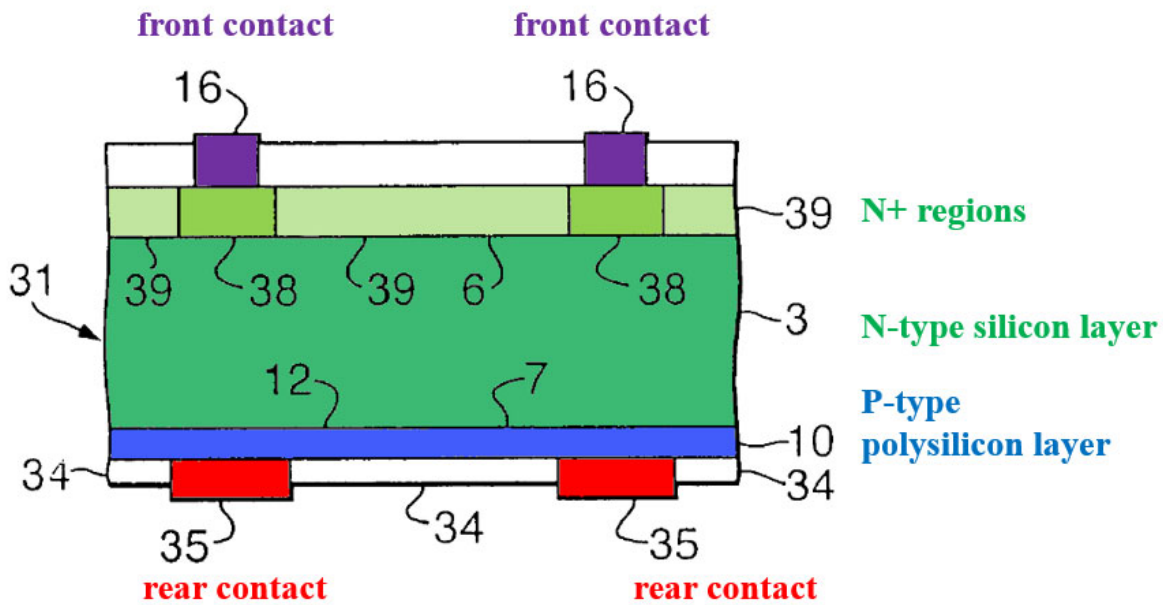
165. Froitzheim teaches *diffusing dopants into a front surface of the silicon substrate*. Specifically, Froitzheim teaches “*diffus[ing] [] Phosphorous* from the gas phase to form a front side **n+ layer**.” Ex.1004-Froitzheim, [0043]-[0044]. As I explained above in Section VII.A.1 (Overview of Solar Cells – Doping), phosphorous was a well-known dopant. *See, e.g.*, Ex.1052-Avery, 1:19-31 (“phosphorus atoms to **diffuse from the glass into the silicon surface** in accordance with well known diffusion”); Ex. 1019-Krygowski, 1 (“POCl₃ diffusion step is used to co-diffuse the emitter and pre-alloyed BSF”); Ex.1030-Benick (explaining POCl₃

diffusion as PSG (phosphosilicate glass) deposition and subsequent diffusion); Ex.1007-Smith, 3:56-57 (“atmosphere containing phosphorus oxychloride”). Froitzheim teaches diffusing phosphorous dopants into the front surface of the **N-type silicon layer**, the silicon substrate, to form **N+ regions**, as shown above. Thus, Froitzheim teaches *diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.*

f. Element 9[e]: forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

166. Froitzheim teaches *forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.*

167. Froitzheim teaches forming **front contacts 16** on the **n+ regions**, which are portions of the **n-type silicon body layer**. The **n+ regions** are more heavily doped with n-type dopants than the body layer (substrate). Ex.1004-Froitzheim, [0015]-[0018], [0022]. **Front contacts 16** are *a metal contact*, and, because they are formed on the **n+ regions**, which are part of the substrate, **front contacts** are formed *on the front surface of the silicon substrate*. Front contacts, n+ regions, and n-type silicon body layer are shown in the following Figure 3 of Froitzheim:



Ex.1004-Froitzheim, Fig.3.

168. Moreover, as shown in the figure above, Froitzheim teaches that **front contacts 16** are *electrically coupled* to the **n-type silicon body layer**, via the **n+ regions of** the substrate. As additional detail, Froitzheim teaches an “advantage of arranging an **n+ doped region** underneath the **front contact** is that **a better electrical connection is obtained**, in particular when screen-printed/fired front contacts are used. In this way a possible metal/semiconductor Schottky contact can be overcome by tunnelling.” Ex.1004-Froitzheim, [0016]. Froitzheim thus teaches that the front contacts are *electrically coupled* to the **n-type silicon body layer** through **n+ doped region 38**.

169. Accordingly, the combination of Froitzheim and Gan renders claim 9 obvious.

3. **Claim 10: The method of claim 9 wherein the first dopant source layer comprises P-type dopants.**

170. Claim 10 depends from claim 9. I therefore incorporate my analysis in Section XI.A.2. For the reasons I described in Sections XI.A.2.b-c (Ground I, Elements 9[a]-9[b]), the combination of Froitzheim and Gan teaches that *the first dopant source layer comprises P-type dopants*. For instance, and as discussed, Froitzheim teaches forming a “p-doped layer” with a p-type dopant source layer. Sections XI.A.2.b-c (Ground I, Elements 9[a]-9[b]). Gan teaches forming “p-type polysilicon emitter” with a p-type dopant source layer. Sections XI.A.2.b-c (Ground I, Elements 9[a]-9[b]). Thus, the combination of Froitzheim and Gan renders claim 10 obvious.

4. **Claim 11: The method of claim 9 wherein the first dopant source layer comprises borosilicate glass.**

171. Claim 11 depends from claim 9. I therefore incorporate my analysis in Section XI.A.2 (Ground I, Claim 9). The combination of Froitzheim and Gan further teaches that *the first dopant source layer comprises borosilicate glass*.

172. As discussed in Sections VII.A.1 (Overview of Solar Cells – Doping) and XI.A.2.c (Ground I, Element 9[b]), boron was a very common p-type dopant

source, and borosilicate glass is simply the material that forms when boron is present on a silicon surface and reacts with oxygen and the silicon surface. *E.g.*, Ex.1053-Schlosser, 2:17-23 (applying “a diffusion source layer that contains boron as a dopant” and “driv[ing] in the dopant”); Ex.1054-Gee, 16:63-17:28 (explaining use of spin-on glasses such as PSG and BSG (borosilicate glass) as dopant sources). The boron in the glass layer is diffused into the silicon when heat is applied. Ex.1053-Schlosser, 2:17-23; Ex.1054-Gee, 16:63-17:28.

173. Froitzheim teaches *the first dopant source layer comprises borosilicate glass*. Specifically, Froitzheim teaches that the first “diffusion source layer that contains boron as [a P-type] dopant is applied, e.g., spun, only onto the back of the n- doped silicon wafer...out of which the boron is thermally driven.” Ex.1004-Froitzheim, [0041]. A person of ordinary skill in the art would have understood that boron “applied” or “spun” onto silicon forms *borosilicate glass*, for the reasons I explained. Ex.1004-Froitzheim, [0041]; Ex.1054-Gee, 16:63-17:28. Thus, Froitzheim’s diffusion source layer, which is the claimed *the first dopant source layer*, teaches *borosilicate glass*.

174. A person of ordinary skill in the art would have also understood that Gan also teaches *the first dopant source layer comprises borosilicate glass*. As explained in Section XI.A.2.c, Gan teaches forming a first dopant source layer by

“[d]oped *glass* deposition” to make a “p-type polysilicon emitter.” Ex.1005-Gan, 246-48. As boron was widely known as the most common p-type dopant source, a person of ordinary skill in the art would have understood that Gan was referring to forming borosilicate glass on the silicon. Thus, the combination of Froitzheim and Gan renders claim 11 obvious.

175. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s methods to implement Gan’s **P-type polysilicon emitter** and also would have had a reasonable expectation of success in doing so. In particular, a person of ordinary skill in the art would have been motivated to follow Gan’s manufacturing steps to implement the polysilicon emitter in Froitzheim, which would involve depositing the layer of polysilicon over the backside of Froitzheim’s **n-type silicon layer**, forming *a dopant source layer that comprises borosilicate glass* over the layer of polysilicon, and then diffusing dopants from the first dopant source layer to the layer of polysilicon to form a **P-type polysilicon emitter** which would thus form a backside junction with the silicon substrate.

5. **Claim 12: The method of claim 9 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

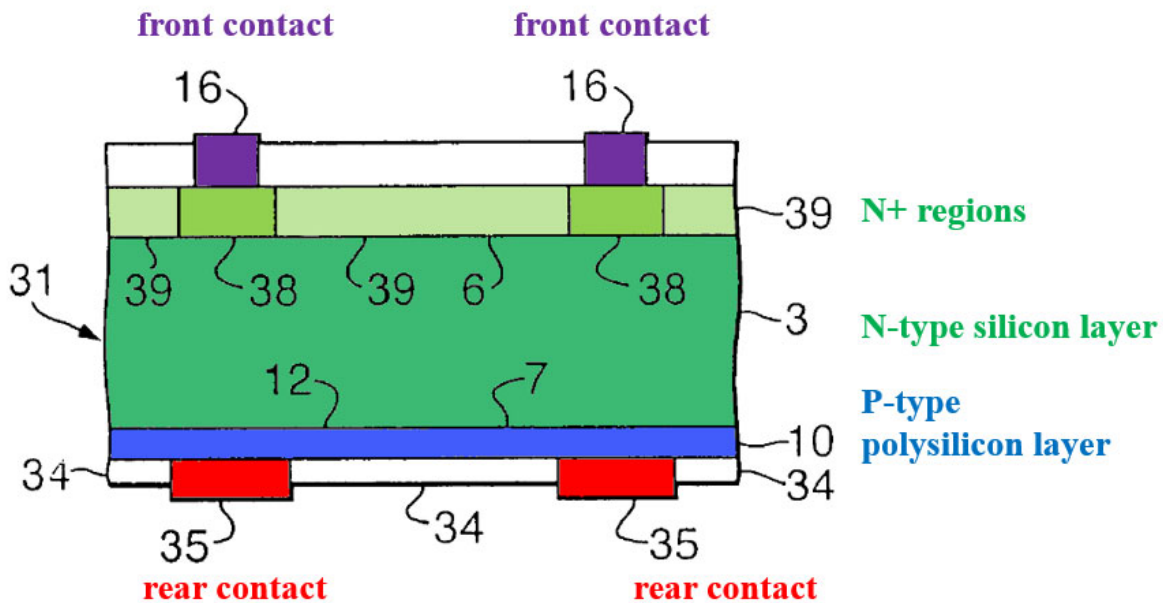
176. Claim 12 depends from claim 9. I therefore incorporate my analysis in Section XI.A.2 (Ground I, Claim 9). The combination of Froitzheim and Gan further teaches *diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.*

177. As I explained in Section XI.A.2.e (Ground I, Element 9[d]), Froitzheim teaches forming **N+ regions** by diffusing phosphorous into the frontside of the silicon substrate, the **N-type silicon layer**. Ex.1004-Froitzheim, [0044] (“diffusion of Phosphorous from the gas phase to form a front side n+ layer”). Therefore, Froitzheim teaches *diffusing dopants into the front surface of the silicon substrate.*

178. Froitzheim also teaches the rest of claim 12, which merely describes a typical solar cell diffusion process that was widely used before 2008. See Section VII.A.1 (Overview of Solar Cells – Doping). Specifically, “[d]iffusion of Phosphorous from the gas phase,” as taught by Froitzheim, was commonly achieved through “POCl₃” diffusion in the art. A POCl₃ diffusion involved (1) forming a layer

of glass with phosphorous dopants at the silicon surface, and (2) diffusing phosphorous dopants from the formed glass layer into the silicon substrate. *See, e.g.*, Ex.1052-Avery, 1:19-31 (“a layer of phosphorous pentoxide glass [] is deposited over the entire surface of the wafer through chemical **vapor deposition by flowing phosphorous oxychloride [POCl₃]** and oxygen into a diffusion chamber using a carrier gas of dry nitrogen. The interaction of the silicon wafer with these gases and the **formation of the phosphorous pentoxide glass** provides sufficient phosphorus atoms to **diffuse from the glass into the silicon surface** in accordance with well known diffusion”); Ex.1023-Nelson, 187 (“Phosphorus may be deposited either from the vapour phase by exposure to nitrogen gas bearing POCl₃; from solid phase, for example by chemical vapour deposition of phosphorus oxide”); Ex. 1019-Krygowski, 1 (“POCl₃ diffusion step is used to co-diffuse the emitter and pre-alloyed BSF”); Ex.1030-Benick (explaining POCl₃ diffusion as PSG (phosphosilicate glass) deposition and subsequent diffusion); Ex.1007-Smith, 3:56-57 (“atmosphere containing phosphorus oxychloride”); Ex.1004-Froitzheim, [0044] (“diffusion of Phosphorous from the gas phase”).

179. Thus, phosphorus diffusion as taught by Froitzheim entailed (1) forming a second dopant source layer over the silicon substrate and (2) diffusing dopants from the second dopant source layer into the silicon substrate.



Ex.1004-Froitzheim, Fig.3. Thus, the combination of Froitzheim and Gan renders claim 12 obvious.

6. **Claim 14: The method of claim 9 further comprising: texturing the front surface of the silicon substrate; and forming an antireflective layer over the textured front surface of the silicon substrate.**

180. Claim 14 depends from claim 9. I therefore incorporate my analysis in Section XI.A.2 (Ground I, Claim 9). The combination of Froitzheim and Gan further teaches *texturing the front surface of the silicon substrate[] and forming an antireflective layer over the textured front surface of the silicon substrate.*

181. As discussed in Section VII.A.4 (Overview of Solar Cells – Texturing and Antireflection Coating), it was well known by 2008 that solar cell manufacturing

often included front surface texturing to increase absorption and thus solar cell efficiency. Froitzheim also teaches implementing this common feature of solar cells. Froitzheim's explanation of using "etching...to **texture the surface [of the n-type silicon layer]** in order to improve the geometry of incidence of light in order to prevent reflection" was a common practice to texture the front surface of solar cells to increase absorption. Ex.1004-Froitzheim, [0039], [0023], [0056] ("After etch removal, texture etching was applied to the [n-type] wafers."), [0087]. Thus, Froitzheim teaches *texturing the front surface of the silicon substrate*.

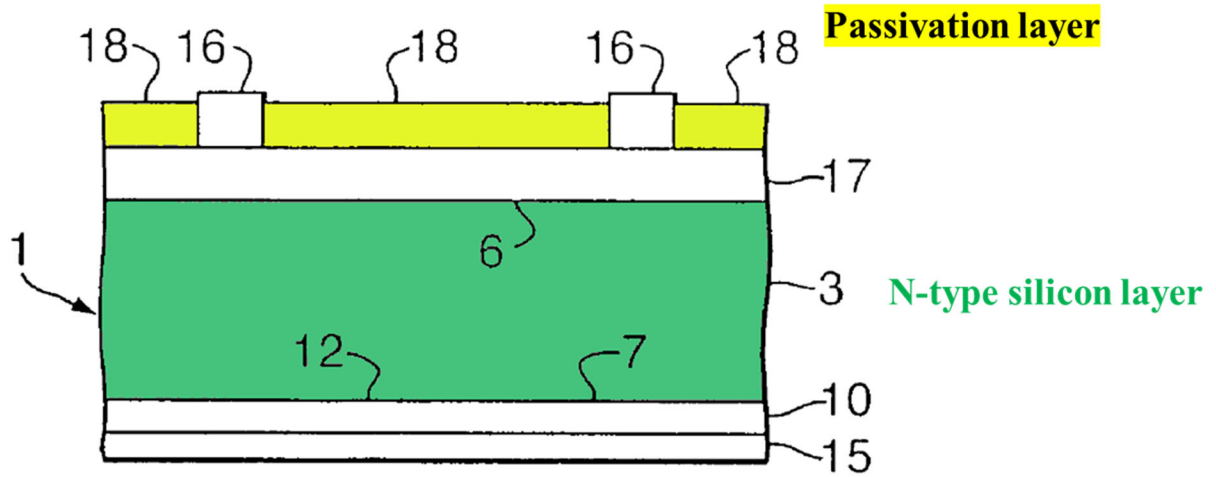
182. As I discussed in Section VII.A.4 (Overview of Solar Cells – Texturing and Antireflection Coating), it was routine for antireflective layers to be formed over textured front surfaces by 2008. Antireflective layers (also often called antireflection coatings or AR coatings) had been extensively studied and implemented because they were known to increase solar cell efficiency by increasing the amount of sunlight entering the solar cell. Section VII.A.4 (Overview of Solar Cells – Texturing and Antireflection Coating).

183. Froitzheim's solar cells also are made to include this well-known feature, as is explained by Froitzheim's discussion of using "an anti-reflective coating...*as known in the art.*" Ex.1004-Froitzheim, [0030]-[0031], [0060]. Froitzheim also provides additional details on its antireflective coating.

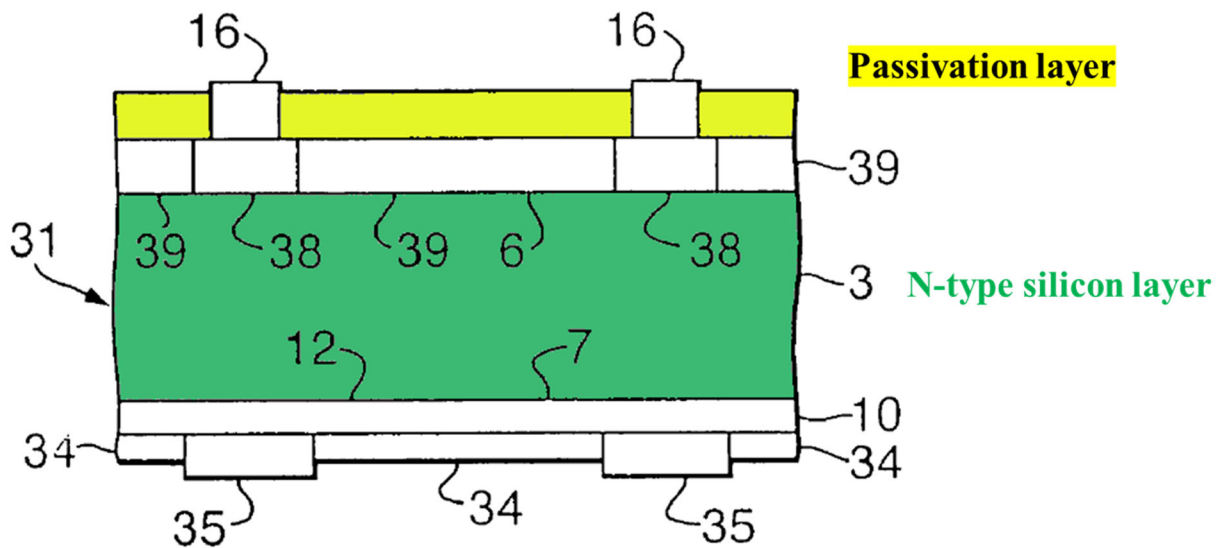
Froitzheim's solar cell includes a **passivation layer** formed from silicon nitride (SiN). Ex.1004-Froitzheim, [0030], [0019], [0023], claim 7. Froitzheim explains that, in addition to performing passivation functions (i.e., decreasing recombination), silicon nitride is used for "**antireflection** as well." As I discussed above, silicon nitride was commonly used as an antireflective layer. Ex.1016-Komp, 34 ("[S]ilicon nitride antireflection coatings are used on commercial solar cells."); Ex.1018-Nelson, 188 ("Suitable materials for silicon [AR coating include]...silicon nitride (Si₃Ni₄)"). Consequently, a person of ordinary skill in the art would have understood that the silicon nitride layer in Froitzheim's solar cell was an *antireflective layer*.

184. Froitzheim's Figures 1 and 3 below show that the antireflective silicon nitride layer (i.e., **passivation layer**) is formed *over* (i.e., closer to the sun) the *textured n-type silicon layer*.¹⁰ Ex.1004-Froitzheim, [0024], [0039]. Figure 3 of Froitzheim contains additional layers and contacts as compared to Figure 1 but is otherwise identical. Ex.1004-Froitzheim, [0033]-[0034].

¹⁰ Froitzheim teaches that the **n-type silicon layer** has a textured front surface. Although Froitzheim teaches the **n-type silicon layers** are textured, the textured front surfaces are not depicted in Figures 1 and 3.



Ex.1004-Froitzheim, Fig.1.



Ex.1004-Froitzheim, Fig.3. Thus, a person of ordinary skill in the art would have understood that Figures 1 and 3 of Froitzheim depict the *antireflective* silicon nitride layer over the textured **n-type silicon layer**.

185. Froitzheim also teaches that, during the manufacturing process for its disclosed solar cell, the antireflective silicon nitride layer is applied after texturing the **n-type silicon layer**. Ex.1004-Froitzheim, [0038]-[0039], [0050]. The sequence of steps makes sense because it would be unnecessarily complex (and not consistent with standard manufacturing techniques) to place the antireflective layer underneath a separate layer of textured silicon. A person of ordinary skill in the art therefore would have understood that Froitzheim teaches *forming an antireflective layer* (in this case, a silicon nitride **passivation layer**) *over the textured front surface of the silicon substrate*. Thus, the combination of Froitzheim and Gan renders claim 14 obvious.

