

Supplemental Declaration of Sanjay Banerjee
In Support of Petitioner's Reply to Patent Owner Response

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

CANADIAN SOLAR INC.,
Petitioner,

v.

MAXEON SOLAR PTE. LTD.,
Patent Owner.

Case No. IPR2024-01040
U.S. Patent No. 8,878,053

**SUPPLEMENTAL DECLARATION OF SANJAY BANERJEE, Ph.D.
IN SUPPORT OF PETITIONER'S REPLY TO PATENT OWNER'S
RESPONSE**

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In Support of Petitioner's Reply to Patent Owner Response

I, Sanjay Banerjee, do hereby declare and state, 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, under Section 1001 of Title 18 of the United States Code.

Executed on: July 1, 2025



Sanjay Banerjee

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1. I am the Sanjay Banerjee, Ph.D. who has previously submitted a declaration in this proceeding. *See* EX1003. I have set forth the details of my engagement, background and qualifications, compensation and prior testimony, information considered, and understanding of relevant legal standards in my previously submitted Declaration Of Sanjay Banerjee, Ph.D. Regarding U.S. Patent No. 8,878,053, EX1003, which I hereby incorporate by reference.

2. I have been asked to offer additional opinions to address certain issues raised in Patent Owner's Response (Paper No. 25) and the accompanying Declaration of Douglas Ruby, Ph.D. (EX2020).

3. The analysis that I provide in this declaration is based on my experience, the evidence submitted in these proceedings to date, the evidence identified in my initial declaration, evidence submitted by Patent Owner, the transcript from the deposition of Douglas Ruby (EX1081), and the additional materials I identify in this declaration (listed below):

- Merabet (EX1077)
- Kermani (EX1078)
- Petitdidier (EX1079)
- Wolf (EX1080)

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I. Froitzheim and Gan (Grounds 1 and 2)

4. I provide the following additional opinions regarding the combination of Froitzheim and Gan in response to Dr. Ruby's declaration.

A. A Skilled Artisan Would Know to Use Lower Range of Anneal Temperatures in Froitzheim

5. Dr. Ruby argues that "the temperatures required by each [of Gan and Froitzheim] are incompatible" because Gan "teaches best results are achieved when the second anneal to drive in dopants is at 900°C or below," while "Froitzheim teaches that the temperature to drive in dopant is preferably at 1000°C to 1100°C." EX2020, ¶143. I disagree.

6. First, I note that while Froitzheim prefers a diffusion temperature of 1000°C to 1100°C, it did not teach that a lower temperature cannot be used. In fact, Froitzheim discloses that the dopant drive in can be performed "at a temperature of 900 to 1200 degree centigrade." EX1006, ¶42. A Skilled Artisan would have understood that polycrystalline silicon (i.e., polysilicon) as disclosed in Gan would not need to be subjected to the higher anneal temperatures preferred in Froitzheim. This is because the higher temperature was preferable due to Froitzheim's preference of using a monocrystalline substrate, and the dopant is diffused into that substrate in Froitzheim. Polysilicon as disclosed in Gan can be diffused with dopants at the lower temperature range disclosed by Froitzheim.

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7. Specifically, Froitzheim explains that the body of the disclosed solar cell can be “made from crystalline silicon, and can be of the mono-, multi-, or polycrystalline type,” but “[p]referably, Czochralski grown Silicon is used.” EX1006, ¶24. The Czochralski process is generally used to produce monocrystalline silicon, meaning the silicon consists of a single continuous lattice containing no grain boundaries. Thus, Froitzheim's preferred substrate was monocrystalline.

8. Froitzheim also describes that after the silicon wafer is exposed to a doping liquid, “the wafer is treated in an atmosphere that contains oxygen at a temperature of 900 to 1200 degrees centigrade, preferably between 1000 and 1100 degree C, to generate an oxide layer and to drive in the dopant.” EX1006, ¶42. This preferred temperature range is due to Froitzheim's preferred use of monocrystalline silicon. Polycrystalline silicon, in contrast, contains many grain boundaries that help facilitate the diffusion of the dopants throughout the silicon as compared to monocrystalline silicon. Thus, I disagree with Dr. Ruby, and a Skilled Artisan would have understood that Froitzheim's lower temperature could be used if the dopant is to be driven into polysilicon.

9. Reports since at least 1994 have indicated that a Skilled Artisan would know that polysilicon has greater diffusivity for dopants than monocrystalline, and

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thus the drive-in anneal can be performed at lower temperature. Merabet (EX1077) is one of these reports and is titled “Dopant Redistribution during Rapid Thermal Annealing in a Self-Aligned Polysilicon Emitter Bipolar Structure Compatible with a Complementary Metal-Oxide-Semiconductor Technology.” Merabet explores the influence grain boundaries have on dopant diffusion (namely, arsenic and boron) through a polysilicon emitter layered over a thin oxide film.

10. On the differences in diffusivity, Merabet states that “[i]t is well known that *arsenic dopants move along polysilicon grain boundaries*, when annealing is performed, and can present a wide range of *diffusivities, from 100 up to 10000 higher than arsenic diffusivity in monocrystalline silicon* during classical thermal annealings [CTA].” EX1077 at 78 (emphasis added). It also notes that the “*boron diffusion coefficient* [in polysilicon] is assumed to be from *50 up to 200 times greater than* B[oron] diffusivity in *monosilicon* during CTA.” *Id.* (emphasis added). Merabet concluded that grain boundaries do not “act only mechanically as pipelines” for dopants, but that diffusion through “polysilicon has a structural (i.e. depth-dependent grain boundary density) and an electrical (i.e. grain boundary trap saturation) influence” on a dopant’s promoted diffusivity. *Id.* at 83-84. In other words, a Skilled Artisan would understand from Merabet that it is far easier to diffuse dopants through polysilicon than monocrystalline silicon and

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thus could perform diffusion at a lower temperature than would be preferred for monocrystalline silicon.