7. Claim 16

186. Claim 16, in addition to the steps of claim 9, includes *forming an oxide layer over a back surface of a silicon substrate*, which is obvious over the combination of Froitzheim and Gan.

a. Element 16[pre]: A method of fabricating a solar cell comprising.

187. For the reasons I described in Section XI.A.2.a (Ground I, Element 9[pre]), Froitzheim teaches *a method of fabricating a solar cell* and Gan also teaches *a method of fabricating a structure for a solar cell*.

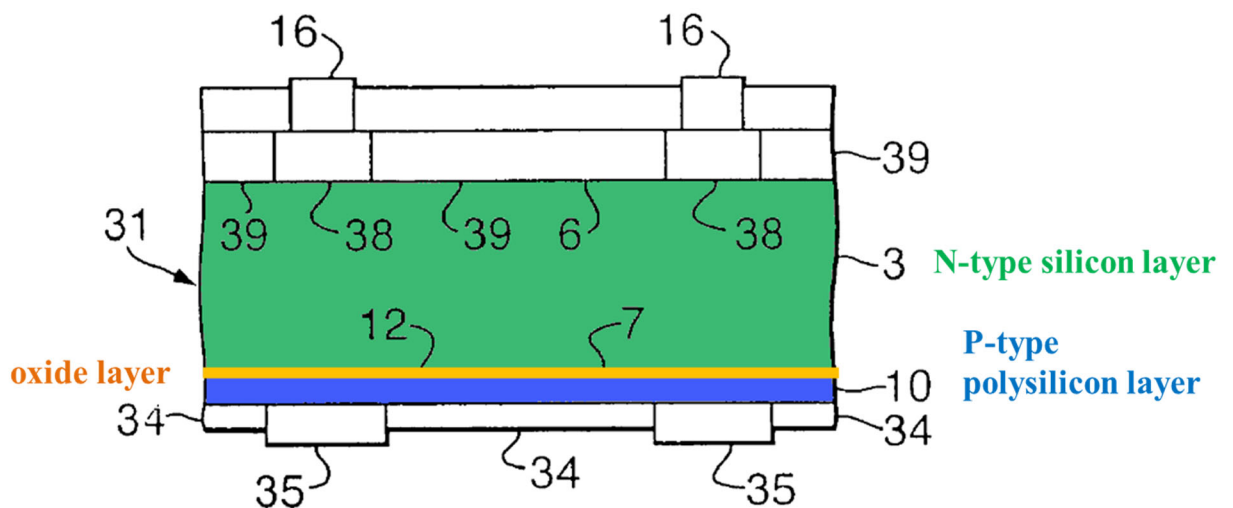
b. Elements 16[a]-[b]: forming an oxide layer over a back surface of a silicon substrate; forming a layer of polysilicon over the oxide layer.

188. The combination of Froitzheim and Gan teaches *forming an oxide layer over a back surface of a silicon substrate and forming a layer of polysilicon over the oxide layer*.

189. Gan teaches manufacturing a solar cell including the step of forming a “thermally grown interfacial oxide” (i.e., *oxide layer*) over the surface of a silicon substrate. Ex.1005-Gan, 245. As discussed in Section XI.A.1 (Ground I, Motivation to Combine), Gan studies a solar cell structure having a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245-246. By describing the oxide as being “interfacial,” a person of ordinary skill in the art would have understood that Gan teaches that the oxide layer is formed between a substrate and an emitter layer—i.e., at their interface. As discussed in Section X.B (Overview of the Prior Art – Gan), Gan is a paper about controlling the oxide layer between a p-type polysilicon emitter and a silicon substrate to ultimately improve solar cell efficiency. Ex.1005-Gan, 249 (“[C]ell efficiency can be improved with polysilicon emitters of characteristics given here.”).

190. As discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim

to manufacture a solar cell by forming a **P-type polysilicon emitter** and **oxide layer** between the back surface of the **substrate** and the **emitter** layer as taught by Gan with a reasonable expectation of success. This modification can be seen in the following modified Figure 3 of Froitzheim and would simply involve *forming an interfacial oxide layer over the back surface of Froitzheim's silicon substrate, forming a layer of polysilicon over the oxide layer, and then doping the polysilicon layer to form the emitter.*



Ex.1004-Froitzheim, Fig.3; Ex.1005-Gan, 245-249. The combination of Froitzheim and Gan therefore teaches *forming an oxide layer over a back surface of a silicon substrate and forming a layer of polysilicon over the oxide layer.*

- c. **Elements 16[c]-[e]:** diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a

metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

191. As described in Sections XI.A.2.c-f (Ground I, Element 9[b]-9[e]), the combination of Froitzheim and Gan teaches *diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.*

192. Accordingly, the combination of Froitzheim and Gan renders claim 16 obvious.

8. **Claim 17: The method of claim 16 wherein diffusing dopants into the layer of polysilicon to form the backside junction with the silicon substrate comprises: forming a first dopant source layer over the layer of polysilicon; and diffusing dopants from the first dopant source layer into the layer of polysilicon.**

193. Claim 17 depends from claim 16. I therefore incorporate my analysis in Section XI.A.7 (Ground I, Claim 16). Also, for the reasons I explained in Sections XI.A.2.d and XI.A.7 (Ground I, Element 9[c] and Claim 16), the combination of Froitzheim and Gan teaches *forming a first dopant source layer over the layer of polysilicon; and diffusing dopants from the first dopant source layer into the layer*

of polysilicon. Accordingly, the combination of Froitzheim and Gan renders claim 17 obvious.

9. **Claim 18: The method of claim 16 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

194. Claim 18 depends from claim 16. I therefore incorporate my analysis in Section XI.A.7 (Ground I, Claim 16). Also, for the reasons I explained in Sections XI.A.5 and XI.A.7 (Ground I, Claim 12 and Claim 16), the combination of Froitzheim and Gan teaches *diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.* Accordingly, the combination of Froitzheim and Gan renders claim 18 obvious.

10. **Claim 19: The method of claim 16 further comprising: texturing the front surface of the silicon substrate.**

195. Claim 19 depends from claim 16. I therefore incorporate my analysis in Section XI.A.7 (Ground I, Claim 16). Also, for the reasons I explained in Section XI.A.6 (Ground I, Claim 14), Froitzheim teaches *texturing the front surface of the silicon substrate.* Accordingly, the combination of Froitzheim and Gan renders claim 19 obvious.

**11. Claim 20: The method of claim 19 further comprising:
forming an antireflective layer over the textured front
surface of the silicon substrate.**

196. Claim 20 depends from claim 19. I therefore incorporate my analysis in Section XI.A.10 (Ground I, Claim 19). Also, for the reasons I explained in Section XI.A.6 (Ground I, Claim 14), Froitzheim further teaches *forming an antireflective layer over the textured front surface of the silicon substrate*. Accordingly, the combination of Froitzheim and Gan renders claim 20 obvious.

B. Ground II: Claims 1-20 Are Invalid as Obvious over Froitzheim, Gan, and Smith

197. It is my opinion that claims 1-20 would have been obvious over the combination of Froitzheim, Gan, and Smith. Ground II challenges every claim of the '053 patent. Ground II adds Smith to the combination of Froitzheim and Gan. As I explain herein, Smith teaches deposition and diffusion methods for solar cell structures like Froitzheim and Gan (and Li). As explained below, the combination of Froitzheim, Gan, and Smith renders claims 1-20 obvious.

1. Motivation to Combine

198. It is my opinion that each requirement for obviousness is met for the combination of Froitzheim, Gan, and Smith. **First**, Smith is analogous art for the same reasons as Froitzheim and Gan. Section XI.A.1 (Ground I, Motivation to Combine); Ex.1007-Smith, Abstract, 1:15-61, 3:40-4:2. Furthermore, Smith is

analogous art because Smith's goals include decreasing the cost to manufacture an efficient solar cell. This also is the goal of the '053 patent, and a person of ordinary skill in the art likewise would have found cost an important consideration in determining how to best manufacture the combined structure of Froitzheim and Gan. Ex.1007-Smith, 1:15-40 ("techniques for simplifying the fabrication of solar cells are generally desirable"), 3:40-4:2 ("As can be appreciated the use of in-situ steps to drive dopants into wafer 102 simplifies the fabrication process."); Ex.1001-USP053 1:47-49, 3:49-55.

199. **Second**, for the reasons I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to combine Froitzheim, Gan, and Smith with a reasonable expectation of success. Therefore, I incorporate by reference Section XI.A.1 (Ground I, Motivation to Combine). In particular, a person of ordinary skill in the art would have understood that the combination of Froitzheim's manufacturing of a back-junction solar cell, Gan's manufacturing of a polysilicon emitter and oxide layer structure, and Smith's solar cell manufacturing techniques simply amounts to using a known structural feature—polysilicon emitter and oxide layer on a silicon wafer as taught by Gan—and known manufacturing techniques, as taught by Smith, to improve a similar apparatus—Froitzheim's back-junction solar cell. The combination of

Froitzheim, Gan, and Smith achieves goals common to the references and the industry—increasing a solar cell’s efficiency to thereby increase its power output while also lower manufacturing costs. Indeed, as detailed below, Smith teaches well-known solar cell manufacturing steps that maintain the quality of the produced cells while simultaneously lowering manufacturing costs.

200. A person of ordinary skill in the art looking to manufacture a combined structure of Froitzheim’s back-junction solar cell with Gan’s polysilicon emitter and oxide layer would have known that lowering manufacturing costs was an important consideration in addition to maximizing efficiency. The efficiency of a solar cell was important, but, in practice, a person of ordinary skill in the art would not have overlooked manufacturing costs to survive in the market. Reducing costs is important in many applications—for instance, when the solar cells are produced to be sold commercially and need to compete with other solar cells on the market or other commercially available energy sources. Indeed, reducing manufacturing costs for commercial solar cells is specifically recognized by the ’053 patent. Ex.1001-USP053, 3:49-55 (“[T]o be competitive with other energy sources, a solar cell manufacturer must be able to fabricate an efficient solar cell at relatively low cost.”). Thus, a person of ordinary skill in the art would have appreciated methods that would achieve both goals.

201. Furthermore, solar cell manufacturing processes commonly involved multiple deposition and heating steps, which are sources of costs. For example, Froitzheim teaches multiple steps to create the backside p-type emitter and frontside n⁺ layer. For instance, Froitzheim teaches creating the p-type emitter by creating a “diffusion source layer” and then thermally driving the dopant from the source layer into the silicon wafer by heating the wafer and dopant source layer to a temperature of 900-1200°C. Ex.1004-Froitzheim, [0041]-[0042]. Froitzheim explains that “after the p-doped region has been formed,” diffusion steps can be performed to create the “front side n⁺ layer.” Ex.1004-Froitzheim, [0043]. Gan also teaches depositing doped glass on a wafer and diffusing the dopants from the glass to the wafer at a temperature of 900-1000°C. Ex.1005-Gan, 246. As noted, each deposition and heating step increases the manufacturing cost of the solar cell, which is an important consideration for commercial solar cells.

202. As detailed in Section XI.A (Ground I), a person of ordinary skill in the art would have understood that implementing Gan’s polysilicon emitter and oxide layer in Froitzheim would have simply involved forming an oxide layer over the backside of Froitzheim’s silicon substrate, forming a polysilicon layer over the oxide layer, and then forming a dopant source layer over the polysilicon layer to diffuse dopants into the polysilicon layer to form the emitter. A person of ordinary skill in

the art would have understood that additional manufacturing steps, as taught by Froitzheim, were required to complete the cell, which would include forming the frontside n⁺ doped layer. *See* Ex.1004-Froitzheim, [0044]. A person of ordinary skill in the art would have appreciated that the aggregate manufacturing costs would be lowered if the overall number of manufacturing steps were reduced. *See* Ex.1007-Smith, 1:36-40 (“each step employed in the manufacture of solar cells has an associated cost”). Therefore, a person of ordinary skill in the art fabricating a solar cell would have considered ways to decrease the number of manufacturing steps and thus costs.

203. Smith specifically teaches “simplifying the fabrication of solar cells” and reducing the number of solar cell manufacturing steps to lower manufacturing costs. Ex.1007-Smith, 1:36-40 (“Just like in most manufacturing processes, each step employed in the manufacture of solar cells has an associated cost. Thus, techniques for simplifying the fabrication of solar cells are generally desirable.”). A person of ordinary skill in the art would have considered Smith’s simplified manufacturing techniques and looked to obtain the efficiency benefits from the combined structure of Froitzheim and Gan, but at a lower manufacturing cost.

204. Smith has several teachings that a person of ordinary skill in the art would have known how to apply to Froitzheim’s and Gan’s manufacturing processes

to make a cost-efficient, high-efficiency solar cell. As an initial matter, Smith explains its diffusion steps in the manufacture of a “back side contact” (i.e., back-contact) solar cell. *E.g.*, Ex.1007-Smith, Fig.7. A person of ordinary skill in the art would have understood that Smith’s fabrication techniques are not limited to back-contact solar cells. *See, e.g.*, Ex.1007-Smith, 2:7-13 (“In the present disclosure, numerous specific details are provided such as examples of apparatus, process parameters, materials, process steps, and structures to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details.”), 4:11-16 (“While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.”), cl.9 (“A method of fabricating a solar cell...”), cl.17. A person of ordinary skill in the art instead would have found Smith’s processes advantageous and applicable to manufacturing processes designed to fabricate the combined structure of Froitzheim and Gan. Ex.1007-Smith, Fig.7, cl. 9, 17.

205. As an example of a technique that a person of ordinary skill in the art would have known how to apply to Froitzheim’s and Gan’s manufacturing

processes, Smith teaches depositing dopant source layers, such as BSG, using “APCVD.” Ex.1007-Smith, 2:44-49 (“In one embodiment, boron-doped silicon dioxide 104 is deposited to a thickness of about 1000 Angstroms using an atmospheric pressure chemical vapor deposition process (APCVD).”). APCVD was a well-known manufacturing process. *E.g.*, Ex.1056-Agostinelli, 20:27-29 (explaining depositing oxide on the rear side using APCVD); Ex.1015-Meier, 6:20-25 (explaining using APCVD to deposit a titanium dioxide anti-reflective coating); Ex.1057-NREL (1999 report explaining APCVD and tools). A person of ordinary skill in the art would have understood that APCVD was a well-known and routine process to create a dopant source layer on a single side of the silicon wafer for doping.

206. Smith further teaches that “an undoped silicon dioxide” layer is deposited over the dopant source layer. Ex.1007-Smith, 2:53-60. The undoped silicon dioxide layer acts as a diffusion barrier (or capping layer) so that dopants diffuse only into the targeted surface. Ex.1007-Smith, 3:50-55. Smith explains that deposition processes such as APCVD “advantageously allow[] for one-sided deposition,” which is “particularly useful in the manufacture of back side contact solar cells where only one side of the solar cell is textured.” Ex.1007-Smith, 2:58-62.

207. Thus, a person of ordinary skill in the art would have understood the benefits of one-sided APCVD deposition (as Smith teaches) to fabricate more efficient and less costly solar cells, as the dopant source layers are deposited only on the desired side. Otherwise, the doping process would require additional steps because the dopants would also end up on the undesired sides (e.g., the opposite side) and must be removed, such as by etching processes, thereby adding to manufacturing costs.

208. To the extent that the Patent Owner argues that the combination of Froitzheim and Gan do not teach forming dopant source layers to diffuse dopants into polysilicon or silicon, a person of ordinary skill in the art would have been motivated to implement Smith's APCVD deposition to dope the polysilicon layer (as taught by Gan) and n^+ layer on the front of the silicon substrate (as taught by Froitzheim). A person of ordinary skill in the art would have understood that implementing Smith's APCVD deposition technique would ensure that dopants are not introduced into the incorrect layers while also minimizing additional processing steps that may be required. In other words, a person of ordinary skill in the art would have been motivated to apply Smith's known APCVD deposition technique to a similar device—the combination of Froitzheim and Gan that results in a higher efficiency solar cell—to obtain the manufacturing benefits taught by Smith.

209. A person of ordinary skill in the art would have also been motivated to manufacture the combination of Froitzheim and Gan using Smith's "in-situ" diffusion process. Smith's teaching of "in-situ" diffusion to "simplif[y] the fabrication process" would have been another motivating reason to use Smith's processes to create the combined structure of Froitzheim and Gan. Ex.1007-Smith, 3:40-4:2. Smith states that "in-situ" diffusion means that the steps are "performed in one loading of wafer [] into the wafer processing tool." Ex.1007-Smith, 3:40-42.¹¹ A person of ordinary skill in the art would have found in-situ diffusion (and the simultaneous diffusion from multiple dopant sources, or "co-diffusion," in general) advantageous because it would simplify fabrication by reducing processing steps, thereby decreasing costs. For example, Krygowski reported in 1997 that the

¹¹ As explained in more detailed in Section X.B.8 (Ground II, Claim 15), the '053 patent explains that the term "in situ" as used in the '053 patent (and recited in claim 15) refers to multiple processing steps that are performed after a single manual loading of the substrate in a furnace. Ex.1001-USP053, 5:9-15 ("in-situ, which in the context of the present disclosure means a single manual (i.e., by fabrication personnel) loading of the substrate...in a furnace or other single chamber or multi-chamber processing tool.").

co-diffusion technique was used by Sandia National Lab and Interuniversity Microelectronics Centre (IMEC). Ex.1019-Krygowski, 1 (“To fabricate high efficiency solar cells with minimal thermal processing, simultaneous diffusion techniques can be employed to co-diffuse the emitter and Back Surface Field (BSF). Researchers...have demonstrated an aluminum and phosphorus diffusion technique in which one high temperature ($>800\text{ }^{\circ}\text{C}$) POCl_3 diffusion step is used to co-diffuse the emitter and pre-alloyed BSF[.] Workers at IMEC have simultaneously diffused boron and phosphorus [] on opposite sides of a silicon wafer [2]”); *see also* Ex.1054-Gee, 12:39-42 (“following screen printing and cure of boron diffusion barrier 94, a phosphorus diffusion step, such as using POCl_3 (30 to 60 S.2/sq), is employed, resulting in the co-diffusion of boron and phosphorus”).

210. A person of ordinary skill in the art would have known that it would be desirable to apply Smith’s diffusion barrier and in-situ diffusion processes to Froitzheim’s and Gan’s manufacturing methods. Specifically, a person of ordinary skill in the art would have known that if both sides of the subject wafer (i.e., Froitzheim’s silicon substrate) could be doped after the wafer is loaded one single time in a furnace, it would decrease the number of required steps and thus fabrication costs. Indeed, in alternative processes, on the other hand, the wafer would have to be subjected to multiple additional steps, including being (1) removed from the

machine, (2) prepared for the next loading (for instance, by the application of masking layers to protect doped surfaces that were already doped), reloaded into the machine, and (3) then further processed (for instance, removing the masking layers). These additional steps would have increased costs, which a person of ordinary skill in the art would have sought to avoid. Thus, a person of ordinary skill in the art would have understood that applying Smith's diffusion barrier and in-situ diffusion processes to the combination of Froitzheim and Gan was simply applying a known technique that had been used to improve similar devices in similar ways.

211. **Third**, in addition to the reasons I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have had a reasonable expectation of success at using Smith's manufacturing techniques to manufacture the combination of Froitzheim's back-junction solar cell and Gan's polysilicon emitter and oxide layer structure. As discussed in Section XI.A.1 (Ground I, Motivation to Combine) and in this section above, manufacturing techniques for solar cells were well-known by 2008, including the techniques taught by Smith, Froitzheim, and Gan. Moreover, each reference teaches similar processes for diffusing dopants and teaches similar temperature ranges. *E.g.*, Ex.1004-Froitzheim, [0042] (teaching a temperature range of 900-1200 °C); Ex.1005-Gan, 246 (teaching a temperature range of 900-1000°C). Ex.1007-Smith (teaching

temperatures of about 750°C, about 975°C, and about 1000°C). As a result, a person of ordinary skill would have understood that the references teach compatible manufacturing processes.

212. Moreover, as discussed in Section XI.A.1 (Ground I, Motivation to Combine), the '053 patent itself assumes (correctly) that a person of ordinary skill in the art would have understood how to manufacture a solar cell. The '053 patent generically describes manufacturing its disclosed solar cell structure but does not provide specific implementation details. *See generally* Ex.1001-USP053. Thus, a person of ordinary skill in the art would have readily understood how to implement Smith's manufacturing techniques in the combination of Froitzheim and Gan. That is, a person of ordinary skill in the art would have had a reasonable expectation of success at using Smith's manufacturing processes with the combination of Froitzheim and Gan because doing so would simply involve using known manufacturing techniques to improve known solar cell designs in a similar way (lower manufacturing costs).

213. Accordingly, for the reasons I explained here and Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to combine Froitzheim, Gan, and Smith with a reasonable expectation of success.

2. Claim 9

a. Element 9[pre]: A method of fabricating a solar cell.

214. For the reasons I explained in Section XI.A.2.a (Ground I, Element 9[pre]), Froitzheim teaches *a method of fabricating a solar cell* and Gan also teaches *a method of fabricating a structure for a solar cell*.

215. Smith also teaches *a method of fabricating a solar cell*. Ex.1007-Smith, Title, Figs.1-7, 1:15-19, 1:44-4:11, claims 1-20. For the reasons I explained in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim's process in view of Gan and Smith.

b. Element 9[a]: forming a layer of polysilicon over a back surface of a silicon substrate.

216. For the reasons I explained in Section XI.A.2.b (Ground I, Element 9[a]), the combination of Froitzheim and Gan teaches *forming a layer of polysilicon over a back surface of a silicon substrate*.

c. Element 9[b]-[c]: forming a first dopant source layer over the layer of polysilicon; diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate.

217. For the reasons I explained in Section XI.A.2.c-d (Ground I, Elements 9[b]-[c]), the combination of Froitzheim and Gan teaches *forming a first dopant source layer over the layer of polysilicon; diffusing dopants from the first dopant*

source layer to the layer of polysilicon to form a backside junction with the silicon substrate.

218. Smith further teaches *forming a first dopant source layer and diffusing dopants from the first dopant source layer*. Smith explains its process of “a method of forming doped regions in a substrate of a back side contact solar cell.” Ex.1007-Smith, Abstract. The process includes “steps of depositing a **first doped oxide layer** on a back side of a **substrate**, depositing a first undoped oxide layer over the first doped oxide layer, [and] diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region in the substrate.” Ex.1007-Smith, Abstract. Smith uses the “first doped oxide layer” as a *first dopant source layer* in its diffusion process, and the substrate is an N-type. Ex.1007-Smith, 1:43-3:55, claims 1-5, 9-13.

219. For example, Smith uses “boron-doped silicon dioxide (SiO_2) (‘BSG’),” which is a P-type dopant source, as a “**first doped oxide layer**.” Ex.1007-Smith, 2:44-64. Smith explains that “boron-doped silicon dioxide 104 is deposited to a thickness of about 1000 Angstroms using an atmospheric pressure chemical vapor deposition process (APCVD).” Ex.1007-Smith, 2:46-49. Later in Smith’s manufacturing process, boron dopants from this source layer (“boron-doped silicon dioxide 104”) are diffused into the wafer 102, an n-type substrate. Ex.1007-Smith,

3:44-47. The '053 patent also describes a similar process using a “P-type dopant source compris[ing] BSG (borosilicate glass) deposited to a thickness of about 500 to 1000 Angstroms by atmospheric pressure CVD (APCVD).” Ex.1001-USP053, 4:21-24. Below, Smith’s Figure 2 shows the *first dopant source layer* (“**first doped oxide layer**”), which is a “boron-doped silicon dioxide 104” layer “doped with P-type dopants” formed over the **substrate 102**. Ex.1007-Smith, 2:44-64.



Ex.1007-Smith, Fig.2.

220. As discussed in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify the combination of Froitzheim and Gan to implement Smith’s diffusion methods and also would have had a reasonable expectation of success in doing so. Implementing Smith’s diffusion methods in the combination of Froitzheim and Gan would have simply involved forming a layer of polysilicon, creating a *dopant source layer* over the layer of polysilicon, and then *diffusing dopants from the source layer* into the

layer of polysilicon to create the emitter that would form a *backside junction with the silicon substrate*.

d. Element 9[d]: diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.

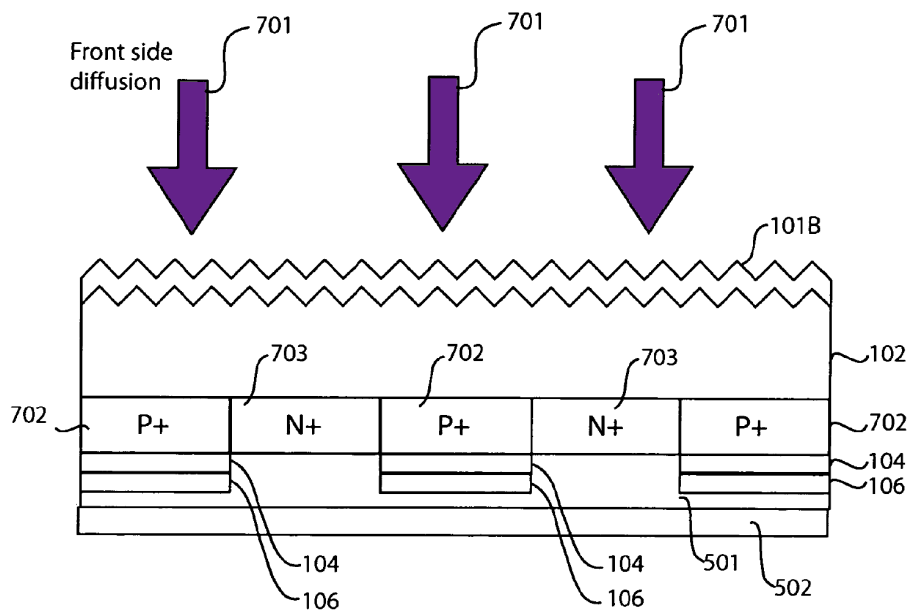
221. For the reasons I explained in Section XI.A.2.e (Ground I, Element 9[d]), Froitzheim teaches *diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation*.

222. Smith also teaches claim element 9[d]. Smith teaches “diffusing a second dopant into the substrate by way of a front side of the substrate.” Ex.1007-Smith, Abstract, 1:43-3:55, claims 1-2, 4, 8, 9, 12, 14-19. The “front side of the substrate” is *the front surface of the silicon substrate facing the sun during normal operation*. Ex.1007-Smith, Abstract, 1:43-3:55, claims 1-2, 4, 8, 9, 12, 14-19.

223. Smith teaches starting with a “[w]afer 102 [that] serves as the substrate of the solar cell being fabricated.” Ex.1007-Smith, 2:32-37. The “[w]afer 102 has a front side 101 and a back side 103.” Ex.1007-Smith, 2:32-37. The “[f]ront side 101 is the side of the solar cell configured to receive solar radiation, and thus faces the sun in operation.” Ex.1007-Smith, 2:32-37. Smith therefore teaches a solar cell

having a front surface of the silicon substrate facing the sun during normal operation, which was a routine feature of solar cells.

224. Moreover, Smith Figure 7 and the text describing it teach a method of diffusing phosphorus “as an N-type dopant into wafer 102 from its front side,” meaning the sun-facing side. Thus, Figure 7 shows phosphorus diffusion into *the front surface of the silicon substrate*. Ex.1007-Smith, 3:40-61. In Figure 7, phosphorus diffusion is represented by arrows directed to the front of the substrate.



Ex.1007-Smith, Fig.7.

225. As I explained in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify the combination of Froitzheim and Gan to implement Smith’s diffusion methods and

would have had a reasonable expectation of success in doing so. Implementing Smith's diffusion methods in the combination of Froitzheim and Gan would have simply involved diffusing dopants as taught by Smith into the top of Froitzheim's silicon substrate to create Froitzheim's n⁺ layer.

e. Element 9[e]: forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

226. For the reasons I discussed in Section XI.A.2.f (Ground I, Element 9[e]), Froitzheim teaches *forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate*.

227. For the reasons discussed, the combination of Froitzheim, Gan, and Smith renders claim 9 obvious.

3. Claim 10: The method of claim 9 wherein the first dopant source layer comprises P-type dopants.

228. Claim 10 depends from claim 9. I therefore incorporate my analysis in Section XI.B.2 (Ground II, Claim 9). For the reasons I explained in Section XI.B.2.c (Ground II, Elements 9[b]-9[c]), the combination of Froitzheim, Gan, and Smith teaches *the first dopant source layer comprises P-type dopants*. See, e.g., Ex.1007-Smith, 2:63-64 ("doped with P-type dopants"). Thus, the combination of Froitzheim, Gan, and Smith renders claim 10 obvious.

4. **Claim 11: The method of claim 9 wherein the first dopant source layer comprises borosilicate glass.**

229. Claim 11 depends from claim 9. I therefore incorporate my analysis in Section XI.B.2 (Ground II, Claim 9). For the reasons I explained in Section XI.A.4 (Ground I, Claim 11), the combination of Froitzheim and Gan teaches *the first dopant source layer comprises borosilicate glass*.

230. As I also explained in Section XI.B.2.c (Ground II, Elements 9[b]-[c]), Smith further teaches using BSG (borosilicate glass) as *a first dopant source layer*. Smith specifically teaches that the **first doped oxide layer 104** (*the first dopant source layer*) may be “boron-doped silicon dioxide (SiO₂) (‘BSG’),” which was a known p-type dopant source. Ex.1007-Smith, 2:44-64; *see also* Ex.1001-USP053, 4:21-24 (discussing BSG); Section XI.A.4 (Ground I, Claim 11); Ex.1053-Schlosser, 2:17-23 (applying “a diffusion source layer that contains boron as a dopant” and “driv[ing] in the dopant”); Ex.1054-Gee, 16:63-17:28 (explaining use of spin-on glasses such as PSG and BSG (borosilicate glass) as dopant sources). The **first doped oxide layer 104** is shown in the following Smith Figure 2.



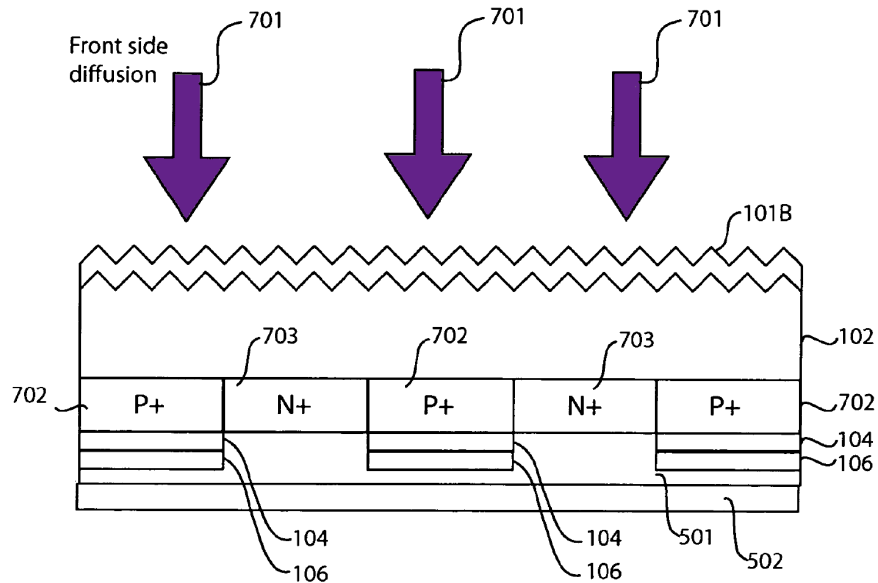
Ex.1007-Smith, Fig.2. As I explained in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify the combination of Froitzheim and Gan to implement Smith's diffusion methods and would have had a reasonable expectation of success in doing so. Implementing Smith's diffusion methods in the combination of Froitzheim and Gan would have involved forming a *first dopant source layer comprising borosilicate glass* over the polysilicon layer to dope the polysilicon layer with p-type dopants. Thus, the combination of Froitzheim, Gan, and Smith renders claim 11 obvious.

5. **Claim 12: The method of claim 9 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

231. Claim 12 depends from claim 9. I therefore incorporate my analysis in Section XI.B.2 (Ground II, Claim 9). The combination of Froitzheim, Gan, and Smith teaches that *diffusing dopants into the front surface of the silicon substrate*

comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate. As I explained in Section XI.A.5 (Ground I, Claim 12), Froitzheim teaches this claim, which merely describes how typical solar cell diffusion works, as was widely known by 2008.

232. For the reasons I explained in Sections XI.B.2.d (Ground II, Element 9[d]), Smith also teaches *forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.* For further detail, in Figure 7, which is annotated below, diffusing dopants from the second dopant source layer into the silicon substrate is shown graphically by **arrows (“front side diffusion” 701)** pointing to the front of the substrate. Ex.1007-Smith, 3:40-4:11. The arrows indicate the dopant is being driven in by diffusion. Ex.1007-Smith, 3:66-67.



Ex.1007-Smith, Fig. 7. In this step, Smith teaches that “phosphorus oxychloride” (POCl_3) is used. Ex.1007-Smith, 3:56-4:2.

233. As I explained in Section XI.A.5 (Ground I, Claim 12), POCl_3 diffusion was a common technique that entailed (1) forming a layer of glass (which would be phosphorus doped silicon dioxide or PSG) with phosphorous dopants at the silicon surface, and (2) diffusing phosphorous dopants from the glass layer into the silicon substrate, which are the “*forming...*” and “*diffusing...*” parts of claim 12, respectively. Ex.1007-Smith, 3:56-60, claims 1, 9, 14, 17, 20; *see also* Section XI.A.5 (Ground I, Claim 12); Ex.1052-Avery, 1:19-31 (“a layer of phosphorous pentoxide glass [] is deposited over the entire surface of the wafer through chemical vapor deposition by flowing phosphorous oxychloride [POCl_3] and oxygen into

a diffusion chamber using a carrier gas of dry nitrogen. The interaction of the silicon wafer with these gases and the **formation of the phosphorous pentoxide glass** provides sufficient phosphorus atoms to **diffuse from the glass into the silicon surface** in accordance with well known diffusion”); Ex.1023-Nelson, 187 (“Phosphorus may be deposited either from the vapour phase by exposure to nitrogen gas bearing POCl_3 ; from solid phase, for example by chemical vapour deposition of phosphorus oxide”); Ex. 1019-Krygowski, 1 (“ POCl_3 diffusion step is used to co-diffuse the emitter and pre-alloyed BSF”); Ex.1030-Benick (explaining POCl_3 diffusion as PSG (phosphosilicate glass) deposition and subsequent diffusion).

234. As discussed in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify the combination of Froitzheim and Gan to implement Smith’s diffusion methods and would have had a reasonable expectation of success in doing so. Implementing Smith’s diffusion methods in the combination of Froitzheim and Gan would have simply involved *forming a second dopant source layer over the frontside of Froitzheim’s silicon substrate* and then *diffusing dopants from the second dopant source layer into Froitzheim’s silicon substrate*. Thus, the combination of Froitzheim, Gan, and Smith renders claim 12 obvious.

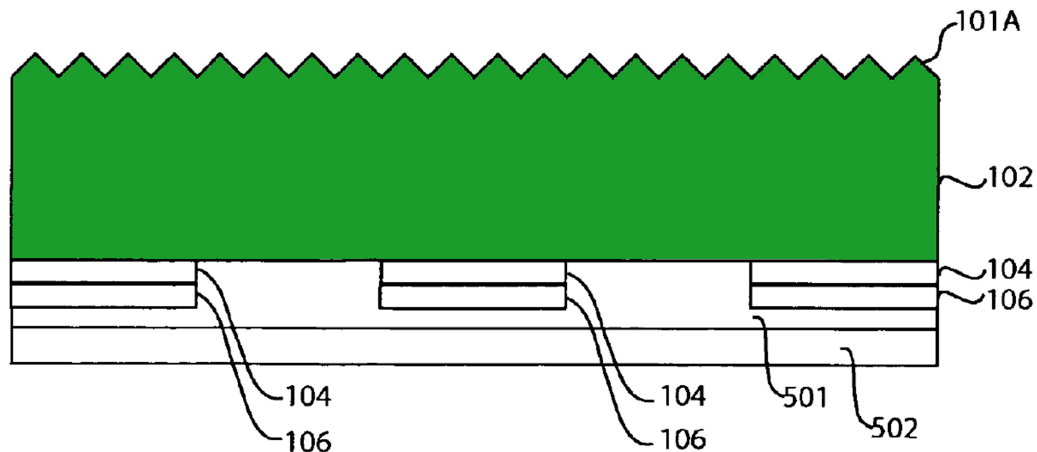
6. **Claim 13: The method of claim 12 wherein the second dopant source layer comprises phosphorus doped silicon dioxide.**

235. Claim 13 depends from claim 12. I therefore incorporate my analysis in Section XI.B.5 (Ground II, Claim 12). The combination of Froitzheim, Gan, and Smith further teaches *the second dopant source layer comprises phosphorus doped silicon dioxide*. As I explained in Section XI.B.5 (Ground II, Claim 12), Smith teaches forming a layer of glass with phosphorous dopants (which would be *phosphorus doped silicon dioxide*) as part of the POCl₃ diffusion. See Ex.1007-Smith, 3:19-55 (describing dopant source layers of “phosphorus doped silicon dioxide” formed during phosphorus doping processes), claims 1-2, 4. Thus, the combination of Froitzheim, Gan, and Smith renders claim 13 obvious.

7. **Claim 14: The method of claim 9 further comprising: texturing the front surface of the silicon substrate; and forming an antireflective layer over the textured front surface of the silicon substrate.**

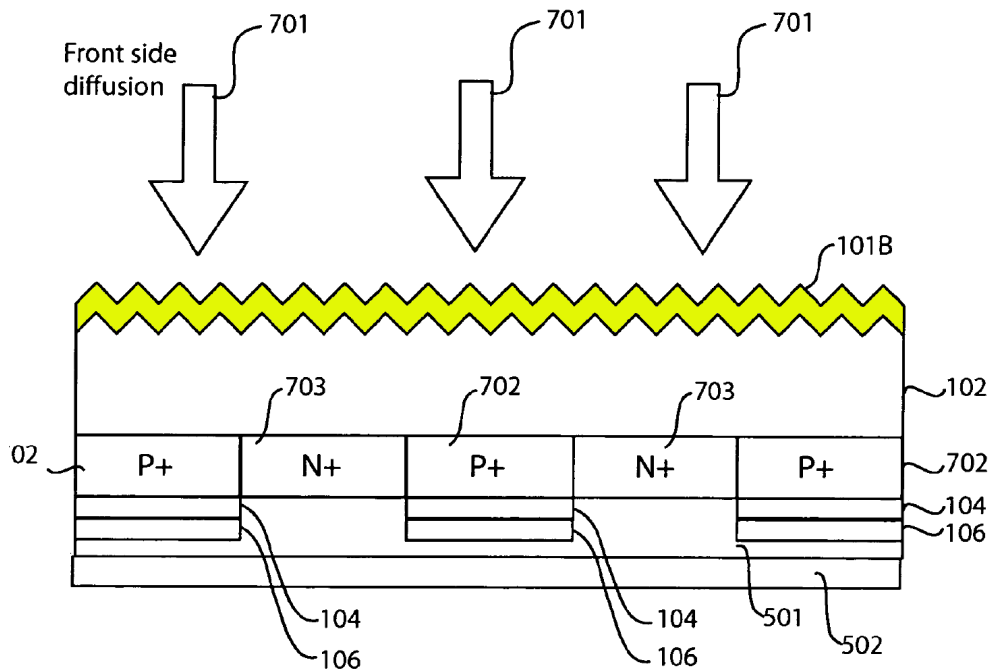
236. Claim 14 depends from claim 9. I therefore incorporate my analysis in Section XI.B.2 (Ground II, Claim 9). For the reasons discussed in Section XI.A.6 (Ground I, Claim 14), Froitzheim further teaches *texturing the front surface of the silicon substrate; and forming an antireflective layer over the textured front surface of the silicon substrate*. Thus, the combination of Froitzheim, Gan, and Smith renders claim 14 obvious.

237. Smith also teaches *texturing the front surface of the silicon substrate; and forming an antireflective layer over the textured front surface of the silicon substrate*. As shown in Smith Figure 6, below, Smith teaches the fabrication step of texturing the front side “using a wet etch process comprising potassium hydroxide and isopropyl alcohol.” Ex.1007-Smith, 3:32-38. As was commonly done, “[t]he wet etch textures front side 101 with random pyramids, thereby improving the solar radiation collection efficiency.” Ex.1007-Smith, 3:32-38; 2:60-62. In Figure 6, the textured surface is shown by **jagged edges**:



Ex.1007-Smith, Fig.6.

238. Also in accordance with common practices at the time, in Figure 7 and corresponding text, Smith teaches forming “an anti-reflective coating (e.g., silicon nitride) on front side 101B” over the textured silicon surface:



Ex.1007-Smith, 4:3-6 (“The fabrication of the sample of FIG.7 may be completed using a back-end process to form electrodes coupled to the P+ and N+ regions of wafer 102 and to include an anti-reflective coating (e.g., silicon nitride) on front side 101B.”). As I explained in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim to implement Smith’s manufacturing methods, including texturing and anti-reflective coating methods as they were common features in solar cell manufacturing at the time. A person of ordinary skill in the art also would have had a reasonable expectation of success in doing so. Thus, Smith teaches the added elements of claim 14, and the combination of Froitzheim, Gan, and Smith renders claim 14 obvious.

8. **Claim 15: The method of claim 9 wherein the diffusion of dopants from the first dopant source layer to the layer of polysilicon and the diffusion of dopants into the front surface of the silicon substrate are performed in situ.**

239. Claim 15 depends from claim 9. I therefore incorporate my analysis in Section XI.B.2 (Ground II, Claim 9).

240. As discussed in Section XI.B.2.c-d (Ground II, Elements 9[b]-9[d]), the combination of Froitzheim, Gan, and Smith teaches *the diffusion of dopants from the first dopant source layer to the layer of polysilicon and the diffusion of dopants into the front surface of the silicon substrate*, which merely recites how basic diffusion is performed. The combination of Froitzheim, Gan, and Smith further teaches that these diffusion steps are *performed in situ*.