11. Thus, a Skilled Artisan combining Froitzheim and Gan would not have considered these two references to be incompatible, as Dr. Ruby claims. Instead, he or she would have understood that Froitzheim's preferred higher temperature was not necessary when the in-substrate diffused emitter of Froitzheim is replaced with a polysilicon layer with interfacial oxide from Gan.

B. A Skilled Artisan Would Be Able to Reliably Grow a Thermal Oxide

12. Dr. Ruby argues that a Skilled Artisan would not "have any expectation of success in combining the polysilicon and interfacial oxide layer of Gan with the silicon wafer disclosed in Froitzheim" because the Gan Thesis reports that its thin-oxide growth recipe used was not reliable and produced inconsistent results. EX2020, ¶¶184-186. Dr. Ruby is incorrect that the Gan Thesis indicates no expectation of success. As I explained below, methods for reliably growing oxide layers with controllable thicknesses on silicon wafers have been known in the industry since at least the 1990s and would have been well within the repertoire of a Skilled Artisan in 2006. These methods were able to finely tune conditions such as reaction time, temperature, pressure, and oxygen concentration of the oxidation reaction as it occurs to obtain reliable formation of thin oxide layers.

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13. For instance, Lemiti, a 1994 reference that cites to Gan, indicated that “thin oxide films were achieved taking into account the growth kinetics” of the oxidation reaction. EX1048 at 1376. Specifically, Lemiti noted that their procedure was derived from “results obtained in our group,” with the procedure calling for “a stagnant ambient of O₂ and N₂O [i.e., controlling oxygen concentration] with a 0.15 bar overpressure [i.e., controlling pressure] and a process temperature fixed in the 1000°C-1200°C [i.e., controlling temperature].” *Id.* Lemiti concluded that “***we have evidenced among others the ability of our system to achieve reproducible in-situ oxide/polysilicon stack*** with acceptable MOS device performance.” *Id.* (emphasis added). A Skilled Artisan would not have been discouraged from combining Froitzheim and Gan out of fear that they would not be able to reliably grow a thermal oxide layer because methods of growing such oxide layers with controllable thicknesses were well known in the industry since at least 1994.

14. As to the growth rates of oxides, Lemiti also noted that “the growth rate [of the oxide] is greatly enhanced at the initial stage of Si oxidation.” EX1048 at 1376. Lemiti referenced a 1991 publication by Kermani for the proposition that “it appears preferable in the future to work at a lower oxidation temperature and/or oxygen process pressure” to slow the initial growth rate of the oxide. *Id.* Kermani (EX1078) is a 1991 article titled “Single-Wafer Rapid Thermal CVD Technology

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for Fabrication of MOS and Bipolar Devices.” Kermani reports conditions to produce a thin interfacial oxide of 10 to 30 Å, i.e., one to three nanometers, for bipolar transistors through reducing the oxidation kinetics by “reducing the oxidation temperature, pressure and by lowering the partial pressure of oxygen.” EX1078 at 570. As I explained in my prior declaration, a Skilled Artisan would apply bipolar transistor teachings to solar cells. *See, e.g.*, EX1003, ¶¶ 59-60. Thus, if the process for growing the oxide on silicon was yielding oxide layers with thicknesses beyond what Gan describes as ideal, it was within the capabilities of a Skilled Artisan to optimize the oxidation conditions and procedure to achieve an oxide layer of a preferred thickness, as Lemiti and Kermani's researchers had.

15. Dr. Ruby also raised the Gan Thesis as evidence that a Skilled Artisan would have been discouraged from combining Froitzheim and Gan because the Gan Thesis disclosed Gan's struggles with predictably growing an oxide layer during Gan's years as a graduate student *before 1990*. To the extent that a Skilled Artisan would consult the Gan Thesis for its teachings, I disagree with Dr. Ruby.

16. As a professor, I have supervised over 80 Ph.D. students throughout the writing of their Thesis. A Thesis is the culmination of a Ph.D. student's efforts in advancing their field of study, whether successful or not. A Thesis generally includes comprehensive reports of the Ph.D. student's studies and often reports on

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the years of experimentation and fine-tuning of parameters the Ph.D. student performed to arrive at their findings.

17. A Skilled Artisan consulting the Gan Thesis would not have been discouraged from its findings because the Skilled Artisan would have understood that the Gan Thesis was the result of a graduate student's journey in pursuing the skills to qualify as a Skilled Artisan. As a result, the Skilled Artisan would most likely place greater weight on Gan, which contained a curated set of conclusions selected for dissemination to the community of experts at an IEEE Conference, as compared to the discussions in the Gan Thesis, which should not be used to improperly undermine the results Gan disclosed to the IEEE community.

18. And the struggles of a graduate student in 1990 do not evidence the level of skill of a Skilled Artisan in 2006. Indeed, the findings of the Gan Thesis would in fact be useful to the Skilled Artisan because the Gan Thesis did not just report on the problems, it also identified the source of the problem and indicated a solution. Specifically, based on experiments conducted to identify the problem, the Gan Thesis reports:

From the above, it appears that the variation of the oxide thickness results mainly from the oxide-growth step. If this is the case, it is possible that the thin oxide growth can be improved by performing the

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oxidation at lower temperature such that the oxidation rate can be controlled more precisely. [EX2003, 112]

19. Lowering the temperature slows down the chemical reaction between silicon and oxygen in the formation of silicon oxide and thus allows for greater control on the thickness of the oxide layer. As Gan Thesis shows, the oxide thickness increases with time, and slowing that process down by lowering the temperature allows a Skilled Artisan to optimize the oxygen flow time in order to achieve the desired thickness. EX2003, 111.

C. A Skilled Artisan Would Have Understood Gan Teachings to Be Applicable to Non-Concentrator Solar Cells

20. In his declaration, Dr. Ruby argues that “Gan addresses silicon **concentrator** solar cells and not one sun solar cells that are the concern of Froitzheim and the '053 Patent.” EX2020, ¶132. Based on this, Dr. Ruby concludes that “a POSITA focused on developing a one sun cell as taught by the '053 patent would not turn to the teachings of Gan because of its focus on silicon concentrator solar cells” and “would not look to modifying the one sun solar cell structure of Froitzheim with the teachings of Gan relating to concentrator solar cells.” *Id.*, ¶136. I disagree, and Dr. Ruby is incorrect.

21. First, although concentrator and one sun solar cells have differences in requirements, they both operate under the same fundamental laws of physics.

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Both benefit from having, for example, *lower* values of J_o (i.e., an indication of electron *recombination*) and lower ρ_c resistivity, which Gan's teachings promoted. Teachings from the development of either system often are directly applicable to the advancement of the other, and Froitzheim and Gan are no different.

22. Second, and more specifically, Gan explicitly taught that its findings are "quite useful for silicon solar cells." EX1007, 249. Gan did not limit this statement to just concentrator cells, and it would be understood by a Skilled Artisan to be applicable generally to include non-concentrator one sun solar cells.

23. Third, Dr. Ruby based his opinion of the non-desirability of diffusing at 900°C on the resulting ρ_c of 18 $\mu\Omega\text{-cm}^2$ (or $1.8 \times 10^{-5} \Omega/\text{cm}^2$) reported by Gan in Table 1. EX2020, ¶174. Dr. Ruby dismisses this value because he opines that Gan deems "useful" a ρ_c value to be $1 \times 10^{-5} \Omega/\text{cm}^2$. *Id.* But Dr. Ruby misreads Gan, and his suggestion that this reported $1.8 \times 10^{-5} \Omega/\text{cm}^2$ value was somehow not useful is incorrect. With respect to $1 \times 10^{-5} \Omega/\text{cm}^2$, Gan reports only that the authors had achieved this ρ_c value, and did not suggest that this value was somehow an absolute limit not to be crossed. EX1007 (Abstract) ("Both J_o and ρ_c are measured for the polysilicon emitter (contact) which is annealed under various conditions. $J_o \leq 5 \times 10^{-14} \text{ A/cm}^2$ and $\rho_c \sim 1 \times 10^{-5} \Omega\text{-cm}^2$ are obtained for both n- and p-type polysilicon emitters.").

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24. Indeed, Gan also reports that “most of ρ_c [in FIG 6] are also lower than $5 \times 10^{-5} \Omega/\text{cm}^2$ ” and that “[t]his means that the potential [i.e., voltage] drop across the contact is negligible as long as the current density is less than $100 \text{ A}/\text{cm}^2$.” *Id.* Dr. Ruby's dismissal of Gan's data is incorrect because the ρ_c of $1.8 \times 10^{-5} \Omega/\text{cm}^2$ is less than $5 \times 10^{-5} \Omega/\text{cm}^2$ and thus the difference is negligible according to Gan. And the current density of *less than* $100 \text{ A}/\text{cm}^2$ would apply to the one-sun solar cell of Froitzheim/Gan combination.

25. As Dr. Ruby acknowledges, the current density of $100 \text{ A}/\text{cm}^2$ corresponds to the extreme “equivalent to 2500 suns.” EX2020, ¶132. Non-concentrator one sun solar cells do not have such a high current density, and thus the potential/voltage drop associated with a ρ_c of $1.8 \times 10^{-5} \Omega/\text{cm}^2$ is negligible.

26. Dr. Ruby acknowledges that “[s]eries resistance is particularly problematic for concentrator solar cells” because “higher currents make it necessary to significantly reduce series resistance to keep voltage losses low.” EX2020, ¶65. As such, Dr. Ruby states that “a concentrator cell operating at 100 suns concentration should be less than $1 \times 10^{-4} \text{ ohm-cm}^2$.” *Id.* But non-concentrator one sun solar cells do not generate that high of a current density because there is less light hitting the solar cell. Thus, for standard operations, a one sun cell does

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not require as low of specific contact resistivity (ρ_c) as concentrator solar cells.

This was well known in the art even before Gan.

27. For example, Wolf (EX1080) is a 1963 report titled “Series Resistance Effects on Solar Cell Measurements” that describes the effects of series resistance on different types of solar cells. *See* EX1080 at Fig. 3 (showing a greater drop-off the short circuit current output with increasing solar irradiance (i.e. higher concentrator levels)). Wolf demonstrated that a solar cell “exhibits a linear relationship between short circuit current and solar irradiance [concentrator levels].” *Id.* at 461. As recognized by Wolf, standard solar cells optimized for performance on earth “may therefore not give optimum performance at increased light intensities as may be encountered in space vehicle applications in closer proximity to the sun or in the use of solar cells combined with radiation concentrating devices [concentrator solar cells].” *Id.* at 463. From this, a Skilled Artisan would understand that some of the results described as less than optimal in Gan would not be problematic in the context of a non-concentrator solar cell such as Froitzheim, because a non-concentrator solar cell does not require as low of a series resistance to be effective.