241. Claim 15 recites that the diffusing dopants into the polysilicon and substrate is performed “in situ.” The ’053 patent explains, “[t]he drive-in step to dope the polysilicon emitter [] on the backside and to form the N-type doped regions...on the front side may be formed in-situ, which in the context of the present disclosure means a single manual (i.e., by fabrication personnel) loading of the substrate [] in a furnace or other single chamber or multi-chamber processing tool,” “which advantageously helps in lowering fabrication cost.” Ex.1001-USP053, 5:9-18. Thus, the ’053 patent explains that the term “in situ” as used in the ’053 patent

(and recited in claim 15) refers to multiple processing steps that are performed after a single manual loading of the substrate in a furnace. Ex.1001-USP053, 5:9-18.

242. Prior to 2008, *in situ* diffusion (a subset or specific implementation of a “co-diffusion” process) was a well-known process. As I explained in Section XI.B.1 (Ground II, Motivation to Combine), co-diffusion and *in situ* diffusion (as it is defined in the ’053 patent) were known in the art. Ex.1019-Krygowski, 1 (“To fabricate high efficiency solar cells with minimal thermal processing, simultaneous diffusion techniques can be employed to co-diffuse the emitter and Back Surface Field (BSF). Researchers at Sandia National Laboratories [] have demonstrated an aluminum and phosphorus diffusion technique in which one high temperature (>800 °C) POCl₃ diffusion step is used to co-diffuse the emitter and pre-alloyed BSF[.] Workers at IMEC have simultaneously diffused boron and phosphorus [] on opposite sides of a silicon wafer [2]”); *see also* Ex.1054-Gee, 12:39-42 (“following screen printing and cure of boron diffusion barrier 94, a phosphorus diffusion step, such as using POCl₃ (30 to 60 Ω/sq), is employed, resulting in the co-diffusion of boron and phosphorus”).

243. Smith specifically teaches *in situ* deposition, and its teachings were consistent with the knowledge of persons of ordinary skill in the art prior to 2008.

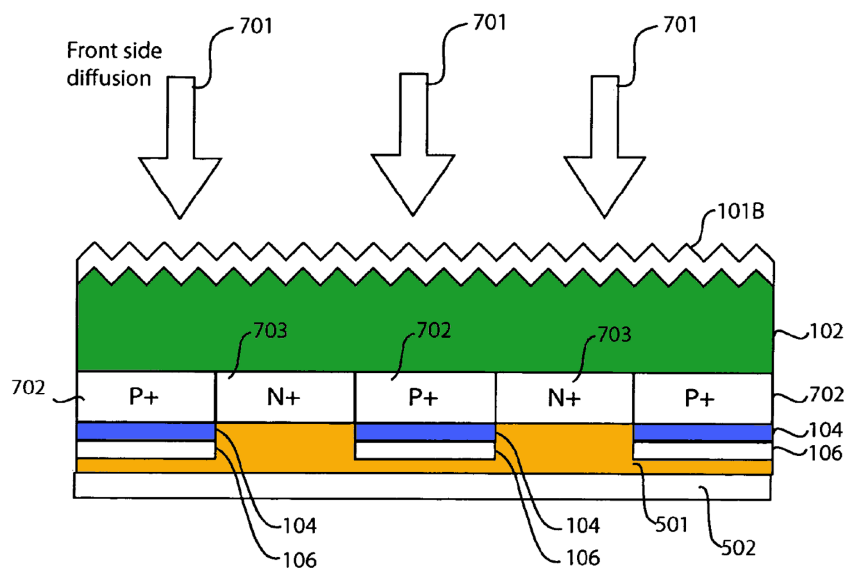
Smith's **teachings** and **benefits** of *in situ* diffusion are the **teachings** and **benefits** of *in situ* diffusion explained in the '053 patent:

'053 Patent	Smith
"The drive-in step to dope the polysilicon emitter 108 on the backside and to form the N-type doped regions...on the front side may be formed in-situ, which in the context of the present disclosure means a single manual (i.e., by fabrication personnel) loading of the substrate 101 in a furnace or other single chamber or multi-chamber processing tool." Ex.1001-USP053, 5:9-15.	In Fig. 7, the sample of Fig. 6 is subjected to in-situ steps. The steps are in-situ in that they are performed in one loading of wafer 102 into the wafer processing tool. Ex.1007-Smith, 3:40-42.
"In one embodiment, the drive-in step is performed in a diffusion furnace. " Ex.1001-USP053, 5:15-16.	"In one embodiment, the in-situ steps are performed in a furnace. " Ex.1007-Smith, 3:42-43.
"[I]n-situ diffusion ... advantageously helps in lowering fabrication cost. " Ex.1001-USP053, 5:16-18.	"[T]he use of in-situ steps to drive dopants into wafer 102 simplifies the fabrication process. " Ex.1007-Smith, 3:66-4:2.

244. In particular, Smith teaches fabricating a solar cell with *in situ* diffusion of different types of dopants to the frontside and the backside of the solar cell. Ex.1007-Smith, 3:40-4:22, Abstract, claims 1-2, 9, 10. Notably, Smith defines "in-situ" as steps performed "in one loading of wafer 102 into the wafer processing tool," which is the same as the '053 patent. Ex.1007-Smith, 3:40-42; Ex.1001-USP053, 5:9-15. Thus, Smith's *in situ* diffusion involves loading the wafer in the furnace and

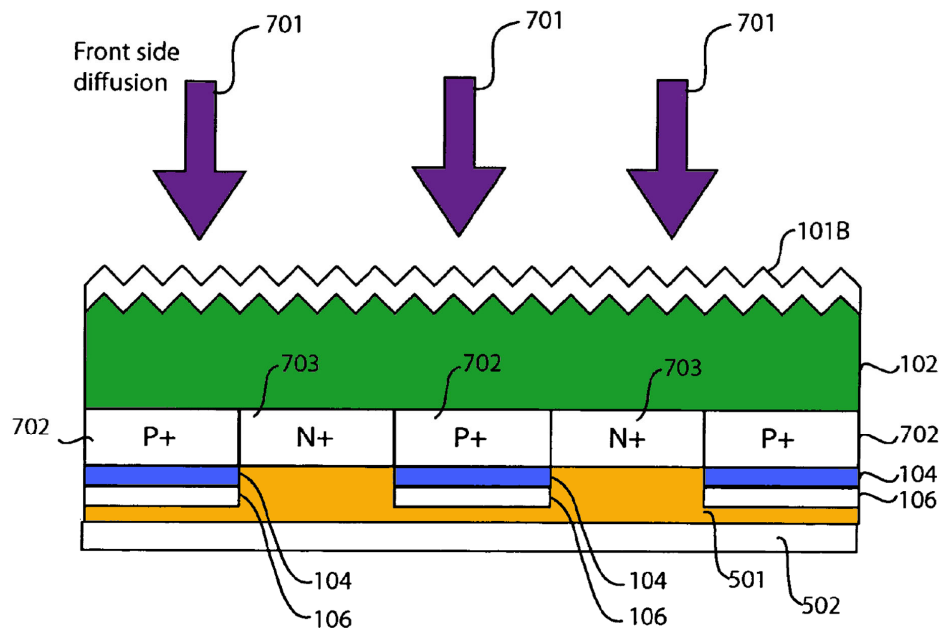
then performing two diffusion steps without removing the wafer (i.e., a single loading of the substrate).

245. Smith teaches a “first in-situ step” to diffuse p-type dopants and n-type dopants into the backside of the substrate. Ex.1007-Smith, 3:40-55. Specifically, “**wafer 102** is heated to about 1000 °C for one hour to diffuse dopants from **boron-doped silicon dioxide 104** and **phosphorus-doped silicon dioxide 501** into **wafer 102**.” Ex.1007-Smith, 3:43-55. Smith’s first *in situ* diffusion step is shown in the below annotated version of Figure 7, which depicts the **p-type dopant source 104** and **n-type dopant source 501**. Thus, the p-type and n-type dopants are diffused into the **wafer 102** from the backside during the first *in situ* diffusion step to form P+ regions 702 and N+ regions 703. Ex.1007-Smith, 3:40-55.



Ex.1007-Smith, Fig.7.

246. Smith teaches a second “in-situ” step that involves changing “**the furnace conditions...to diffuse phosphorus as an N-type dopant into wafer 102** from its front side.” Ex.1007-Smith, 3:56-4:2, Abstract, claims 1-2, 9, 10, 20. Smith’s second *in situ* diffusion step is shown in the below annotated version of Figure 7, which depicts the **N-type dopants** (purple arrows) being diffused into the frontside of the **wafer 102** to form an N+ region at the frontside of the **wafer 102**. As noted above, the second “in-situ” step is performed without removing the wafer from the furnace. That is, the first and second “in-situ” steps are performed after the wafer is loaded into the furnace (and the wafer is not removed from the furnace between steps).



Ex.1007-Smith, Fig.7.

247. Therefore, Smith teaches frontside and backside diffusion *performed in situ*. As discussed in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify the combination of Froitzheim and Gan to implement Smith's diffusion methods and would have had a reasonable expectation of success in doing so. Implementing Smith's diffusion methods in the combination of Froitzheim and Gan would have involved diffusing dopants from the first dopant source layer into the layer of polysilicon and diffusing dopants into the front surface of the silicon substrate using Smith's *in situ* diffusion process. Thus, the combination of Froitzheim, Gan, and Smith renders claim 15 obvious.

9. Claim 16

248. Claim 16, in addition to the steps of claim 9, includes *forming an oxide layer over a back surface of a silicon substrate*, which is obvious over the combination of Froitzheim, Gan, and Smith.

a. Element 16[pre]: A method of fabricating a solar cell comprising.

249. For the reasons I described in Section XI.B.2.a (Ground II, Element 9[pre]), Froitzheim and Smith teach *a method of fabricating a solar cell*, and Gan also teaches *a method of fabricating a structure for a solar cell*.

- b. Element 16[a]-[b]: forming an oxide layer over a back surface of a silicon substrate; forming a layer of polysilicon over the oxide layer.**

250. For the reasons I explained in Section XI.A.7.b (Ground I, Elements 16[a]-[b]), the combination of Froitzheim and Gan teaches *forming an oxide layer over a back surface of a silicon substrate and forming a layer of polysilicon over the oxide layer.*

- c. Elements 16[c]-[e]: diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.**

251. For the reasons I explained in Sections XI.A.7.c and XI.B.2.c-e (Ground I, Elements 16[c]-[e], Ground II, Elements 9[b]-[e]), the combination of Froitzheim, Gan, and Smith teaches *diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.*

252. As I discussed in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim in view of Gan and Smith. For these reasons, the combination of Froitzheim, Gan, and Smith renders claim 16 obvious.

10. **Claim 17: The method of claim 16 wherein diffusing dopants into the layer of polysilicon to form the backside junction with the silicon substrate comprises: forming a first dopant source layer over the layer of polysilicon; and diffusing dopants from the first dopant source layer into the layer of polysilicon.**

253. Claim 17 depends from claim 16. I therefore incorporate my analysis in Section XI.B.9 (Ground II, Claim 16). For the reasons I discussed in Sections XI.A.2.c-d, XI.A.7, XI.B.2.c, XI.B.9 (Ground I, Elements 9[b]-[c] and Claim 16; Ground II, Elements 9[b]-[c] and Claim 16), the combination of Froitzheim, Gan, and Smith teaches *forming a first dopant source layer over the layer of polysilicon; and diffusing dopants from the first dopant source layer into the layer of polysilicon*. The combination of Froitzheim, Gan, and Smith renders claim 17 obvious.

11. **Claim 18: The method of claim 16 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

254. Claim 18 depends from claim 16. I therefore incorporate my analysis in Section XI.B.9 (Ground II, Claim 16). For the reasons I discussed in Sections

XI.B.5 and XI.B.9 (Ground II, Claims 12 and 16), Froitzheim and Smith further teach *forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate*. As such, the combination of Froitzheim, Gan, and Smith renders claim 18 obvious.

12. Claim 19: The method of claim 16 further comprising: texturing the front surface of the silicon substrate.

255. Claim 19 depends from claim 16. I therefore incorporate my analysis in Section XI.B.9 (Ground II, Claim 16). For the reasons I discussed in Section XI.B.7 (Ground II, Claim 14), Froitzheim and Smith further teach *texturing the front surface of the silicon substrate*. Thus, the combination of Froitzheim, Gan, and Smith renders claim 19 obvious.

13. Claim 20: The method of claim 19 further comprising: forming an antireflective layer over the textured front surface of the silicon substrate.

256. Claim 20 depends from claim 19. I therefore incorporate my analysis in Section XI.B.12 (Ground II, Claim 19). For the reasons discussed in Section XI.B.7 (Ground II, Claim 14), Froitzheim and Smith further teach *forming an antireflective layer over the textured front surface of the silicon substrate*. Consequently, the combination of Froitzheim, Gan, and Smith renders claim 20 obvious.

14. Claim 1

257. Claim 1 includes the elements of claim 9 but specifically recites (1) the dopant type (n- vs. p-Type) and (2) “forming a capping layer.” These additional claim elements are also obvious over the combination of Froitzheim, Gan, and Smith.

- a. Element 1[pre]: A method of fabricating a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the method comprising**

258. As discussed in Sections XI.A.2.a and XI.B.2.a (Grounds I and II, Element 9[pre]), Froitzheim and Smith *teach a method of fabricating a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side* and Gan also teaches *a method of fabricating a structure for a solar cell*.

- b. Element 1[a]: forming a layer of polysilicon over a back surface of an N-type silicon substrate on the backside of the solar cell.**

259. As discussed in Sections XI.A.2.b and XI.B.2.b (Grounds I and II, Element 9[a]), the combination of Froitzheim and Gan teaches *forming a layer of polysilicon over a back surface of an N-type silicon substrate on the backside of the solar cell*.

c. Element 1[b]: forming a P-type dopant source over the layer of polysilicon.

260. As discussed in Sections XI.A.2.c and XI.B.2.c (Ground I, Element 9[b], Ground II, Elements 9[b]-[c]), the combination of Froitzheim, Gan, and Smith teaches *forming a P-type dopant source over the layer of polysilicon*.

d. Element 1[c]: forming a capping layer over the P-type dopant source.

261. The combination of Froitzheim, Gan, and Smith teaches *forming a capping layer over the P-type dopant source*.

262. As I discussed in Sections XI.A.2.c and XI.B.2.c (Ground I, Element 9[b], Ground II, Elements 9[b]-[c]), Froitzheim and Gan teach a P-type dopant source. Furthermore, Smith teaches *forming a capping layer over the P-type dopant source*. In Smith, the capping layer is referred to as a **first undoped oxide layer**.

263. Specifically, Smith teaches “a method of forming doped regions in a substrate of a back side contact solar cell.” Ex.1007-Smith, Abstract. The process includes “steps of depositing a **first doped oxide layer** on a back side of a **substrate**, depositing a **first undoped oxide layer** over the first doped oxide layer, [and] diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region in the substrate.” Ex.1007-Smith, Abstract, 1:43-3:55, claims 1-5, 11-13. The “**first doped oxide layer**” may be “boron-doped silicon dioxide

(SiO₂) ('BSG')," which is a *p-type dopant source*, as in claim element 1[c].
Ex.1007-Smith, 2:44-64; *see also* Ex.1001-USP053, 4:21-25 (discussing BSG).

264. Smith further teaches that the **undoped oxide layer** may be "**undoped silicon dioxide 106** [] deposited to a thickness of about 1200 Angstroms also by APCVD." Ex.1007-Smith, 2:55-57. APCVD deposition was a known technique used to deposit layers on a desired side of a wafer during solar cell manufacturing. Ex.1056-Agostinelli, 20:27-29 (explaining depositing oxide on the rear side using APCVD); Ex.1015-Meier, 6:20-25 (explaining using APCVD to deposit titanium dioxide anti-reflective coating); Ex.1057-NREL (1999 report explaining APCVD and tools).



Ex.1007-Smith, Fig.2.

265. A person of ordinary skill in the art would have known the undoped oxide layer is a capping layer. For instance, Smith teaches that the undoped oxide layer prevents the dopants from moving to unintended locations, similar to the '053 patent's description of the capping layer. *Compare* Ex.1007-Smith, claim 11, 3:50-

55 (“[U]ndoped silicon dioxide 106 beneficially prevents phosphorus from phosphorus-doped silicon dioxide 501 from diffusing into boron doped silicon dioxide 104. Also, undoped silicon dioxide 502 beneficially prevents phosphorus from phosphorus doped silicon dioxide 501 from diffusing into the furnace.”) *with* Ex.1001-USP053 4:18-21 (“A dielectric capping layer 462 is formed on the P-type dopant source 461 to prevent dopants from escaping [into the furnace] from the backside of the solar cell during the drive-in step.”). As discussed in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim to implement Smith’s diffusion methods and would have had a reasonable expectation of success in doing so.

e. Element 1[d]: diffusing P-type dopants from the P-type dopant source to the layer of polysilicon to form a backside junction with the N-type silicon substrate.

266. For the reasons I explained in Sections XI.A.2.d and XI.B.2.c (Ground I, Element 9[c], Ground II, Elements 9[b]-[c]), the combination of Froitzheim, Gan, and Smith teaches *diffusing P-type dopants from the P-type dopant source to the layer of polysilicon to form a backside junction with the N-type silicon substrate*.

f. Element 1[e]: diffusing N-type dopants into a front surface of the N-type silicon substrate.

267. As discussed in Sections XI.A.2.e and XI.B.2.d (Grounds I and II, Element 9[d]), Froitzheim and Smith teach *diffusing N-type dopants into a front surface of the N-type silicon substrate*.

g. Element 1[f]: forming a metal contact on the front side of the solar cell, wherein the metal contact is electrically coupled to the N-type silicon substrate.

268. As discussed in Sections XI.A.2.f and XI.B.2.e (Grounds I and II, Element 9[e]), Froitzheim teaches forming a metal contact on the front side of the solar cell, wherein the metal contact is electrically coupled to the N-type silicon substrate.

269. For these reasons, the combination of Froitzheim, Gan, and Smith renders claim 1 obvious.

15. Claim 2: The method of claim 1 wherein the P-type dopant source comprises borosilicate glass.

270. Claim 2 depends from claim 1. I therefore incorporate my analysis in Section XI.B.14 (Ground II, Claim 1). As discussed in Sections XI.A.4 and XI.B.4 (Grounds I and II, Claim 11), the combination of Froitzheim, Gan, and Smith teach *the P-type dopant source comprises borosilicate glass*. Thus, the combination of Froitzheim, Gan, and Smith render claim 2 obvious.

16. **Claim 3: The method of claim 1 wherein diffusing N-type dopants into the front surface of the N-type silicon substrate includes forming an N-type dopant source over the N-type silicon substrate and diffusing N-type dopants from the N-type dopants source into the N-type silicon substrate.**

271. Claim 3 depends from claim 1. I therefore incorporate my analysis in Section XI.B.14 (Ground II, Claim 1). For the reasons discussed in Sections XI.A.5 and XI.B.5 (Grounds I and II, Claim 12), Froitzheim and Smith teach *forming an N-type dopant source over the N-type silicon substrate and diffusing N-type dopants from the N-type dopants source into the N-type silicon substrate*. Thus, the combination of Froitzheim, Gan, and Smith renders claim 3 obvious.

17. **Claim 4: The method of claim 3 wherein the N-type dopant source comprises phosphorus doped silicon dioxide.**

272. Claim 4 depends from claim 3. I therefore incorporate my analysis in Section XI.B.16 (Ground II, Claim 3). For the reasons discussed in Section XI.B.6 (Ground II, Claim 13), the combination of Froitzheim, Gan, and Smith further teaches *the N-type dopant source comprises phosphorus doped silicon dioxide*. Thus, the combination of Froitzheim, Gan, and Smith renders claim 4 obvious.

18. **Claim 5: The method of claim 1 further comprising: texturing the front surface of the N-type silicon substrate; and forming an antireflective layer over the textured front surface of the N-type silicon substrate.**

273. Claim 5 depends from claim 1. I therefore incorporate my analysis in Section XI.B.14 (Ground II, Claim 1). For the reasons discussed in Sections XI.A.6

and XI.B.7 (Grounds I and II, Claim 14), Froitzheim and Smith further teach *texturing the front surface of the N-type silicon substrate and forming an antireflective layer over the textured front surface of the N-type silicon substrate*. Therefore, the combination of Froitzheim, Gan, and Smith renders claim 5 obvious.

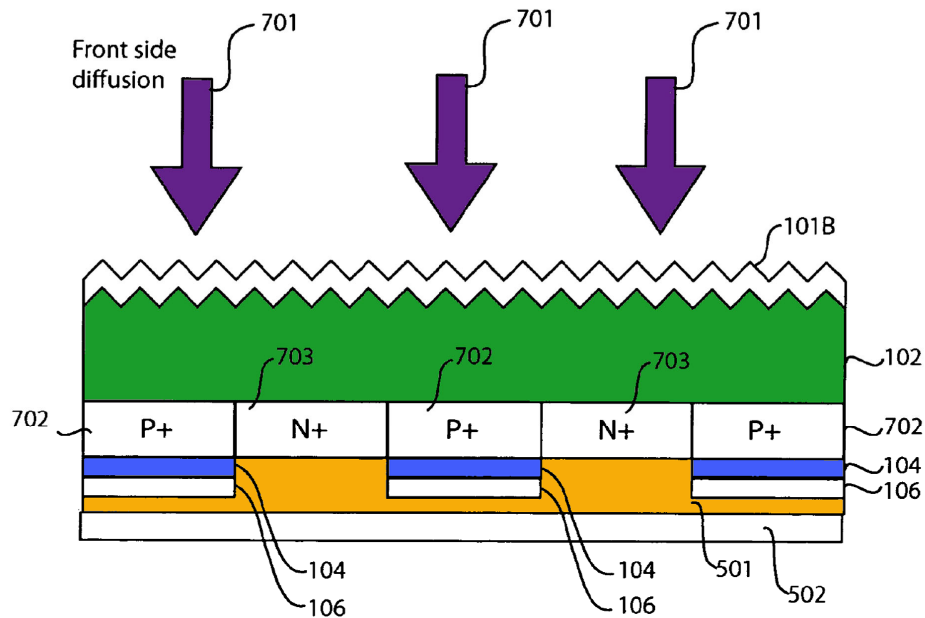
19. Claim 6: The method of claim 5 wherein the antireflective layer comprises silicon nitride.