28. A Skilled Artisan would thus have understood that ultra-low values of ρ_c are a requirement unique to concentrator cells, and that non-concentrator cells

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do not suffer from having values of ρ_c that would otherwise render a concentrator cell not useful. Therefore, a Skilled Artisan would not have been discouraged from combining Froitzheim and Gan based on Gan's disclosure of a ρ_c of $1.8 \times 10^{-5} \Omega\text{-cm}^2$.

II. Froitzheim and Kwark (Grounds 3 and 4)

29. Kwark, like Gan, teaches the application of an oxide layer in conjunction with a polysilicon emitter. But, while Gan grew its oxide layer using thermal oxidation, Kwark instead grew its oxide layer through a wet chemical method to produce an oxide layer that Kwark refers to as "chemox."

A. A Skilled Artisan Would Have a Reasonable Expectation of Success in Combining Froitzheim and Kwark

30. Dr. Ruby argues that Kwark notes that at an annealing temperature of 1000°C , the proposed solar cell loses any benefit from the improved J_o that comes from the chemox. EX2020, ¶154. This is incorrect. While the J_o is definitely better at 900°C , Figure 4 of Kwark clearly shows that the J_o is still lower for the polysilicon emitter with chemox compared to without chemox even at 1000°C . EX1008 at 745.

31. Dr. Ruby also ignores the benefit in J_o that is attributable to the use of a polysilicon emitter as opposed to a diffused emitter like that used in Froitzheim. As Figure 4 of Kwark demonstrates (reproduced below), J_o values were highest for

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the “Al contact” – the only samples using diffused emitters alone. *Id.* A Skilled Artisan reading Kwark in light of Froitzheim would understand that Froitzheim's device's J_0 could be improved by simply replacing Froitzheim's diffused emitter with *the polysilicon layer with an interfacial oxide layer disclosed by Kwark.*

Figure 4 shows that this structure yields J_0 values up to *one hundred times smaller* than a diffused emitter (“Al contact”) comparable to the one in Froitzheim.

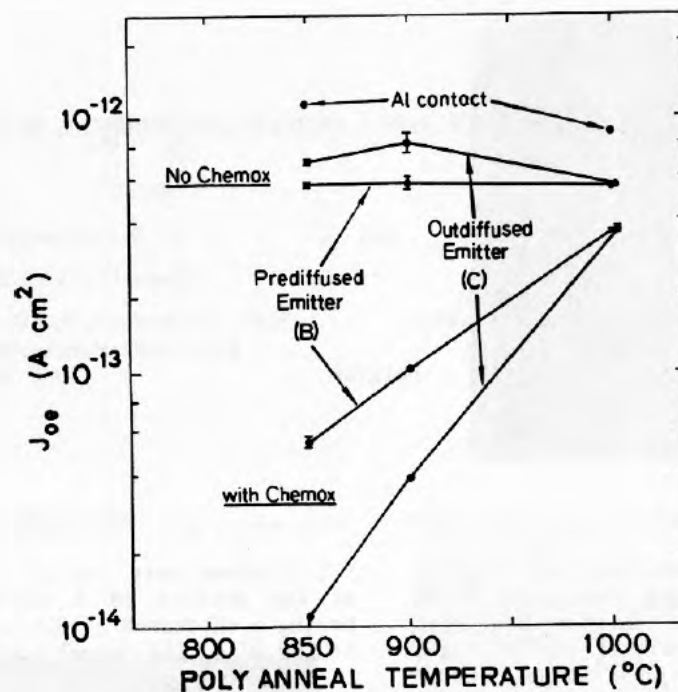


Fig. 4: emitter saturation current for POLY contacts with and without a chemically grown interfacial layer vs. anneal temperature. Thicknesses range from 3000-3600 angstroms. Note the large difference when the interfacial oxide is missing.

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32. Dr. Ruby's extrapolation of what the values for J_o would be if the annealing temperature were extended beyond 1000°C does not have any support, and Kwarik itself did not report on it. EX2020, ¶199. Such an extrapolation is incorrect for at least two reasons. First, Dr. Ruby does not explain how, based on his unsupported extrapolation, the chemox/polysilicon J_o measurements would increase to levels beyond the pure polysilicon (without chemox) measured value of J_o . If at higher temperatures the interfacial oxide layer is degraded, then at best there will be an asymptote where the J_o flattens out at the J_o level of the polysilicon without a chemox layer.

33. Finally, even if the higher temperature shows less improvement in J_o , a Skilled Artisan would know that the benefits to J_o can be achieved by simply annealing the device at 900°C, which is included in Froitzheim's temperature range, as I discussed above in relation to Gan. See ¶6 above. Dr. Ruby's reading of Froitzheim to exclude use of 900°C dopant drive in temperature is incorrect as I discussed in paragraphs 8-11 above.

B. A Skilled Artisan Would Understand How to Optimize to Achieve Low Contact Resistance

34. Contact resistance refers to the resistance to electrical current flow at the interface between two dissimilar materials such as a metal in contact with a semiconductor, or a polysilicon layer in contact with a single crystal Si substrate.

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For metal-semiconductor contacts, the contact resistance depends on the metal work function, and the semiconductor doping level. For polysilicon-single crystal Si contacts, it can depend on the presence of an interfacial oxide. Contact resistance equals the specific contact resistivity ρ_c divided by the contact surface area between the two conductive materials. The greater the surface area (denominator), the lower the contact resistance. Contact resistance is also reduced when ρ_c is reduced such as by reducing the thickness of the interfacial oxide layer between the polysilicon layer and the substrate. As the Gan Thesis recognized, ρ_c is equal to resistivity multiplied by oxide thickness divided by the broken areal fraction. EX2003, 9.

35. In his declaration, Dr. Ruby argues that “the Gan Thesis disparages the use of Chemox” because it reports an SIS emitter with a chemically grown interfacial oxide to have a ρ_c value “as high as $4 \times 10^{-4} \Omega\text{-cm}^2$ at the doping concentration of $1 \times 10^{20} \text{ cm}^{-3}$.” EX2020, ¶202. Dr. Ruby notes that the Gan Thesis states that this would be “intolerable” as it would be “four times higher than the value mentioned in the previous chapter as our goal.” *Id.* (citing EX2003, 58). But this “goal” of $1 \times 10^{-4} \Omega\text{-cm}^2$ was related to concentrator cells and not non-concentrator cells such as the solar cell of Froitzheim. Specifically, the Gan Thesis states that “the requirements for the emitter to be used in the **concentrator** solar

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cells were determined....The requirements are 2×10^{-14} A/cm² for J_o , and less than 1×10^{-4} Ω -cm² for ρ_c for both types.” EX2003, 23 (emphasis added). Dr. Ruby agrees that this 1×10^{-4} Ω -cm² is for concentrator cells. EX2020, ¶65 (“back contact resistivity for a concentrator cell operating at 100 suns concentration should be less than 1×10^{-4} ohm-cm[²].”).

36. However, as I explained above, a Skilled Artisan would understand that the ρ_c requirement for a one sun non-concentrator cell is not as stringent as for concentrator cell, and would allow for a higher ρ_c value. Indeed, Dr. Ruby admits that for one-sun cells, the ρ_c resistivity should only be “less than 1×10^{-2} ohm-cm²” for the back contact. EX2020, ¶64. Thus, the ρ_c value of 4×10^{-4} Ω -cm² reported by Gan Thesis for the device using chemox layer is still more than an order of magnitude lower than the ρ_c resistivity required by Dr. Ruby for one sun cells. Thus, a Skilled Artisan would not have understood the ρ_c value reported by the Gan Thesis to be detrimental to one-sun cells or the combined Froitzheim/Gan solar cell.

37. Moreover, a Skilled Artisan would have understood that utilizing the full back metal contact (15) of Froitzheim (as shown in Figure 1) would have also reduced the overall contact resistance (and therefore compensate for the higher ρ_c) because contact resistance is dependent on the surface area of the contact, as I

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explained in paragraph 34 above. Indeed, this is exemplified in the TOPCon paper discussed by Dr. Ruby in EX2020, ¶¶74-76. *See* EX1040, 3 (“While the passivated contact’s specific contact resistance takes a value of about $10\text{ m}\Omega\text{cm}^2$, its contribution to R_s can be neglected since the rear is fully metallized.”).

38. Further, a Skilled Artisan would also have understood that resistivity is a function of the thickness of the oxide layer. If the resistivity for any given thickness was high, it would be within the capability of a Skilled Artisan to optimize the reaction variables (such as the treatment solution, time, temperature, and pH) to fine tune the thickness of the chemox layer.

39. For instance, Petitdidier, a 2005 paper titled “Growth mechanism and characterization of chemical oxide films produced in peroxide mixtures on Si(100) surfaces,” reported on growth kinetics of silicon chemical oxides. This included showing the growth kinetics of various solutions at different pH values and temperatures, including as a function of time. EX1077 at Abstract; *see also id.* at 52. For example, in Figure 2 of the paper, the researchers plotted oxide thickness vs. the square root of time for their oxidation processes at different times using different solutions. *Id.* at 54. Petitdidier’s results indicate that since at least 2005, a Skilled Artisan would have been capable of reproducibly achieving oxide thicknesses *down to an Angstrom level*.

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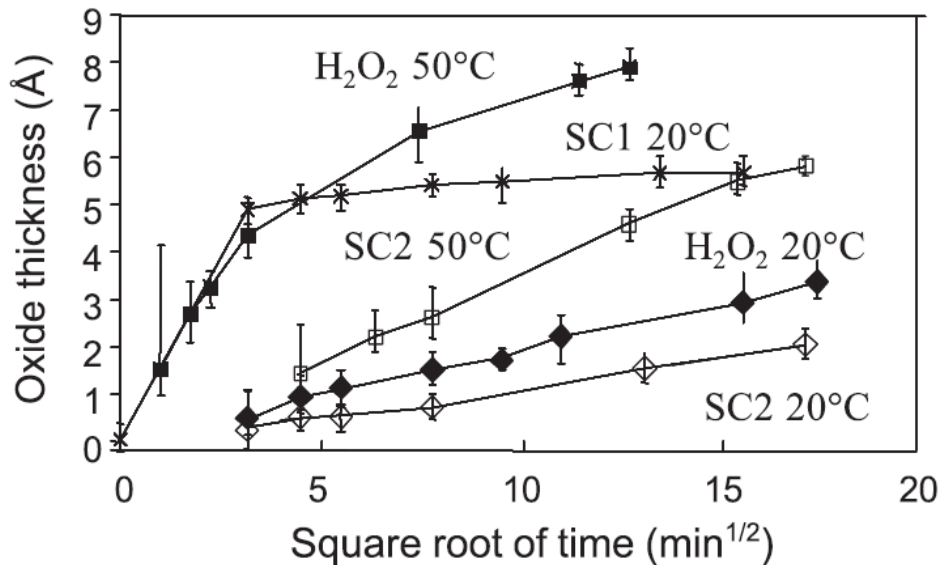


Fig. 2. Optical thickness from ellipsometry vs. time for different process conditions.