274. Claim 6 depends from claim 5. I therefore incorporate my analysis in Section XI.B.18 (Ground II, Claim 5). For the reasons discussed in Sections XI.A.6 and XI.B.7 (Grounds I and II, Claim 14), Froitzheim and Smith further teach *the antireflective layer comprises silicon nitride*. Therefore, the combination of Froitzheim, Gan, and Smith renders claim 6 obvious.

20. Claim 7: The method of claim 1 wherein the diffusion of P-type dopants from the P-type dopant source to the layer of polysilicon and the diffusion of N-type dopants into the front surface of the N-type silicon substrate are performed in situ.

275. Claim 7 depends from claim 1. I therefore incorporate my analysis in Section XI.B.14 (Ground II, Claim 1). As discussed in Section XI.B.8 (Ground II, Claim 15), the combination of Froitzheim, Gan, and Smith further teaches *the diffusion of P-type dopants from the P-type dopant source to the layer of polysilicon and the diffusion of N-type dopants into the front surface of the N-type silicon substrate are performed in situ*.

276. For further detail, Smith teaches fabricating a solar cell with *in situ* diffusion of different types of dopants to the frontside and the backside of the solar cell. Ex.1007-Smith, 3:40-4:22, Abstract, claims 1-2, 9, 10. For instance, in Figure 7 and in the text describing Figure 7, Smith teaches *in situ* diffusion that involves two steps. The “first in-situ step” diffuses p-type dopants 104 and n-type dopants 501 to the substrate’s backside. Ex.1007-Smith, 3:40-55. The “second in-situ step” diffuses n-type dopants such as phosphorus to the front side. Ex.1007-Smith, 3:56-4:2.



Ex.1007-Smith, Fig. 7. This is a subset of a technique known in the art as “co-diffusion,” as I discussed above. *E.g.*, Ex.1019-Krygowski; *see also* Section XI.B.8 (Ground II, Claim 15). As discussed in Section XI.B.1 (Ground II, Motivation to

Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim to implement Gan's polysilicon emitter with Smith's diffusion methods and would have had a reasonable expectation of success. Thus, the combination of Froitzheim, Gan, and Smith renders claim 7 obvious.

21. Claim 8: The method of claim 1 wherein the capping layer comprises undoped silicon dioxide.

277. Claim 8 depends from claim 1. I therefore incorporate my analysis in Section XI.B.14 (Ground II, Claim 1). As discussed in Section XI.B.14.d (Ground II, Element 1[c]), the combination of Froitzheim, Gan, and Smith further teaches *the capping layer comprises undoped silicon dioxide*. Therefore, the combination of Froitzheim, Gan, and Smith renders claim 8 obvious.

C. Ground III: Claims 9-20 Are Invalid as Obvious over Li, Gan, and Smith

278. It is my opinion that claims 9-20 would have been obvious over the combination of Li, Gan, and Smith. Ground III relies on Li as the primary reference instead of Froitzheim. Li is similar to Froitzheim in that both Li and Froitzheim teach solar cells having a backside PN junction, among other features. Li teaches depositing an emitter over the rear surface of a substrate rather than creating a diffused emitter like Froitzheim. Gan also teaches a deposited emitter. Smith teaches deposition and diffusion methods for structures like Li and Gan (and

Froitzheim). As explained below, the combination of Li, Gan, and Smith renders claims 9-20 obvious.

1. Motivation to Combine

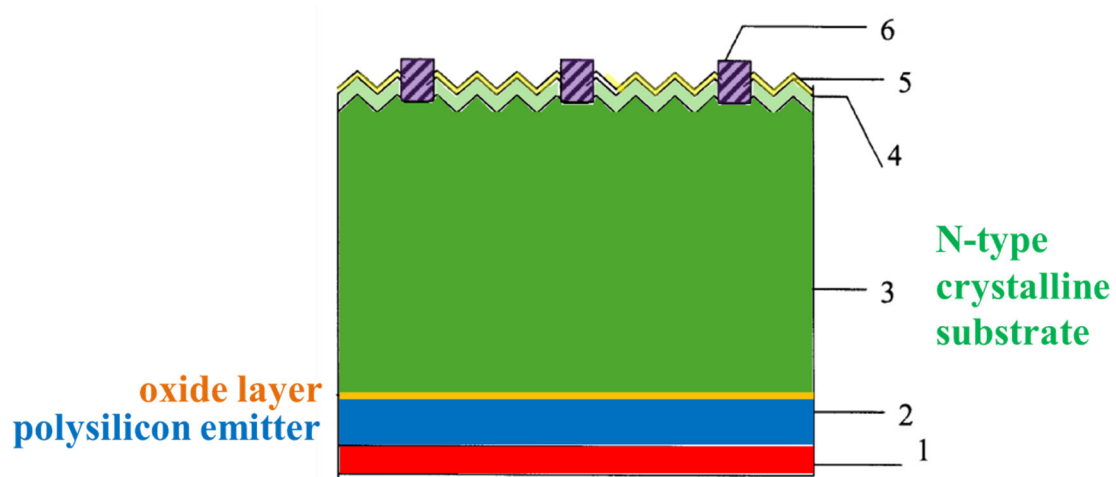
279. It is my opinion that each requirement for obviousness is met for the combination of Li, Gan, and Smith. **First**, like Froitzheim, Li is analogous art to the Challenged Claims. Li teaches solar cells, and Li is thus in the same field as the Challenged Claims. Li is also reasonably related to solving the problems addressed in the Challenged Claims, namely, increasing efficiency. Li further uses the same types of solutions as the Challenged Claims, namely, optimizing solar cell configuration. Ex.1008-Li, 1-4; Section XI.A.1 (Ground I, Motivation to Combine). Li is also focused on decreasing manufacturing costs. Ex.1008-Li, 3 (“Adoption of the amorphous silicon emitting region has the advantage that the amorphous silicon has a good surface passivation effect. Moreover, a deposition temperature is low (200°C), and a process is relatively simple, such that a high-temperature process is avoided, and **the manufacturing cost of the cell** is reduced.”), 4 (“According to the cell with the novel structure, because a PN junction is placed on the back surface of the cell, requirements for the minority carrier lifetime are high, and thus, high-quality crystalline silicon materials need to be used. **However, improvement of the**

cell efficiency and simplification of processes can make up for adverse influence caused by increase of material costs.”).

280. **Second**, a person of ordinary skill in the art would have been motivated to modify Li to incorporate a polysilicon emitter and tunnel oxide layer, as taught by Gan, with a reasonable expectation of success. Similar to Section XI.A (Ground I), the combination of Li’s back-junction solar cell and Gan’s polysilicon emitter and oxide layer simply amounts to using a known structural feature—Gan’s polysilicon emitter and tunnel oxide layer between the PN junction—to improve a similar device—Li’s back-junction cell. The combination of Li and Gan achieves goals common to both references and the industry—increasing a solar cell’s efficiency to thereby increase its power output.

281. The combination of Li’s back-junction solar cell and Gan’s polysilicon emitter and tunnel oxide layer structure would have also been a simple modification because it would have simply involved replacing Li’s deposited silicon thin film with Gan’s deposited **polysilicon emitter** and implementing an oxide layer between Li’s **N-type crystalline substrate** and the deposited **polysilicon emitter**. The implementation of Gan’s tunnel oxide layer and polysilicon emitter to Li is shown in the below figure, which depicts the **oxide layer** implemented on the backside of Li’s **N-type crystalline substrate** and the P-type **polysilicon emitter** implemented

over the **oxide layer** to form a PN junction with the **N-type crystalline substrate** on the backside of the solar cell.



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245-249.

282. In particular, a person of ordinary skill in the art would have been motivated to combine Li and Gan with a reasonable expectation of success for the reasons discussed in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine), which are incorporated by reference here.

283. For example and as described in Section X.D (Overview of the Prior Art – Li), similar to Froitzheim, Li teaches a solar cell that includes an n-type substrate and p-type emitter on the rear side of the substrate to form a backside PN junction. Ex.1008-Li, 2, Fig.2. Li teaches that this configuration improves a solar cell's efficiency. Ex.1008-Li, 2-4 (explaining that its solar cell is constructed such that it “avoids light loss caused by the amorphous silicon layer and the transparent

conductive thin film on the front surface, such that the cell efficiency can be improved by 10% or above,” compared to “an amorphous silicon/crystalline silicon heterojunction solar [‘HIT’] cell”). As I described in Sections VII.B (Overview of Solar Cell Efficiency), XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine), multiple references, including Gan and Borden-575, taught the benefits of using a polysilicon emitter and oxide layer. As I also described in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have understood that these teachings regarding the benefits of using a polysilicon emitter and oxide layer were applicable to backside junction solar cells, and applying these features to a backside junction solar cell would improve the efficiency of the cell. Gan specifically teaches that its polysilicon emitter and oxide layer were applicable to p-type emitters and backside junctions, just like the emitter and backside junction disclosed in Li. Ex.1005-Gan, 245-249; Ex.1008-Li, 4, Fig.1.

284. Additionally, similar to the motivations explained in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine) regarding the Froitzheim and Gan combination, a person of ordinary skill in the art would also have been motivated to retain a backside PN junction, as taught by Li, when implementing a polysilicon emitter and oxide layer. As discussed in Section

XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have understood that implementing the polysilicon emitter on the rear side of the cell would allow the cell to obtain the benefits of a polysilicon emitter and oxide layer, as taught by Gan, while avoiding the potential absorption drawback of a polysilicon emitter on the front side of the cell.

285. A person of ordinary skill in the art would have also been motivated to modify Li's back-junction solar cell to incorporate Gan's polysilicon emitter and oxide layer because each reference teaches similar and compatible solar cell structures. Li and Gan each teach solar cell structures that have the same basic configuration of a silicon wafer substrate, p-type emitter, and metal contacts. Ex.1008-Li, Abstract, 4, Fig.1; Ex.1005-Gan, 245-249. Indeed, Li and Gan both teach solar cell structures that have deposited emitters over a silicon substrate. Ex.1008-Li, 4, Fig.1; Ex.1005-Gan, 245-246. As a result, a person of ordinary skill in the art would have understood that Li and Gan's deposited emitters were easily interchangeable without needing additional equipment—e.g., a furnace for diffusion—to manufacture the modified solar cell.

286. Accordingly, for the reasons explained here and in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.B.1 (Ground II, Motivation to Combine),

a person of ordinary skill in the art would have been motivated to modify Li's backside PN junction (with a reasonable expectation of success) to incorporate a polysilicon emitter and oxide layer as taught by Gan.

287. For the reasons I explained in Section XI.B.1 (Ground II, Motivation to Combine), a person of ordinary skill in the art would have been further motivated to combine Smith with the combined structure of Li and Gan. As I explained in Section X.C (Overview of the Prior Art – Smith), Smith teaches solar cell manufacturing techniques. In particular, Smith teaches “simplifying the fabrication of solar cells” to lower manufacturing costs. Ex.1007-Smith, 1:36-40. A person of ordinary skill in the art would have been thus motivated to obtain the manufacturing efficiencies taught by Smith acknowledging that decreasing manufacturing cost was, like increasing cell efficiency, an important consideration. Ex.1008-Li, 3 (discussing processing such that “the manufacturing cost of the cell is reduced.”). As explained previously, a person of ordinary skill in the art would have understood that Smith's APCVD, diffusion barrier, and in-situ diffusion processes would have been readily applied to creating the combined structure of Li and Gan, and it would have been desirable to do so. For instance, as discussed in Section XI.B.1 (Ground II, Motivation to Combine), Smith's teachings would have allowed the front side and

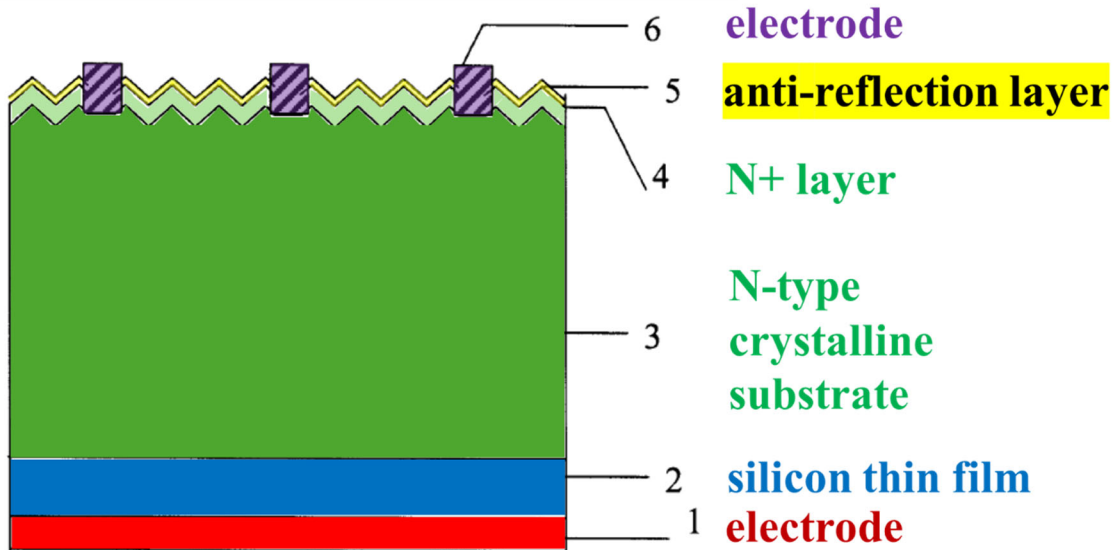
the back side of the wafers to be doped at the same time, decreasing the number of required steps and thus the cost.

288. As a result, a person of ordinary skill in the art would have been motivated to manufacture the combination of Li and Gan using Smith's manufacturing techniques because using Smith's techniques would improve Li's emitter and efficiency (by implementing Gan's emitter) and simplify the diffusion process by reducing the number of steps and costs involved (by implementing Smith's teachings to the combination of Li and Gan). *See* Sections XI.A.1 and XI.B.1 (Grounds I and II, Motivation to Combine). Such routine solar cell fabrication steps would have been implementable with a reasonable expectation of success for the same reasons I explained in Sections XI.A.1 and XI.B.1 (Grounds I and II, Motivation to Combine), including because Li has a similar structure to Froitzheim (back-junction solar cell) and to Gan (deposited emitter) as well as similar manufacturing processes to Froitzheim and Gan, which could be improved by implementing Smith. Consequently, a person of ordinary skilled in the art would have been motivated to combine Li, Gan, and Smith with a reasonable expectation of success.

2. **Claim 9**

a. **Element 9[pre]: A method of fabricating a solar cell.**

289. Li teaches *a method of fabricating a solar cell*. Ex.1008-Li, Title, Abstract, 3-4, Claims 1-6, Fig.1. For instance, Li teaches multi-step instructions for manufacturing a solar cell. Specifically, Li teaches providing “[a] high-quality **N-type monocrystalline silicon wafer (3)**,” whose “surfaces are cleaned and textured by a standard industrial process.” Ex.1008-Li, 4. Then, “a highly doped **N+ layer (4)** with a sheet resistance of 100–300 Ω/cm is first diffused on the front surface.” Ex.1008-Li, 4. Next, “[a] **thin film (5)** having an anti-reflection effect, such as SiN or SiO₂, etc., with a thickness of 70–120 nm, is deposited or grows on the N+ layer.” Ex.1008-Li, 4. Then, “[a] **silicon thin film (2)**, such as amorphous silicon, microcrystalline silicon, or nanocrystalline silicon, with a thickness of 20-200 nm, is deposited on the back surface of the **N-type monocrystalline silicon wafer (3)**.” Ex.1008-Li, 4. “Finally, a positive **electrode (6)** is prepared on the **anti-reflection layer (5)**, and a negative **electrode (1)** is prepared on the **silicon thin film**.” Ex.1008-Li, 4.



Ex.1008-Li, Fig.1.

290. For the reasons I explained in Section XI.B.2.a (Ground II, Element 9[pre]), Smith teaches *a method of fabricating a solar cell* and Gan also teaches *a method of fabricating a structure for a solar cell*.

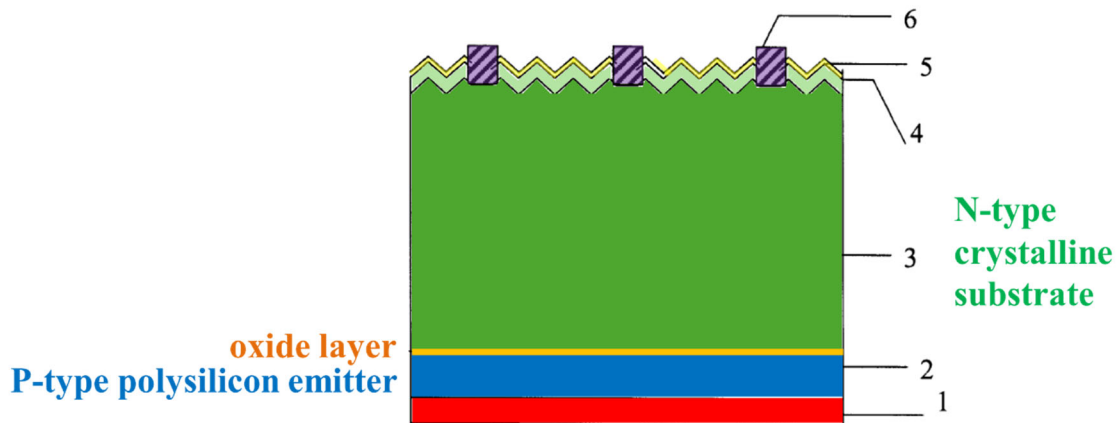
b. Element 9[a]: forming a layer of polysilicon over a back surface of a silicon substrate.

291. The combination of Li and Gan teaches *forming a layer of polysilicon over a back surface of a silicon substrate*.

292. Li teaches *forming (depositing) a layer of silicon over a back surface of a silicon substrate*. Ex.1008-Li, 4, Abstract, claims 1, 3, and 5, Fig.1. Li teaches “[a] **layer of silicon thin film [2]** is deposited on a back surface of **N-type monocrystalline silicon** to form an emitting region (a P-type silicon thin film can

be deposited on a layer of intrinsic silicon thin film which is first deposited on the back surface of the N-type monocrystalline silicon, or a P-type silicon thin film can be directly deposited on the N-type monocrystalline silicon)” (i.e. the **silicon thin film** is *formed over a back surface of the substrate*). Ex.1008-Li, 4, Abstract, claims 1, 3 and 5, Fig.1. Li teaches that the **layer of silicon thin film 2** is “P-type.” Ex.1008-Li, 4, claim 6.

293. In addition, as I discussed in Section XI.A.2.b (Ground I, Element 9[a]), Gan teaches *forming a layer of polysilicon* on a silicon substrate. *See, e.g.*, Ex.1005-Gan, 246 (“Polysilicon deposition”). As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li by replacing Li’s **layer of silicon thin film** with Gan’s **P-type polysilicon emitter**, both of which are deposited emitters. Because Li’s and Gan’s emitters are both deposited emitters, the process of adding the emitters to the substrate would have been similar in both Li and Gan, and thus, as I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have had a reasonable expectation of success. The combined structure of Li’s back-junction solar cell with Gan’s polysilicon emitter and oxide layer is shown below. Accordingly, the combination of Li and Gan teaches this element.



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245-249.

c. Element 9[b]: forming a first dopant source layer over the layer of polysilicon

294. The combination of Li, Gan, and Smith teaches *forming a first dopant source layer over the layer of polysilicon*.

295. As I explained above in Section XI.C.2.b (Ground III, Element 9[a]), Li teaches that a “layer of [P-type] silicon thin film is deposited on a back surface of N-type monocrystalline silicon to form an emitting region.” Ex.1008-Li, 4, 1-3 (discussing p-type emitters). Also, as I explained above, Gan teaches a polysilicon emitter. Section X.B (Overview of the Prior Art – Gan). Thus, the combined structure of Li and Gan teaches a backside polysilicon emitter layer.

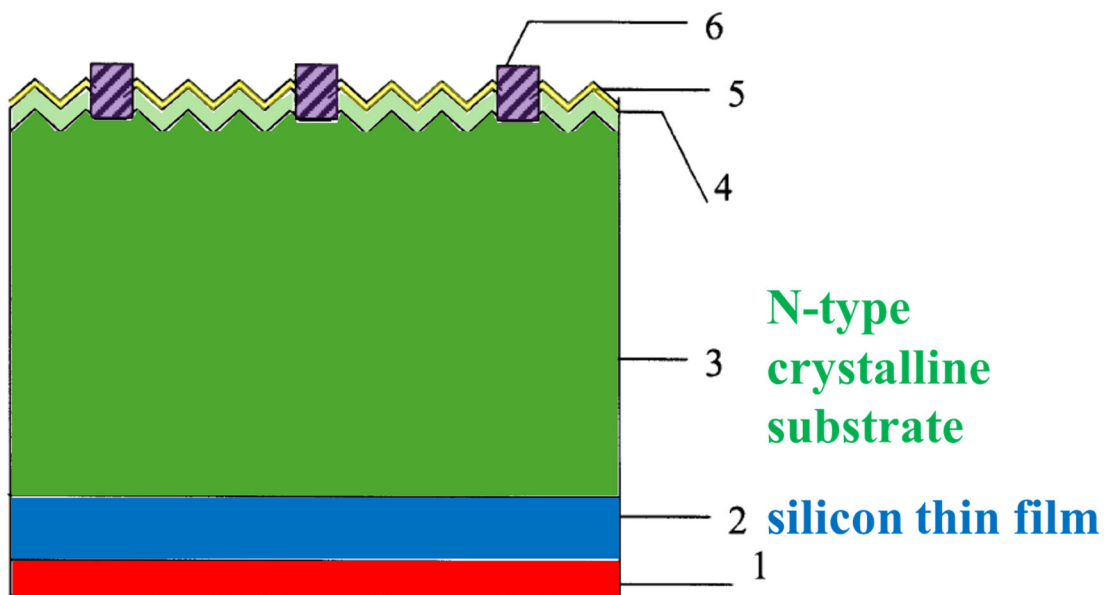
296. Gan and Smith each further teaches *forming a first dopant source layer over the layer of polysilicon*. For example, as explained in Sections XI.A.2.b-c (Ground I, Elements 9[a]-[b]), Gan’s “process sequence” includes depositing a layer

of polysilicon on the substrate, and then depositing “[d]oped glass” (which would be the claimed *forming a first dopant source layer*) on “both sides” of the wafer (which would include the claim language *over a layer of polysilicon*). Ex.1005-Gan, 246. The doped glass contains p-type dopants and is used to create a “p-type polysilicon emitter.” Ex.1005-Gan, 246, 248. As I explained in Section XI.B.2.c (Ground II, Element 9[b]-[c]), Smith further teaches forming a *first dopant source layer*. As discussed in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to replace Li’s **layer of silicon thin film** with Gan’s polysilicon layer and utilize Gan’s or Smith’s methods of introducing a *dopant source layer* to introduce a *dopant source layer over the layer of polysilicon*, with a reasonable expectation of success. Thus, the combination of Li, Gan, and Smith teaches *forming a first dopant source layer over the layer of polysilicon*.

d. Element 9[c]: diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate

297. The combination of Li, Gan, and Smith teaches *diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate*.

298. Li teaches forming a *backside junction with the silicon substrate*. A person of ordinary skill in the art would have known that Li's teaching of depositing **the layer of silicon thin film 2** on the "back surface" forms a *backside junction* with the **N-type silicon substrate**. **The layer of silicon thin film 2** is located on the backside of the solar cell and is oppositely doped from the **substrate**, which is consistent with the '053 patent's description of a "backside junction." Ex.1008-Li, 3 ("[A] PN junction is placed on the back surface of the cell."); *see also* Ex.1001-USP053, 1:53-55 ("A bipolar solar cell includes a backside junction formed by an N-type silicon substrate and a P-type polysilicon emitter formed on the backside of the solar cell."). The backside junction configuration resulting from Li's methods is shown below:



Ex.1008-Li, Fig.1.

299. As discussed in Section XI.A.2.d (Ground I, Element 9[c]), Gan further teaches *diffusing dopants from the first dopant source layer to the **layer of polysilicon***. As I previously discussed, Gan teaches doped glass is deposited on the layer of polysilicon and then dopants from the doped glass are driven into the polysilicon at 900-1000 °C. Ex.1005-Gan, 246; Section XI.A.2.d (Ground I, Element 9[c]). A person of ordinary skill in the art would have known that “driv[ing]-in” dopants meant diffusing dopants from the doped glass that had been deposited on the polysilicon layer, consistent with the references I explained in Section VII.A.1 (Overview of Solar Cells – Doping). Ex.1005-Gan, 246; Section XI.A.2.d (Ground I, Element 9[c]). As I discussed in XI.B.2.c (Ground II, Elements 9[b]-9[c]), Smith further teaches *diffusing dopants from a first dopant source layer into a silicon substrate*.

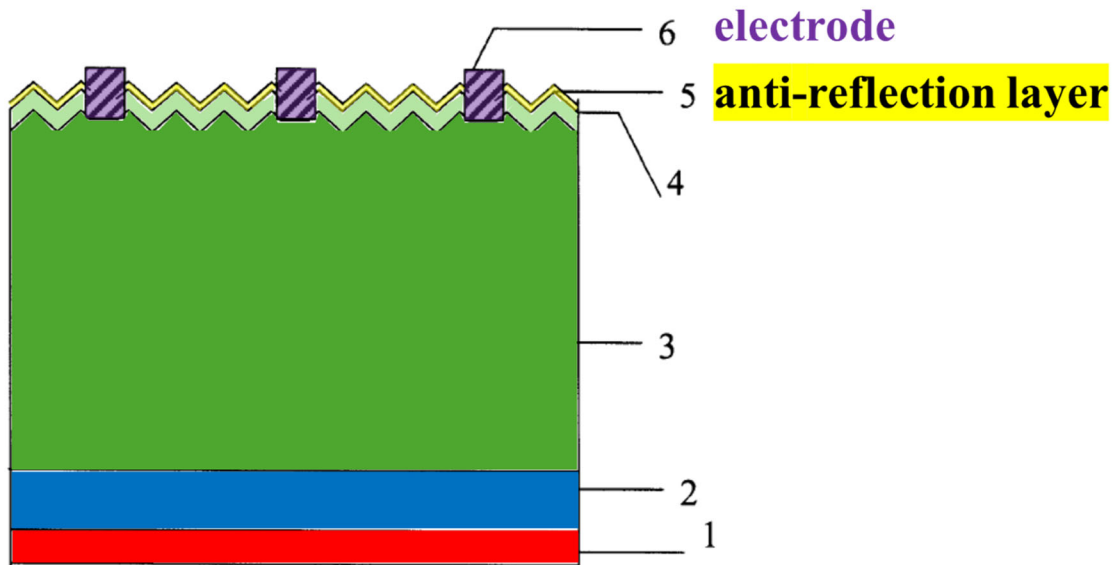
300. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to replace Li’s **layer of P-type silicon thin film**—a deposited emitter—with another (polysilicon) deposited emitter doped by diffusing dopants from a dopant source layer taught by both Gan and Smith. Further, a person of ordinary skill in the art would have had a reasonable expectation of success in doing so. Thus, the combination of Li, Gan,

and Smith teaches *diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate.*

e. Element 9[d]: diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.

301. Li and Smith teach *diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation.*

302. Li teaches fabricating a solar cell with *the front surface of the silicon substrate facing the sun during normal operation.* As shown in Figure 1 of Li below, Li teaches a solar cell that includes a “front surface” and a “back surface.” Ex.1008-Li, Abstract, 4, Fig., claims 1-3. A person of ordinary skill in the art would have known that the “front surface” faced the sun to collect solar radiation during normal operation. A person of ordinary skill in the art would have known that the front surface was opposite to the back surface, as solar cells typically were configured. Furthermore, Li’s figure confirms that its “front surface” is the sun-facing side because it has a textured surface (jagged edges), an **anti-reflection layer 5**, and a front **electrode 6** that does not cover the entire surface, all of which were designed for the solar cell to receive more sunlight. Ex.1008-Li, 4, Fig.1.



Ex.1008-Li, Fig.1.

303. Moreover, Li teaches *diffusing dopants into a front surface of the silicon substrate*. Specifically, Li teaches diffusing “**a highly doped N+ layer (4)** with a sheet resistance of 100–300 Ω/cm ...on the front surface” of the solar cell.

Ex.1008-Li, 4. Li explains that “the layer is used for passivating the front surface of a cell by using changes in doping concentration and for providing good ohmic contact to a front surface electrode.” Ex.1008-Li, 4.

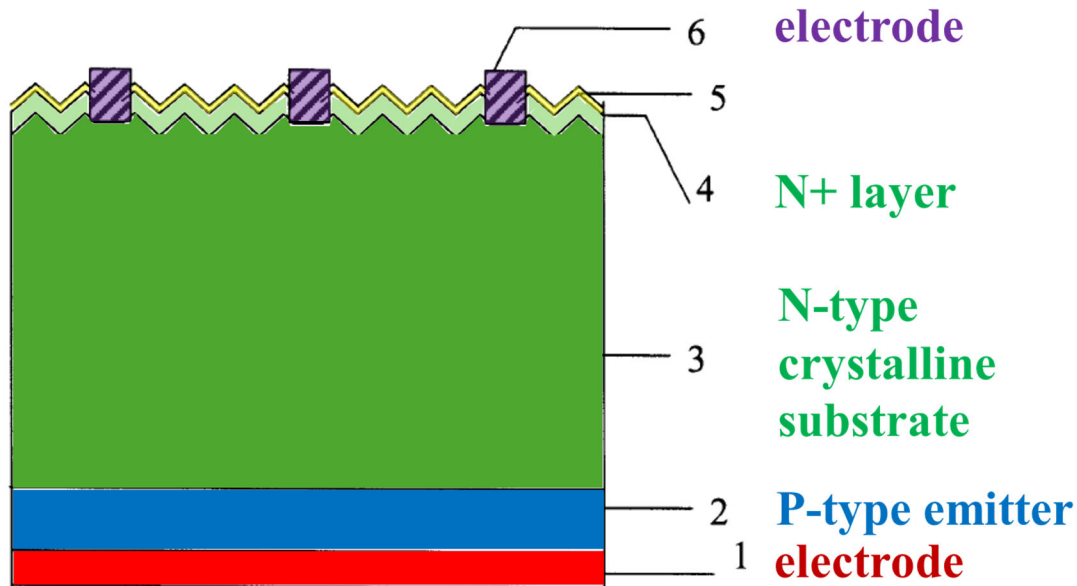
304. In addition, as discussed in Section XI.B.2.d (Ground II, Element 9[d]), Smith teaches *diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation*. Finally, as discussed in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to implement

Smith's diffusion methods, and also would have had a reasonable expectation of success of doing so.

f. Element 9[e]: forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate

305. Li teaches *forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.*

306. Li's solar cell includes a front "**electrode**." Ex.1008-Li, 4. A person of ordinary skill in the art would have understood, as shown in Li's Figure, that the **electrode** is electrically connected to the **N-type crystalline silicon substrate 3** (i.e., *substrate*) via the highly doped **N+ layer 4**. Ex.1008-Li, 4, Fig.1. Li's solar cell also includes a rear **electrode 1** on the back of a **silicon thin film 2** (i.e., *emitter*). Ex.1008-Li, 4, Fig.1. As discussed in Section X.D (Overview of the Prior Art – Li), Li's emitter is a P-type emitter. Thus, as shown below, the rear **electrode 1 (red)** would be electrically connected to the **P-type emitter**.



Ex.1008-Li, Fig.1.

307. A person of ordinary skill in the art would have understood that Li's "electrodes" were *metal contacts*. For instance, Li explains that "a *metal electrode* layer [1] on the back surface can re-reflect light that penetrates the cell back into the cell." Ex.1008-Li, 4; *see also* 3 (discussing the "front surface structure" of background art as having "a metal grid"). A person of ordinary skill in the art would have known that metal electrodes were common in solar cells at the time because electrodes of conductive materials like metal are required for a solar cell to function.

308. Smith and Gan also teach *forming a metal contact, wherein the metal contact is electrically coupled to the silicon substrate*. For instance, the final step of Gan's 12 step process is "[m]etal finger definition," which refers to forming *metal contacts*. Ex.1005-Gan, 246. Likewise, Smith teaches forming a solar cell having

metal contacts, consistent with typical processes for forming contacts. Ex.1007-Smith, 1:20-35, 1:44-57, 2:4:3-11, claim 1; *see also* Section VII.A.3 (Overview of Solar Cells – Metal Contact).

309. Accordingly, the combination of Li, Gan, and Smith renders claim 9 obvious.

3. Claim 10: The method of claim 9 wherein the first dopant source layer comprises P-type dopants.

310. Claim 10 depends from claim 9. I therefore incorporate my analysis in Section XI.C.2 (Ground III, Claim 9). For the reasons described in Section XI.C.2.c (Ground III, Element 9[b]), the combination of Li, Gan, and Smith teaches that *the first dopant source layer comprises P-type dopants*. As such, the combination of Li, Gan, and Smith renders claim 10 obvious.

4. Claim 11: The method of claim 9 wherein the first dopant source layer comprises borosilicate glass.

311. Claim 11 depends from claim 9. I therefore incorporate my analysis in Section XI.C.2 (Ground III, Claim 9). For the reasons described in Section XI.B.4 (Ground II, Claim 11), the combination of Li, Gan, and Smith further teaches *the first dopant source layer comprises borosilicate glass*. As discussed in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to implement Gan's polysilicon emitter and

Smith's diffusion methods with a reasonable expectation of success. As such, the combination of Li, Gan, and Smith further renders claim 11 obvious.

5. **Claim 12: The method of claim 9 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

312. Claim 12 depends from claim 9. I therefore incorporate my analysis in Section XI.C.2 (Ground III, Claim 9). The combination of Li, Gan, and Smith further teaches *forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate*, which merely describes how basic diffusion works, i.e., forming a dopant layer and diffusing dopants from the dopant layer, specifically for the front surface of a solar cell.

313. Li teaches that “[a]fter surfaces [of the substrate] are cleaned and textured by a standard industrial process,” dopants are diffused into the front surface of substrate to form **a highly doped N+ layer (4)**. Ex.1008-Li, 4. A person of ordinary skill in the art would have known that diffusing dopants into the front surface would have entailed creating a dopant source layer on the front surface of the substrate and diffusing dopants from that layer into the substrate. *See* Sections VII.A.1 (Overview of Solar Cells – Doping) and XI.A.5 (Ground I, Claim 12); e.g.,

Ex.1052-Avery, 1:19-31; Ex.1023-Nelson, 187; Ex. 1019-Krygowski, 1; Ex.1030-Benick; Ex.1007-Smith, 3:56-57; Ex.1004-Froitzheim, [0044].

314. In addition, for the reasons discussed in Section XI.C.2.e (Ground III, Element 9[d]), Smith also teaches *forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate*. As discussed in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li in view of Smith's diffusion methods with a reasonable expectation of successfully. As such, the combination of Li, Gan, and Smith renders claim 12 obvious.

6. **Claim 13: The method of claim 12 wherein the second dopant source layer comprises phosphorus doped silicon dioxide.**

315. Claim 13 depends from claim 12. I therefore incorporate my analysis in Section XI.C.5 (Ground III, Claim 12). The combination of Li, Gan, and Smith further teaches that *the second dopant source layer comprises phosphorus doped silicon dioxide*.

316. As I explained in Section XI.B.6 (Ground II, Claim 13), Smith teaches forming a layer of glass with phosphorous dopants (which would be *phosphorus doped silicon dioxide*) as part of the POCl₃ diffusion. *See also* Section XI.B.5

(Ground II, Claim 12); Ex.1007-Smith, 3:19-55 (describing dopant source layers of “phosphorus doped silicon dioxide” formed during phosphorus doping processes), cl. 1-2, 4. Therefore, the combination of Li, Gan, and Smith renders claim 13 obvious.

7. **Claim 14: The method of claim 9 further comprising: texturing the front surface of the silicon substrate; and forming an antireflective layer over the textured front surface of the silicon substrate.**

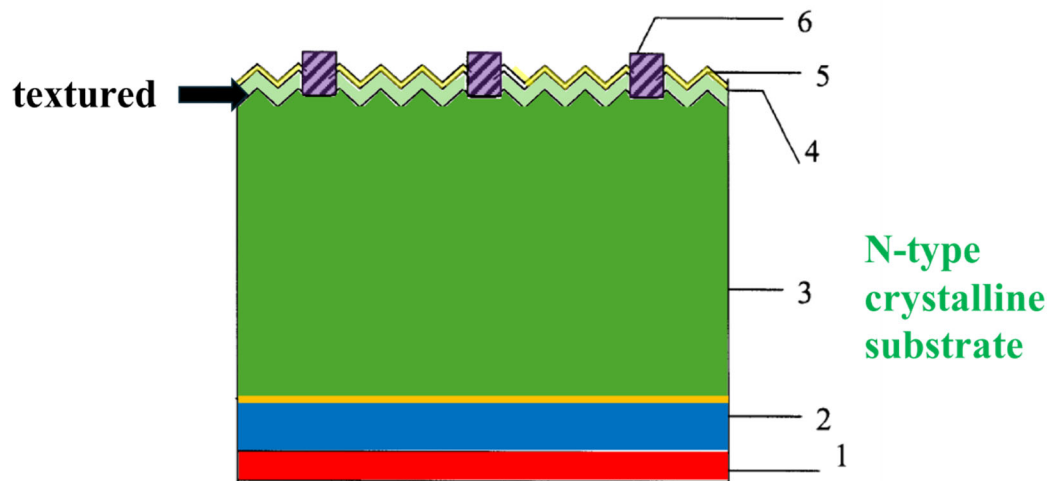
317. Claim 14 depends from claim 9. I therefore incorporate my analysis in Section XI.C.2 (Ground III, Claim 9). The combination of Li, Gan, and Smith further teaches *texturing the front surface of the silicon substrate[] and forming an antireflective layer over the textured front surface of the silicon substrate.*

318. As I explained in Section VII.A.4 (Overview of Solar Cells – Texturing and Antireflection Coating), texturing the front surface of the substrate was a routine and typical process applied to solar cells. Li likewise teaches this well-known and common step. Li teaches that the surfaces of the **N-type crystalline [substrate] 3** are “*textured* by a standard industrial process.” Ex.1008- Li, 4, claim 2 (“[T]he solar cell is structurally a positive electrode/anti-reflection layer/*surface textured N-type crystalline silicon*/silicon thin film/back electrode.”). Li explains the “*texturing treatment*” is used “to reduce light reflection and improve a light trapping effect,

which is conducive to improving the photoelectric conversion efficiency of the cell.”

Ex.1008- Li, 4.

319. In addition to the text description, the **textured** surface is also shown in Li’s modified figure (Li and Gan combined), below, by the jagged edges on the front side of the solar cell, as was commonly done to graphically depict texturing. *E.g.*, Ex.1018-Nelson, 188; Ex.1024-Borden-578, Fig.1A; *see also* Ex.1007-Smith, Fig.7; Ex.1001-USP053, Fig.1. Thus, Li teaches *texturing the front surface of the silicon substrate*.

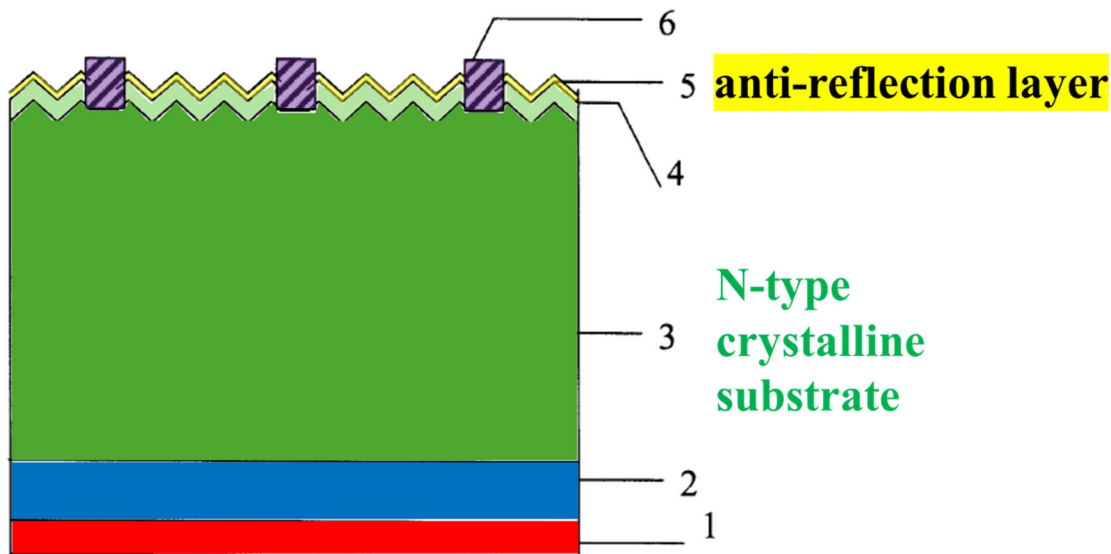


Ex.1008-Li, Fig.1.

320. In addition, as I have discussed, *an antireflective layer over the textured front surface of a substrate* was a standard solar cell feature by 2008. *See* Section VII.A.4 (Overview of Solar Cells – Texturing and Antireflection Coating). As such,

Li also teaches *forming an antireflective layer over the textured front surface of the silicon substrate.*

321. Li teaches forming “[a]n *anti-reflection film*...on the *textur[ed]* surface to further improve the photoelectric conversion efficiency of the cell.” Ex.1008-Li, 4, claim 2. Li’s figure, below, shows a solar cell with an **anti-reflection layer 5** over the textured front surface. The **anti-reflection layer 5** can be a material such as SiN or SiO₂. Ex.1008-Li, 2. A person of ordinary skill in the art would have understood that SiN or SiO₂ were commonly used as an antireflective layer. *E.g.*, Ex.1018-Nelson, 188 (“Suitable materials for silicon [AR coating include]...silicon nitride (Si₃N₄)”).