40. Thus, given the benefits afforded by Kwark's teaching of solar cells, it would have been well within the capability of a Skilled Artisan to optimize these variables to generate a thinner oxide with reduced resistivity. A Skilled Artisan would have been able to capably generate a chemox layer before Froitzheim (published in 2006), and could have readily applied the teachings of Kwark to the solar cell of Froitzheim.

III. Opinions Regarding Reply Evidence

41. In this declaration I cite to a number of papers that have been published in various technical journals, which for convenience I have set forth in the attached Appendix D.

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42. I am and have been throughout my career personally familiar with each of the journals cited in Appendix D. I have read many papers published in these journals during the course of my career, and have myself published papers in many of them. Each cited journal is a well-known, reputable, reliable, and authoritative periodical which publishes compilations of scientific and technical publications and would be generally known to those in the field of solar cell design or manufacture.

43. Moreover, I have inspected each of the exhibits listed in Appendix D. In my opinion, and based on my experience with the journals cited in Appendix D and on the appearance, contents, substance, and distinctive characteristics of such exhibits, each listed exhibit is what it appears to be, *i.e.*, an article published in the journal with which it is associated in the exhibit. Indeed, I see nothing in any of those exhibits to suggest that the exhibit is not what it appears to be, or which raises any doubt as to the exhibit's authenticity or accuracy.

44. Also, in my opinion, and based on my experience, the dates on the exhibits of Appendix D are reliable and trustworthy because journals of the type listed in the Appendix have a reputational incentive to accurately publish the submissions each such journal receives, including by attaching an accurate publication date on such documents. Any such journal that was known to publish

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inaccurate information, including publication dates, would likely soon not be read by those in the field. Indeed, if such journals were not reliable, they would quickly cease to operate because those working in the field would not contribute articles to them.

45. Moreover, it would be very difficult for such dates to be mistakenly or intentionally altered because the underlying document remains available to those working in the field, including the authors and the general public, and from the journals themselves. Any question as to the date of a paper published in any of the journals listed in Appendix D could therefore easily be verified and resolved.

46. It is also my opinion that the exhibits listed in Appendix D are the most probative and best source for both the content of the exhibit and the date of that content's publication because other ways of obtaining that information such as personally contacting the author(s) and publishers of the exhibits listed in Appendix D, would require an unreasonable amount of effort given the publicly available nature of the exhibits.

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APPENDIX D: List of Certain Exhibits Considered and Cited Statements

Exhibit Number	Exhibit Reference	Exhibit Citation
Ex. 1077	Merabet, A. et al., “Dopant Redistribution during Rapid Thermal Annealing in a Self-Aligned Polysilicon Emitter Bipolar Structure Compatible with a Complementary Metal-Oxide-Semiconductor Technology.”	(1) “It is well known that arsenic dopants move along polysilicon grain boundaries, when annealing is performed, and can present a wide range of diffusivities, from 100 up to 10000 higher than arsenic diffusivity in monocrystalline silicon during classical thermal annealing (CTA), depending especially on the polysilicon deposition process. On the other hand, the boron diffusion coefficient is assumed to be from 50 up to 200 times greater than B diffusivity in monosilicon during CTA. Some authors underline that boron does not diffuse at grain boundaries ...” EX1077 at 78.

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Exhibit Number	Exhibit Reference	Exhibit Citation
	1994, Phys. Stat. Sol. (a) 145, 77. (“Merabet”)	(2) “Grain boundaries cannot be considered to act only mechanically as pipelines, but dopants diffuse there assisted by electrical charges (perhaps a part of dangling bonds), which can be saturated by arsenic in As/B co-diffusion and then slow boron diffusion. In conclusion, polysilicon has a structural (i.e. depth-dependent grain boundary density) and an electrical (i.e. grain boundary trap saturation) influence on boron

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Exhibit Number	Exhibit Reference	Exhibit Citation
		diffusion.” EX1077 at 83-84. A. MERABET and C. GONTRAND: Dopant Redistribution during Rapid Thermal Annealing 77 phys. stat. sol. (a) 145, 77 (1994) Subject classification: 66.30; 68.48; 73.40; S5.11 <i>Laboratoire de Physique de la Matière, URA CNRS N° 358 (a) and Centre Inter-Universitaire de Micro-electronique de la Région Lyonnaise (b), Institut National des Sciences Appliquées de Lyon, Villeurbanne¹⁾</i> Dopant Redistribution during Rapid Thermal Annealing in a Self-Aligned Polysilicon Emitter Bipolar Structure Compatible with a Complementary Metal–Oxide–Semiconductor Technology By A. MERABET (a) and C. GONTRAND (a, b) Arsenic and boron concentration profiles, diffused from polycrystalline silicon (polysilicon) into an underlying single crystalline silicon, are analyzed by secondary ion mass spectrometry. This bilayer is the basic structure of a self-aligned bipolar transistor, compatible with a complementary metal–oxide–semiconductor; arsenic and boron codiffusions are studied in an emitter and extrinsic base configuration of bipolar transistors. Rapid thermal annealings are performed to obtain shallow junctions, with temperature and annealing plateau duration as parameters. Finally, the codiffusion process is investigated using simulations. It indicates that diffusion of the dopant at the lowest fluence is slowed, much more because of the in-depth inhomogeneous grain growth induced by amorphization and annealing, than a built-in electric field. Then, it should be assumed that the dopant at the highest dose saturates the grain boundary traps. This hypothesis concerns essentially arsenic, but also boron, to a less extent. 1. Introduction In recent years, the complementary metal–oxide–semiconductor (MOS) combined with a compatible bipolar transistor (BiCMOS) has emerged as a new device. The key idea is to merge the high density of MOS circuits with high current-drive bipolar circuits. In addition, bipolar transistor performances are enhanced when doped polysilicon serves as a diffusion source and as the emitter and extrinsic base contact material [1, 2], so when a thin interfacial oxide layer between the polysilicon and the monocrystalline silicon acts as a tunneling barrier to minority carrier injection into the polysilicon [3]. In fact, in the support BiCMOS technology of our study, the NPN transistor structure is similar to the PMOS one, i.e. polysilicon is used as the contact emitter and as the gate [4]. The extrinsic base is formed during source/drain implantation. The emitter and base junctions of the self-aligned bipolar transistor are formed by alternately driving arsenic and boron atoms from the polysilicon layer into the single crystal silicon substrate. Dopant drive-in must be accomplished with a minimum thermal budget in order to form and maintain the shallow emitter and base structure. The aim of our paper is essentially to study the process diffusion of the dopants into and from polysilicon during rapid thermal annealing. Discussion will be aided by use of a process simulation. ¹⁾ 20 av. A. Einstein, F-69621 Villeurbanne Cedex, France.
Ex. 1078	Kermani, A. et al., “Single-Wafer Rapid	(1) “The interfacial oxide must be thicker than 10 A to be thermally and chemically stable and, thin enough not block dopant atoms, approximately

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	Thermal CVD Technology for Fabrication of MOS and Bipolar Devices.” ULSI Science & Technology, Proc. Vol. 11, 1991, pp. 566-573.	less than 30 A. Furthermore, for best transistor performance, the interracial oxide must have a near-SiO ₂ stoichiometry. For this range of oxide thickness, the oxidation kinetics must be greatly reduced. This can be achieved by reducing the oxidation temperature, pressure and by lowering the partial pressure of oxygen. Using SIMS, the oxidation kinetics of ultrathin oxide films expressed as total integrated dose of oxygen is shown in Figure 4. For these samples, upon completion of the oxidation step, polysilicon caps were in-situ deposited.” Exhibit 1078 at 570.

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		SINGLE-WAFER RAPID THERMAL CVD TECHNOLOGY FOR FABRICATION OF MOS AND BIPOLAR DEVICES Ahmad Kermani, Fred Wong and Kris E. Johnsgard RAPRO Technology Inc., Fremont, CA 94539 In fabrication of MOS, bipolar and BiCMOS integrated circuits, single-wafer rapid thermal chemical vapor deposition (RTCVD) can provide the foundation for a wide range of processes. In addition, a number of processing steps can be integrated to a central wafer handler to provide an application-specific tool. The applications include MOS gate dielectric, poly-emitter bipolar interface engineering, polysilicon deposition, and single or multi-layers of blanket or selective homo or hetero-epitaxy films. It is increasingly apparent, especially with the advanced generation technology employed for large substrates, that the level of control required can only be achieved when processing sequences are executed in a single-wafer mode under a controlled environment. A combination of low-temperature reduced-pressure wafer cleaning, dielectric engineering and polysilicon deposition will satisfy the requirements of this emerging concept of integrated, environmentally controlled front-end processing for the MOS gate and poly-emitter bipolar applications. INTRODUCTION For fabrication of small geometry ICs, reduced thermal budget processing is mandatory to restrict dopant movement for maintaining shallow junctions. Furthermore, for stability reasons, strained layer $\text{Si}_x\text{Ge}_{1-x}$ HBT structures can not be subjected to high-temperature processing [1]. For low-thermal budget processing, RTCVD was introduced to provide an alternative to conventional long-time, slow-response batch furnace technology. In this approach, thermal energy is provided by radiative heating in a cold-wall environment. Due to small thermal mass of the system, rapid changes in wafer temperature, both up and down, is made possible. In parallel, various dry low-temperature wafer cleaning techniques have been developed [2,3,4,5]. The key is to effectively clean the wafer at low temperatures (below 600°C) and to maintain surface cleanliness between various processing steps. Dry-phase, anhydrous HF cleaning at room temperature supplemented by UV/ozone treatment has been used to effectively remove the surface native oxide and hydrocarbon residues [6, 7]. This technique has attracted a lot of attention due to its simplicity, ease of integration and low cost. Furthermore, it can be applied to fabrication of both MOS and bipolar devices. 566
Ex. 1079	Petitdidier, S., et al., "Growth mechanism and characterization of chemical oxide films	(1) Figure 2, EX1079 at 54. Fig. 2. Optical thickness from ellipsometry vs. time for different process conditions.