Ex.1008-Li, Fig.1.

322. Further, as I explained in Section XI.B.7 (Ground II, Claim 14), Smith also teaches *forming an antireflective layer over the textured front surface of a substrate*. Section XI.B.7. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to combine it with Gan. Since both Li and Smith teach *forming an antireflective layer over the textured front surface of a substrate*, a person of ordinary skill in the art would have had a reasonable expectation of success when further combining with Smith. *See* Section XI.C.1 (Ground III, Motivation to Combine). Thus, the combination of Li, Gan, and Smith renders claim 14 obvious.

8. **Claim 15: The method of claim 9 wherein the diffusion of dopants from the first dopant source layer to the layer of polysilicon and the diffusion of dopants into the front surface of the silicon substrate are performed in situ.**

323. Claim 15 depends from claim 9. I therefore incorporate my analysis in Section XI.C.2 (Ground III, Claim 9). For the reasons discussed in Section XI.B.8 (Ground II, Claim 15), the combination of Li, Gan, and Smith further teaches that *the diffusion of dopants from the first dopant source layer to the layer of polysilicon and the diffusion of dopants into the front surface of the silicon substrate are performed in situ*. As I explained Section XI.B.8 (Ground II, Claim 15), Smith teaches *in situ* diffusion. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to

modify the Li-Gan combination to implement one of Smith's manufacturing methods, in situ diffusion, and the reasons for doing so include those discussed in Ground II (the combination of Froitzheim, Gan, and Smith). A person of ordinary skill in the art also would have had a reasonable expectation of success, for the reasons I have discussed. *See* Section XI.C.1 (Ground III, Motivation to Combine). Thus, the combination of Li, Gan, and Smith renders claim 15 obvious.

9. Claim 16

324. Claim 16, in addition to the steps of claim 9, includes *forming an oxide layer over a back surface of a silicon substrate*, which is obvious over the combination of Li, Gan, and Smith.

a. Element 16[pre]: A method of fabricating a solar cell comprising.

325. For the reasons I described in Section XI.C.2.a (Ground III, Element 9[pre]), Li and Smith teach *a method of fabricating a solar cell*, and Gan also teaches *a method of fabricating a structure for a solar cell*.

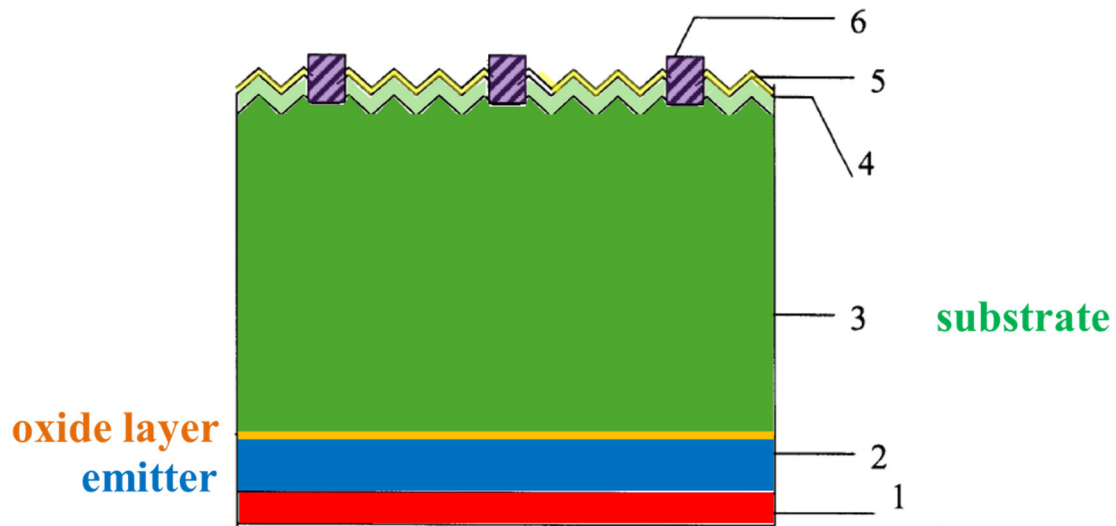
b. Element 16[a]-[b]: forming an oxide layer over a back surface of a silicon substrate; forming a layer of polysilicon over the oxide layer.

326. The combination of Li and Gan teaches *forming an oxide layer over a back surface of a silicon substrate [and] forming a layer of polysilicon over the oxide layer*.

327. For the reasons I discussed in Section XI.C.2.b (Ground III, Element 9[a]), Li teaches forming a back-junction solar cell by depositing a silicon emitter, as shown in Li's figure and corresponding text. As I discussed in Section XI.A.2.b (Ground I, Element 9[a]), Gan also teaches depositing a **P-type polysilicon emitter**, which was particularly useful for solar cells that had PN junctions on the backside.

328. As I discussed in Section XI.A.7.b (Ground I, Elements 16[a]-[b]), Gan teaches manufacturing a solar cell structure including the steps of forming a "thermally grown interfacial oxide" over the surface of a silicon substrate. Ex.1005-Gan, 245-246. Gan thus teaches *forming an oxide layer*.

329. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to manufacture a solar cell by implementing Gan's *oxide layer on the back surface of Li's substrate and replacing Li's emitter with a polysilicon emitter* (as taught by Gan) with a reasonable expectation of success. As shown in the following modified Li Figure, the modification would have been a simple exchange of Li's deposited emitter with Gan's oxide layer and polysilicon emitter (also a deposited emitter):



Ex.1008-Li, Fig.1.

- c. **Element 16[c]-[e]:** diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

330. For the reasons I explained in Sections XI.C.2.d-f (Ground III, Elements 9[c]-9[e]), the combination of Li, Gan, and Smith teaches *diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate; diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.*

331. In sum, the combination of Li, Gan, and Smith renders claim 16 obvious.

10. **Claim 17: The method of claim 16 wherein diffusing dopants into the layer of polysilicon to form the backside junction with the silicon substrate comprises: forming a first dopant source layer over the layer of polysilicon; and diffusing dopants from the first dopant source layer into the layer of polysilicon.**

332. Claim 17 depends from claim 16. I therefore incorporate my analysis in Section XI.C.9 (Ground III, Claim 16). For the reasons I explained in Section XI.C.2.c-d (Ground III, Claims 9[b]-[c]), the combination of Li, Gan, and Smith teaches *forming a first dopant source layer over the layer of polysilicon[] and diffusing dopants from the first dopant source layer into the layer of polysilicon* and renders claim 17 obvious.

11. **Claim 18: The method of claim 16 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.**

333. Claim 18 depends from claim 16. I therefore incorporate my analysis in Section XI.C.9 (Ground III, Claim 16). For the reasons I explained in Section XI.C.5 (Ground III, Claims 12), the combination of Li, Gan, and Smith teaches *forming a second dopant source layer over the silicon substrate and diffusing*

dopants from the second dopant source layer into the silicon substrate and renders claim 18 obvious.

12. Claim 19: The method of claim 16 further comprising: texturing the front surface of the silicon substrate.

334. Claim 19 depends from claim 16. I therefore incorporate my analysis in Section XI.C.9 (Ground III, Claim 16). For the reasons I explained in Section XI.C.7 (Ground III, Claim 14), Li and Smith teach *texturing the front surface of the silicon substrate*. Therefore, the combination of Li, Gan, and Smith renders claim 19 obvious.

13. Claim 20: The method of claim 19 further comprising: forming an antireflective layer over the textured front surface of the silicon substrate.

335. Claim 20 depends from claim 19. I therefore incorporate my analysis in Section XI.C.12 (Ground III, Claim 19). For the reasons I explained in Section XI.C.7 (Ground III, Claim 14), Li and Smith further teach *forming an antireflective layer over the textured front surface of the silicon substrate*. Therefore, the combination of Li, Gan, and Smith renders claim 20 obvious.

XII. SECONDARY CONSIDERATIONS

336. As I explained in Section III (Legal Principles), I understand that secondary considerations may support or rebut the obviousness of a claim. I am not aware of any secondary considerations that support that the claims of the '053 patent are nonobvious. To the extent Patent Owner argues that secondary considerations are relevant here, I reserve the right to respond.

XIII. AVAILABILITY FOR CROSS-EXAMINATION

337. In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

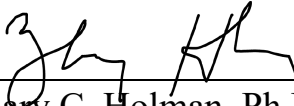
XIV. RIGHT TO SUPPLEMENT

338. I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner raises and to take into account new information as it becomes available to me.

XV. JURAT

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

Dated: August 8, 2024

/s/  _____
Zachary C. Holman, Ph.D.

APPENDIX A

ZACHARY CHARLES HOLMAN

Professor and Vice Dean

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APPOINTMENTS

08/2023–	Vice Dean for Research and Innovation Ira A. Fulton Schools of Engineering, Arizona State University (Tempe, Arizona)
08/2023–	Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
08/2019–07/2023	Associate Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
08/2019–06/2023	Director of Faculty Entrepreneurship Ira A. Fulton Schools of Engineering, Arizona State University (Tempe, Arizona)
06/2021–	Cofounder Beyond Silicon, Inc. (Chandler, Arizona)
03/2020–	Cofounder Sunflex Solar LLC (Phoenix, Arizona)
07/2016–	Cofounder and Chief Technology Officer Swift Coat, Inc. (Tempe, Arizona)
03/2013–07/2019	Assistant Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
07/2014–08/2014	Visiting Professor Photovoltaics and Thin-Film Electronics Laboratory, Institute of Microengineering, Ecole Polytechnique Fédérale de Lausanne (Neuchâtel, Switzerland)
10/2010–03/2013	Postdoctoral Researcher Photovoltaics and Thin-Film Electronics Laboratory, Institute of Microengineering, Ecole Polytechnique Fédérale de Lausanne (Neuchâtel, Switzerland)

EDUCATION

10/2010	Doctor of Philosophy Mechanical Engineering; Nanoparticle Science and Engineering (minor), University of Minnesota (Minneapolis, Minnesota) Dissertation: <i>Germanium nanocrystal solar cells</i> ; Advisor: Prof. Uwe Kortshagen
05/2005	Bachelor of Arts Physics, Reed College (Portland, Oregon) Thesis: <i>Electron transport in amorphous silicon</i> ; Advisor: Prof. John Essick

RESEARCH INTERESTS

Broad research interests span the fields of solar cells, coatings, nanotechnology, semiconductors, plasmas, and aerosols. Specific interests include silicon-based tandem solar cells, contacts to solar cells, light management

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in solar cells, novel uses of nanoparticles in devices, semiconductor nanoparticles, optical and electronic properties of nanoscale materials, plasma synthesis of powders, and deposition of powders and thin films.

AWARDS & HONORS

2023	ASU Fulton Schools of Engineering Top 5% Teaching Award
2022	Hopkins Professorship
2021	American-Made Perovskite Startup Prize Winner
2020	American-Made Solar Prize Winner
2019	IEEE Stuart R. Wenham Young Professional Award
2019	NSF CAREER Award
2018	Gordon and Betty Moore Foundation Inventor Fellowship
2018	Fulton Entrepreneurial Professorship
2017	ASU Fulton Schools of Engineering Top 5% Teaching Award
2016	Trustees of ASU Professorship
2016	Joseph C. Palais Distinguished Faculty Scholar Award
2016	Fulton Outstanding Assistant Professor Award
2015	ASU Fulton Schools of Engineering Top 5% Teaching Award
2014	ASU Senior Sustainability Scientist
2013	3 rd International Conference on Crystalline Silicon Photovoltaics top 5% of papers
2010	NSF EAPSI Fellowship at the Tokyo Institute of Technology
2010	University of Minnesota Doctoral Dissertation Fellowship
2008	Particle Society of Minnesota Scholarship
2007	18 th International Symposium on Plasma Chemistry Best Paper Award
2005	NSF IGERT Fellowship at the University of Minnesota

AWARDS WON BY STUDENTS AND POSTDOCS

2023	Bernard Henry AIMCAL-SVC Scholarship (Zach Leuty)
2022	ARCS (Achievement Awards for College Scientists) Award (David Quispe)
2022	Hool Coury Law Tech Venture Challenge Winner (Wahab Alasfour, Zach Leuty, David Quispe)
2021	ASU Presidential Graduate Assistantship (Vidya Krishnan)
2021	NSF Graduate Research Fellowship (David Quispe)
2021	American-Made Perovskite Startup Prize Winner (Jason Yu, Wahab Alasfour, Zach Leuty, David Quispe)
2020	American-Made Solar Prize Winner (Kate Fisher, Jason Yu, Barry Hartweg)
2020	ASU Dean's Fellowship (Mason Mahaffey)
2020	NSF Graduate Research Fellowship (Justin Huxel)
2020	QESST Best Paper Award (Zachary Leuty)
2019	SiliconPV Best Poster Award (William Weigand and Jason Yu)
2018	ASU Dean's Fellowship (Barry Hartweg)
2018	Palais' Outstanding Doctoral Student Award (Jason Yu)
2018	Venture Madness Hardware Tech Winner (Peter Firth)

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2017	European PV Solar Energy Conference and Exhibition Student Award (Jason Yu)
2017	IEEE Photovoltaic Specialists Conference Most Outstanding Technical Contribution (Jason Yu)
2017	MRS Graduate Student Silver Award (Jason Yu)
2017	Rice Business Plan Competition Department of Energy Cleantech University Prize (Peter Firth and Jonathan Bryan)
2017	ASU Innovation Open SRP Innovation Award (Peter Firth)
2017	SiliconPV Award (Jason Yu)
2017	SiliconPV Award (Mathieu Boccard)
2017	ASU Graduate and Professional Student Association Research Award (Jason Yu)
2017	ThinkSwiss Research Scholarship (Nathan Rodkey)
2017	ARCS (Achievement Awards for College Scientists) Award (Peter Firth)
2017	Zero Mass Water Materials Award (Peter Firth)
2017	DOE Science Undergraduate Laboratory Internship at NREL (Nathan Rodkey)
2017	Rhodes Scholarship (Ngoni Mugwisi)
2016	Palais Senior Design Prize (Heliovation senior design team)
2016	Arizona Student Energy Conference Distinguished Poster Award (Jason Yu)
2016	IEEE Photovoltaic Specialists Conference Best Paper Award (Mathieu Boccard)
2016	IEEE Photovoltaic Specialists Conference Best Poster Award (Mathieu Boccard)
2016	ASU Dean's Fellowship (Will Weigand)
2016	ASU Dean's Fellowship (Jonathan Bryan)
2016	ASU New Venture Challenge Winner (Peter Firth)
2016	ARCS (Achievement Awards for College Scientists) Award (Peter Firth)
2016	Micron Technology Team Prize (Hall Effect senior design team)
2015	IEEE Photovoltaic Specialists Conference Best Poster Award (Jason Yu)
2015	Harold and Lucille Dunn Memorial Engineering Scholarship (Jason Yu)
2015	Barrett Electronic Materials Fellowship (Peter Firth)
2015	ASU Dean's Fellowship (Peter Firth)
2015	Arizona Student Energy Conference Distinguished Poster Award (Priyaranga Koswatta)
2015	NSF Graduate Research Fellowship (Joe Carpenter)
2014	NSF Integrative Graduate Education and Research Traineeship (Michael Bernstein)
2014	NSF Integrative Graduate Education and Research Traineeship (Joe Carpenter)
2014	University Graduate Fellowship (Salman Manzoor)

PROFESSIONAL ACTIVITIES & OUTREACH

- Editor of the IEEE Journal of Photovoltaics (2022–)
- Member of the Industry Liaison Committee for the World Conference on Photovoltaic Energy Conversion (2022)
- Member of the Program Committee for the IEEE Photovoltaic Specialists Conference (2020)
- Member of the Organizing Committee for the International Workshop on Silicon Heterojunction Solar Cells (2019, 2020)
- Symposium Organizer for the E-MRS Spring Meeting (2017)
- Symposium Organizer for the IEEE Photovoltaic Specialists Conference (2016, 2017, 2018, 2021)
- Symposium Organizer or Lead Symposium Organizer for the MRS Spring Meeting (2015, 2016, 2018)

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- Session Chair for IEEE Photovoltaic Specialists Conference, MRS Spring Meeting, SiliconPV (2013–)
- Member of the Fulton Schools of Engineering Dean’s Research Committee (2017–2019)
- Member of the Fulton Schools of Engineering Master Mentors (2019–)
- Co-leader of Thrust 2 of the Quantum Energy and Sustainable Solar Technology ERC (2015–2020)
- Member of the ASU Goldwater Materials Science Facility Steering Committee (2014–2016)
- Member of the ASU Leadership Academy Materials Team (2015–2016)
- Member of the ASU University Undergraduates Standards Committee (2015–2017)
- Member of the ASU Instrument Design and Fabrication Board (2016–2019; 2020–)
- Member and Chair of the ASU Advanced Electronics and Photonics Core Facility Board (2020–)
- Member of the ASU Solar Fabrication Core Facility Board (2021–)
- Member of the ASU Eyring Materials Center Board (2017–2021)
- Member or Chair of an ASU ECEE Faculty Search Committee (2015, 2018, 2020, 2021, 2022)
- Member of the ASU ECEE Website Design Committee (2015, 2019)
- Member of the ASU Faculty Working Group for the MS degree in Innovation and Venture Development
- Designer and instructor of a new course entitled *EEE 598: Manuscript Writing for Engineers*
- Reviewer for funding bodies, including NSF and DOE, and journals, including *Journal of Applied Physics*, *ACS Nano*, *Solar Energy Materials and Solar Cells*, *Thin Solid Films*, *Nanotechnology*, *IEEE Journal of Photovoltaics*
- Volunteer Scientist for ASU’s Night of The Open Door, ASU’s Summer Transportation Institute, Cesar Chavez High School, Minnesota FIRST LEGO League, and the Science Museum of Minnesota

FUNDING

11/2023–10/2028	NSTXL Microelectronics Commons, “Southwest Advanced Prototyping (SWAP) Hub,” (Co-PI)
10/2023–05/2027	DOE SETO, “TEAMUP: Tandems for efficient and advanced modules using ultrastable perovskites,” (Co-PI)
07/2023–04/2024	DOE BES SBIR, “Development of new metallization pastes for front-side tunnel oxide passivated contact crystalline silicon solar cells,” (Co-PI)
07/2023–06/2024	TSMC, confidential project, (PI)
04/2023–03/2024	Applied Materials, confidential project, (PI)
10/2022–10/2023	DOE SETO, “PV Foundry: Increasing manufacturing innovation and capabilities in the US,” (PI)
09/2022–08/2024	US Department of State, “GIST Innovates the Balkans,” (Co-PI)
11/2021–10/2026	USAID, “Center of Excellence for Energy,” (Co-PI)
11/2021–10/2022	AZ New Economy Initiative, “Suns-ERE: A characterization tool to accelerate the learning cycle of thin-film photovoltaics,” (PI)
10/2021–09/2024	EDA Build to Scale, “Arizona semiconductor industry startup entrepreneurial development project,” (Co-PI)
10/2021–11/2025	DOE SETO, “Manufacturing 27%-efficient perovskite/silicon tandem photovoltaic cells using slot die coating at >5000 wafers per hour,” (Co-PI)
04/2021–03/2024	DOE SETO, “The role of hydrogen in the performance and long-term stability of high-efficiency silicon cells and modules,” (Co-PI)

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01/2021–12/2022	Sunflex Solar, “Scaling Sunfoil solar modules,” (PI)
08/2020–08/2020	Corporate gift (PI)
04/2020–03/2023	DOE SETO, “Sonic Wafering™ of III-V substrates for high efficiency cells: A path to <\$0.50/W,” (Co-PI)
10/2019–09/2020	US Government, “Flexible and advanced solar panel technologies,” (PI)
08/2019–07/2021	NSF, “Center to center (C2C) international collaboration on advanced photovoltaics: Electrode manufacturing and indoor power applications,” (Co-PI)
08/2019–07/2022	DOE SETO, “Scalable manufacturing of efficient perovskite/silicon tandem modules,” (Co-PI)
03/2019–02/2024	NSF CAREER, “CAREER: Transparent, passivating, and carrier-selective heterojunction contacts for silicon and cadmium telluride solar cells,” (PI)
01/2019–12/2021	DOE SETO, “Diagnosing and overcoming recombination and resistive losses in non-silicon solar cells using a silicon-inspired characterization platform,” (PI)
01/2019–12/2021	DOE SETO, “Bringing high-efficiency silicon solar cells with heterojunction contacts to market with a new, versatile deposition technique,” (PI)
01/2019–06/2020	DOE SETO, “Wide-bandgap polycrystalline III-Vs as transparent, carrier-selective heterojunction contacts for silicon photovoltaics,” (Co-PI)
01/2019–12/2020	NREL, “ASU-NREL joint silicon solar cell research: passivated contacts, metallization, and bulk defects,” (PI)
01/2019–12/2021	ARPA-E DAYS, “Solid state thermal battery,” (Co-PI)
01/2019–12/2019	FSE/CLAS/AMI Seed, “MRSEC planning and preliminary data collection,” (Co-PI)
10/2018–09/2020	Fulton Entrepreneurial Professors Program, “Aerosol impaction-driven assembly of functional nanomaterial coatings,” (PI)
10/2018–09/2021	Moore Foundation Inventor Fellowship, “Aerosol impaction-driven assembly of functional nanomaterial coatings,” (PI)
10/2018–09/2019	FSE/CLAS/AMI Seed, “Diamond and III-nitride integration for ultra-gap devices,” (PI)
06/2018–05/2019	NSF SBIR, “Non-thermal plasma source for functional metal-oxide nanoparticle coatings,” (Co-PI)
02/2018–09/2018	NREL, “PERC and SHJ silicon solar modules with high infrared reflectance,” (Co-PI)
01/2018–01/2021	ARENA, “Hydrogenated and hybrid heterojunction p-type silicon PV cells R&D project,” (Co-PI)
10/2017–09/2020	DOE PVRD-II, “Perovskite-on-silicon tandem solar cells,” (Co-PI)
10/2017–05/2020	DOE DuraMAT, “Silicon IBC modules with copper foil electrodes: Failure mechanisms of electrically conductive adhesive bonds between cells and foil,” (PI)
10/2017–09/2018	BAPVC, “Low capex solar manufacturing enabled by perovskite semiconductors,” (Co-PI)
08/2017–01/2019	ACAP, “P-type hybrid heterojunction solar cells,” (Co-PI)
05/2017–04/2019	NSF EAGER, “Collaborative research: 30%-efficient, stable perovskite/silicon monolithic tandem solar cells,” (PI)

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02/2017–04/2017	NSF SBIR, “The aerosol-spray deposition of photoluminescent quantum-dot coatings on substrates,” (Co-PI)
01/2017–12/2019	ARPA-E SHIELD, “Single-pane windows with insulating sprayed particulate coatings,” (PI)
12/2016–11/2017	NSF SBIR, “Low damage sputter magnetron for silicon heterojunction PV production,” (Co-PI)
11/2016–10/2018	DOE NextGen-III, “Developing efficient silicon cells for perovskite/silicon tandem devices,” (Co-PI)
09/2016–08/2017	American Jobs Project, “Arizona’s advanced energy landscape,” (PI)
08/2016–07/2019	DOE PVRD, “Monolithic silicon module manufacturing at < 0.40 \$/W,” (PI)
08/2016–07/2018	DOE PVRD, “15%-efficiency (Mg,Zn)CdTe solar cells with 1.7 eV bandgap for tandem applications,” (PI)
08/2016–07/2017	SolarReserve, “Hybrid heliostat development,” (PI)
07/2016–01/2017	FSE Technology Innovation Laboratory, “Advanced manufacturing of nanoparticle-based coatings,” (PI)
06/2016–05/2017	DOE PVRD SIPS, “A new class of tandems: Optically coupled III-V/silicon module with outdoor efficiency exceeding 30%,” (PI)
05/2016–11/2016	FSE Technology Innovation Laboratory, “Hybrid heliostat for combined photovoltaic and solar thermal power plants,” (PI)
04/2016–03/2019	NSF REU Site, “Solar energy research for the Terawatt Challenge,” (PI)
01/2016–12/2018	DOE SuNLaMP, “Overcoming bottlenecks to low-cost, high-efficiency Si PV and industrially relevant, ion implanted interdigitated back passivated contact cell development,” (Co-PI)
09/2015–08/2018	NSF Energy for Sustainability, “Collaborative research: 30%-efficient III-V/silicon tandem solar cells,” (PI)
08/2015–07/2020	NSF ERC, “Nano-Enabled Water Treatment: NEWT,” (Co-PI)
06/2015–05/2020	USAID, “U.S.-Pakistan Centers for Advanced Studies in Energy,” (Co-PI)
05/2015–04/2016	ARPA-E I-Corps Supplement, “PVMirror: Cost competitive solar with storage,” (PI)
02/2015–01/2017	RCSA Scialog, “Scalable tandem architecture for solar water splitting,” (PI)
06/2014–05/2017	ARPA-E FOCUS, “PVMirror: A solar concentrator mirror incorporating PV cells,” (PI)
09/2013–08/2016	DOE FPACE-II, “Thin silicon solar cells: A path to 35% Shockley-Queisser limits,” (Co-PI)
08/2011–07/2021	NSF/DOE ERC, “Quantum Energy and Sustainable Solar Technologies: QESST,” (Co-PI)
06/2010–08/2010	NSF EAPSI, “Novel solar cells using silicon nanocrystals synthesized in an atmospheric-pressure plasma,” (PI)

STUDENTS, POSTDOCS, AND STAFF ADVISED

• Ph.D.:	Ashling Leilaouioun (2013–2018)	Jianwei Shi (2013–2018)
	Jason Yu (2014–2018)	Salman Manzoor (2014–2019)
	Joe Carpenter (2014–2020)	Peter Firth (2015–)

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- | | | |
|---------------------|---|--|
| | Jonathan Bryan (2016–2021) | William Weigand (2016–2023) |
| | Barry Hartweg (2018–2023) | Warda Mushtaq (2018–) |
| | Zachary Leuty (2019–) | Abdulwahab Alasfour (2019–) |
| | David Quispe (2019–) | Mark Li (2019–) |
| | Alan Wu (2019–2021) | Mason Mahaffey (2020–) |
| | Vidya Krishnan (2021–) | Maria Garcia (2021–) |
| | Jason Ro (2022–) | |
| • M.S.: | Salman Manzoor (2013–2014) | Prateek Garg (2013–2015) |
| | Priyaranga Koswatta (2013–2016) | Peter Firth (2014–2015) |
| | Michael Bernstein (2014–2016) | Alec Jackson (2014–2016) |
| | Trent Hoffman (2016–2017) | Sujyot Mony (2018–2019; MORE) |
| | Sagnik Dasgupta (2019–2020) | |
| • Undergraduate: | Claire Block (2017–2018) | Joe Carpenter (2013–2014; FURI) |
| | Christopher Chen (2017–2019) | Angelo Delluomo (2015–2016; FURI) |
| | Angelica Guzman (2018–2019; FURI) | Justin Huxel (2017–2019; FURI) |
| | Sanketh Kamath (2013–2015; FURI) | Mark Kapron (2017–2018; FURI) |
| | Ngoni Mugwisi (2016–2017; Barrett) | Corbin Ott (2017–2018; FURI) |
| | Marcial Rodarte (2016–2017) | Nathan Rodkey (2015–2018; FURI, Barr.) |
| | Kari Sanford (2015–2017; FURI, Barrett) | Nicholas Scheenstra (2015–2016; FURI) |
| | Daniel Sinclair (2017–2018; FURI) | Marshall Styers (2015–2016) |
| | Brian Wu (2018–2019; FURI) | John Hsu (2021–2021; SURI) |
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| • Research faculty: | Jason Yu (2018–) | Arthur Onno (2020–2022) |
| • REU visitor: | Emily Dafflon (2013) | Ethan Bendau (2015) |
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| | Jones Ou (2016) | Matthew Warner (2016) |
| | Jakob Häusele (2017) | Noemi Mundhaas (2017) |
| | Stefan Mercado (2017) | Syeda Mohsin (2017) |
| | Tien Ngo (2017) | Yuji Okamoto (2017) |
| | David Quispe (2017) | Mateo Estrada (2018) |
| | Jewel Haik (2018) | Richelle Javier (2018) |
| | Xingyi Wang (2019) | Alexa Cetta (2019) |
| | Jorge Almeida (2019) | Maria Garcia (2019) |
| • PCASE visitor: | Saleem Ahmed (2016) | Asad Ali (2016) |
| | Asghar Ali (2016) | Waqar Ali (2016) |
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| | Mahmood Jamil (2016) | Mehwish Javed (2016) |
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Saddam Hussain (2019)

COURSES TAUGHT

- EEE 352: Properties of Electronic Materials (F15, F16, F17, F18)
- EEE 436/591: Fundamentals of Solid State Devices (F13, F14, S16)
- EEE 465/591: Photovoltaic Energy Conversion (S15)
- EEE 498/591: Solar Energy (S14)
- EEE 536: Semiconductor Characterization (S17)
- EEE 565: Solar Cells (F22)
- EEE 598: Manuscript Writing for Engineers (F14, F15, F17, F18, F19, F20, F21, F22)
- ASU 101: The ASU Experience (F14)
- IVD 561: Innovation Studio II: Problem Reframing (F21)
- IVD 562: Innovation Studio III: Explore, Fail, Solve (S21, S22)

PEER-REVIEWED PUBLICATIONS

(ASU students in **red**; ASU postdocs and staff in **orange**)

111. **Z. Leuty**, **M. George**, **M. Garcia**, **Z. Yu**, and **Z. Holman**, “High mobility soft sputtered ITO coatings by dual gas-flow sputtering,” (submitted).
110. **Z. Leuty**, **W. Weigand**, **J. Ochoa**, **J. Carpenter**, **Z. Yu**, M. Bertoni, and **Z. Holman**, “Ultra-high throughput inline deposition of silicon oxide for polycrystalline silicon passivating contacts,” (submitted).
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Appendix B (Materials Considered)

APPENDIX B

Appendix B: Materials Considered

No.	Description
1001	U.S. Patent No. 8,878,053 B2 (“USP053”)
1002	File History for U.S. Patent No. 8,878,053 B2 (App. No. 13/495,577) (“FH053”)
1004	EP1732142A1 to Froitzheim (“Froitzheim”)
1005	Gan and Swanson, <i>Polysilicon Emitters for Silicon Concentrator Solar Cells</i> , <i>IEEE Conference on Photovoltaic Specialists</i> , Vol. 1, Pages 245-240 (1990) (“Gan”)
1006	WO 2009/094575 A2 (“Borden-575”)
1007	U.S. Patent No. 6,998,288 to Smith (“Smith”)
1008	CN 1949545A to Li (Translation) (“Li”)
1009	Translation Declaration for Li
1010	Zachary C. Holman, <i>Electron Transport in Amorphous Silicon</i> (May 2005) (Thesis Presented to The Division of Mathematics and Natural Sciences, Reed College) (“Holman-Thesis”)
1015	U.S. Patent No. 7,468,485 to Swanson (“Swanson”)
1016	R. J. Komp, <i>Practical Photovoltaics Electricity From Solar Cells</i> , 3rd Ed. (2002) (“Komp”)
1017	BP Solar Global Marketing, BP-MSX-120, 120-Watt Multicrystalline Photovoltaic Module (“BP-MSX-120”)
1018	J. Nelson, <i>The Physics of Solar Cells</i> , <i>Imperial College Press</i> (2003) (“Nelson”)
1019	T. Krygowski, A. Rohatgi, D. Ruby, <i>Simultaneous P and B Diffusion, In-Situ Surface Passivation, Impurity Filtering and Gettering for High-Frequency Silicon Solar Cells</i> , SAND-97-2620C; CONF-970953- (“Krygowski”)
1020	A. Luque, S. Hegedus, <i>Handbook of Photovoltaic Science and Engineering</i> , Wiley (2003) (“Luque”)
1021	J. Gordon, <i>Solar Energy the State of the Art</i> , ISES (2001) (“Gordon”)
1022	U.S. Patent No. 6,262,359 to Meier (“Meier”)
1023	U.S. Patent No. 4,525,593 to Yablonovitch (“Yablonovitch”)
1024	WO 2009/094578 A2 (“Borden-578”)
1025	U.S. Patent No. 4,665,277 to Sah (“Sah”)

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1026	D. Chapin et al., <i>A New Silicon P-N Junction Photocell for Converting Solar Radiation into Electrical Power</i> , J. Appl. Phys. 25, 676 (1954) (“Chapin”)
1027	W. Shockley, H. J. Queisser, <i>Detailed Balance Limit of Efficiency of pn Junction Solar Cells</i> , J. Appl. Phys. 32, 510 (1961) (“Shockley”)
1028	A. Metz, R. Meyer, B. Kuhlmann, M. Grauvogl, R. Hezel, <i>18.5% Efficient First-Generation MIS Inversion-Layer Silicon Solar Cells</i> , 26th PVSC (1997) (“Metz”)
1029	D. De Ceuster, P. Cousins, D. Rose, D. Vicente, P. Tipones, W. Mulligan, <i>Low Cost, High Volume Production of >22% efficiency silicon solar cells</i> , 22nd European Photovoltaic Solar Energy Conference, 3-7 September 2007, Milan, Italy, pp. 816-819 (“De-Ceuster”)
1030	J. Benick, J. Rentsch, Ch. Schetter, C. Voyer, D. Biro, R. Preu, <i>PECVD PSG as a Dopant Source for Industrial Solar Cells</i> , Presented at the 21st European Photovoltaic Solar Energy Conference, September 4-8, 2006, Dresden (2CV.4.26) (“Benick”)
1031	JP07-106611 to Okayasu (Translation) (“Okayasu”)
1032	Translation Declaration for Okayasu
1033	Robert F. Pierret, <i>Semiconductor Device Fundamentals</i> , Addison Wesley Longman (Part I) (1996) (“Pierret”)
1034	A. I. A. Rahim, C. D. Marsh, P. Ashburn, G. R. Booker, <i>Impact of Ex-Situ and In-Situ Cleans on the Performance of Bipolar Transistors With Low Thermal Budget In-Situ Phosphorus-Doped Polysilicon Emitter Contacts</i> , IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 48, NO. 11 (November 2001) (“Rahim”)
1035	N. S. Parekh, R. V. Taylor, D. O. Massetti, <i>A Simple Method to Control Bipolar Polysilicon Emitter Interfacial Oxide</i> , J. Electrochem. Soc., Vol. 141, No. 11, pp. 3167-3172 (1994) (“Parekh”)
1036	E. Yablonovitch, T. Gmitter, R. M. Swanson, Y. H. Kwark, <i>A 720 mV open circuit voltage SiO_x:c-Si:SiO_x double heterostructure solar cell</i> , Appl. Phys. Lett. 47, 1211-1213 (1985) (“Yablonovitch-1985”)
1039	File History of U.S. Patent App. No. 14/504,771 (“771FH”)

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No.	Description
1040	U.S. Patent No. 8,222,516 B2 (“USP516”)
1042	U.S. Patent Appl. Pub. No. 2002/0142500 A1 (“Foglietti”)
1043	Mark John Kerr, <i>Surface, Emitter and Bulk Recombination in Silicon and Development of Silicon Nitride Passivated Solar Cells</i> (2002) (Ph.D. Thesis, The Australian National University) (“Kerr”)
1045	M. Green, <i>Silicon Solar Cells Advanced Principles & Practice</i> , Centre for Photovoltaic Devices and Systems (1995) (“Green-1995”)
1046	Y. H. Kwark, R. M. Swanson, <i>N-Type Sipos and Poly-Silicon Emitters</i> , Solid-State Electronics Vol. 30, No. 11, pp. 1121-1125 (1987) (“Kwark”)
1047	G. R. Wolstenholme, N. Jorgensen, P. Ashburn, G. R. Booker, <i>An investigation of the thermal stability of the interfacial oxide in polycrystalline silicon emitter bipolar transistors by comparing device results with high-resolution electron microscopy observations</i> , J. Appl. Phys. 61, 225–233 (1987) (“Wolstenholme”)
1049	M. Green, <i>Solar Cells Operating Principles Technology and System Applications</i> (1986) (“Green-1986”)
1050	N. G. Tarr, <i>A polysilicon emitter solar cell</i> , IEEE Electron Device Letters, vol. 6, no. 12, pp. 655-658, Dec. 1985 (“Tarr”)
1051	R. M. Swanson, <i>Point Contact Solar Cells: Modeling and Experiment</i> , Solar Cells, 17, pp. 85-118 (1986) (“Swanson-1986”)
1052	U.S. Patent No. 4,158,591 to Avery (“Avery”)
1053	U.S. Patent No. 5,899,804 to Schlosser (“Schlosser”)
1054	U.S. Patent No. 7,144,751 to Gee (“Gee”)
1056	WO 2006/097303 A1 (“Agostinelli”)
1057	P.V. Meyers, R. Kee, C. Wolden, L. Raja, V. Kaydanov, T. Ohno, R. Collins, M. Aire, J. Kestner, A. Fahrenbruch, <i>Atmospheric Pressure Chemical Vapor Deposition of CdTe for High Efficiency Thin Film PV Devices</i> , NREL Annual Report 26 January 1998 – 25 January 1999 (Sept. 1999) (“NREL-1999”)

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Appendix B (Materials Considered)

No.	Description
1058	R. M. Swanson, R. A. Sinton, <i>High-Efficiency Silicon Solar Cells, Advances in Solar Energy: An Annual Review of Research and Development</i> , vol. 6. Chapter 4 (1990) (“Swanson-1990”)
1059	G. Lubberts, B. C. Burkey, F. Moser, E. A. Trabka, <i>Optical properties of phosphorus-doped polycrystalline silicon layers</i> , J. Appl. Phys. 52(11), (Nov. 1981) (“Lubberts”)
1060	U.S. Patent No. 6,352,876 to Bordogna (“Bordogna”)
1061	E. Centurioni, D. Iencinella, R. Rizzoli, F. Zignani, <i>Silicon Heterojunction Solar Cell: A New Buffer Layer Concept With Low-Temperature Epitaxial Silicon</i> , IEEE Transactions on Electron Devices, Vol. 51, No. 11 (November 2004) (“Centurioni”)
1062	M. Farrokh-Baroughi, H. El-Gohary, S. Sivoththaman, <i>Optical, Electrical, and Structural Properties of PECVD Quasi Epitaxial Phosphorous Doped Silicon Films on Crystalline Silicon Substrate</i> , Canadian Solar Buildings Conference (August 20-24, 2004) (“Farrokh-Baroughi”)

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Appendix C (Challenged Claims)

APPENDIX C

Appendix C: Challenged Claims

Claim 1	
Element	Claim Language
1[pre]	A method of fabricating a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the method comprising:
1[a]	forming a layer of polysilicon over a back surface of an N-type silicon substrate on the backside of the solar cell;
1[b]	forming a P-type dopant source over the layer of polysilicon;
1[c]	forming a capping layer over the P-type dopant source;
1[d]	diffusing P-type dopants from the P-type dopant source to the layer of polysilicon to form a backside junction with the N-type silicon substrate;
1[e]	diffusing N-type dopants into a front surface of the N-type silicon substrate; and
1[f]	forming a metal contact on the front side of the solar cell, wherein the metal contact is electrically coupled to the N-type silicon substrate.

Claim 2

The method of claim 1 wherein the P-type dopant source comprises borosilicate glass.

Claim 3

The method of claim 1 wherein diffusing N-type dopants into the front surface of the N-type silicon substrate includes forming an N-type dopant source over the N-type silicon substrate and diffusing N-type dopants from the N-type dopants source into the N-type silicon substrate.

Claim 4

The method of claim 3 wherein the N-type dopant source comprises phosphorus doped silicon dioxide.

Claim 5

The method of claim 1 further comprising:
texturing the front surface of the N-type silicon substrate; and
forming an antireflective layer over the textured front surface of the N-type silicon substrate.

Claim 6

The method of claim 5 wherein the antireflective layer comprises silicon nitride.

Claim 7

The method of claim 1 wherein the diffusion of P-type dopants from the P-type dopant source to the layer of polysilicon and the diffusion of N-type dopants into the front surface of the N-type silicon substrate are performed in situ.

Claim 8

The method of claim 1 wherein the capping layer comprises undoped silicon dioxide.

Claim 9

Element	Claim Language
9[pre]	A method of fabricating a solar cell comprising:
9[a]	forming a layer of polysilicon over a back surface of a silicon substrate;
9[b]	forming a first dopant source layer over the layer of polysilicon;

Claim 9	
Element	Claim Language
9[c]	diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate;
9[d]	diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and
9[e]	forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

Claim 10
The method of claim 9 wherein the first dopant source layer comprises P-type dopants.

Claim 11
The method of claim 9 wherein the first dopant source layer comprises borosilicate glass.

Claim 12

The method of claim 9 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.

Claim 13

The method of claim 12 wherein the second dopant source layer comprises phosphorus doped silicon dioxide.

Claim 14

The method of claim 9 further comprising:

texturing the front surface of the silicon substrate; and

forming an antireflective layer over the textured front surface of the silicon substrate.

Claim 15	
The method of claim 9 wherein the diffusion of dopants from the first dopant source layer to the layer of polysilicon and the diffusion of dopants into the front surface of the silicon substrate are performed in situ.	

Claim 16	
Element	Claim Language
16[pre]	A method of fabricating a solar cell comprising:
16[a]	forming an oxide layer over a back surface of a silicon substrate;
16[b]	forming a layer of polysilicon over the oxide layer;
16[c]	diffusing dopants into the layer of polysilicon to form a backside junction with the silicon substrate;
16[d]	diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and
16[e]	forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

Claim 17

The method of claim 16 wherein diffusing dopants into the layer of polysilicon to form the backside junction with the silicon substrate comprises:
forming a first dopant source layer over the layer of polysilicon; and
diffusing dopants from the first dopant source layer into the layer of polysilicon.

Claim 18

The method of claim 16 wherein diffusing dopants into the front surface of the silicon substrate comprises forming a second dopant source layer over the silicon substrate and diffusing dopants from the second dopant source layer into the silicon substrate.

Claim 19

The method of claim 16 further comprising:
texturing the front surface of the silicon substrate.

Claim 20

The method of claim 19 further comprising:

Claim 20
forming an antireflective layer over the textured front surface of the silicon substrate.