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	produced in peroxide mixtures on Si(100) surfaces.” 2005, Thin Solid Films, 476, 51-58.	   Available online at www.sciencedirect.com Thin Solid Films 476 (2005) 51–58 Growth mechanism and characterization of chemical oxide films produced in peroxide mixtures on Si(100) surfaces S. Petrididier^a, V. Bertagna^{b,*}, N. Rochat^c, D. Rouchon^c, P. Besson^a, R. Erre^b, M. Chemla^d ^aSTMicroelectronics, 850 rue Jean Monnet, 38926 Croix Cedex, France ^bDepartment of Materials Chemistry, CRM2, CNRS-Université d'Orléans, Rue de Chartres, BP 6759, 45067 Orléans, France ^cCELESTI, CEA-Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France ^dLDC, Université P.M. Curie, 4 place Jussieu, 75005 Paris, France Received 27 October 2003; received in revised form 23 March 2004; accepted 2 September 2004 Available online 22 October 2004 Abstract The growth kinetics of silicon chemical oxides in H₂O₂-containing solutions at various pH values and temperatures was studied by electrochemical impedance spectroscopy (EIS), ellipsometry and X-ray photoelectron spectroscopy. Infrared (IR) spectroscopy was also used to investigate the evolution of the surface chemistry from the initial hydrogen coverage as Si-H bonds to the subsequent oxidation states by analysing the Si-O-Si stretching vibration modes. Successive EIS diagrams obtained as a function of time constituted a series of semicircles indicating that the semiconductor/oxide/electrolyte junction can be modelled as a resistance-capacity (RC) circuit. It was then observed that the resistance term increased with time to almost 1 MΩ cm² after 3 h in SC1 solution. It is generally known that, in alkaline solutions such as SC1, the oxidation rate reaches rapidly a steady regime controlled by the interfacial charge transfer reaction and the subsequent dissolution of the generated oxide. Accordingly, a mechanism involving a diffusion process of reactants through the oxide barrier followed by a simultaneous dissolution of the layer is proposed. Likewise, in acidic media such as SC2, even though the solubility is extremely low, we have extended our model based on the competition between the oxidation rate at the surface and the dissolution of the built-up oxide, and thus it was possible to evidence oxide solubility at the nanoscopic scale. In addition, thickness measurements by ellipsometry together with the observed gradual change in the IR spectrum of the Si-O-Si vibration mode were interesting parameters revealing that the oxide growth proceeds simultaneously with an evolution of the structure leading to a more compact and insulating dielectric layer. The whole of the results lead to a model for the oxidation process accounting for the observed structure and complex impedance properties under various conditions of chemical treatment. © 2004 Elsevier B.V. All rights reserved. PHCS: 73.61–c; 73.40.Mr; 77.55–f; 81.65.Mg; 82.80.F; 84.37 Keywords: Silicon oxide; Growth kinetics; Silicon surface treatment; Electrochemical impedance; SC1; SC2 1. Introduction The RCA process, developed by Kern and Puotinen [1,2], is still widely used in semiconductor industry for the surface cleaning of silicon wafers. New improvements are continually developed aiming at a better cleaning efficiency, a lower cost, and a strict control of the environmental regulations [3,4]. After removal of the native oxide with a HF treatment, the resulting Si-H₂ hydrophobic surface is successively treated in an alkaline ammonia-hydrogen peroxide mixture called SC1, to oxidize the organic contaminants and generate a thin chemical oxide layer which repels all inorganic particles from the surface by setting the zeta potential of both the surface and the particles. In the next step, an acidic HCl-hydrogen peroxide mixture called SC2 allows the metallic contaminants to be dissolved as complex species and excluded from the surface. The pH value of these solutions is the determining * Corresponding author. Tel.: +33 2 38 49 48 65; fax: +33 2 38 41 70 43. E-mail address: valerie.bertagna@univ-orleans.fr (V. Bertagna). 0040-4090/\$ - see front matter © 2004 Elsevier B.V. All rights reserved. doi:10.1016/j.tsf.2004.09.008
Ex. 1080	Wolf, M. et al., “Series Resistance Effects on Solar Cell Measurements.”	(1) “Figure 3 presents a plot of the short circuit current as a function of solar irradiance for the two cells used for the measurements presented in Fig. 2. This plot shows that the low series resistance cell exhibits a linear relationship

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	1963, Advanced Energy Conversion. Vol. 3, pp. 455-479.	between short circuit current and solar irradiance up to 400 mW cm⁻² which is identical to four times the maximum solar irradiance reached at the earth's surface at sea level at noon time on a clear day.” EX1080 at 461 (Figure 3). (2) “Internal series resistance causes a successively larger “rounding” of the characteristic at increasing light intensities. Solar cells are normally designed for best performance at radiation intensities as obtained at the earth's surface. Such cells may therefore not give optimum performance at increased e the sun or in the use of solar cells combined with radiation concentrating devices.” EX1080 at 463.

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		Advanced Energy Conversion Vol. 3, pp. 455-479. Pergamon Press, 1963. Printed in Great Britain SERIES RESISTANCE EFFECTS ON SOLAR CELL MEASUREMENTS* MARTIN WOLF and HANS RAUSCHENBACH† Abstract—Current-voltage characteristics of photovoltaic solar energy converter cells are obtainable by three methods, which yield different results due to the effects of the cell internal series resistance. The three resultant characteristics are: (1) the photovoltaic output characteristic, (2) the p-n junction characteristic, and (3) the rectifier forward characteristic. Choice of the proper method is necessary for obtaining the correct information for the individual application. Most frequently used, e.g. for the determination of solar converter performance, is the photovoltaic output characteristic. A quick way is described for deriving such a characteristic for any light level from a corresponding characteristic obtained at a different light level. This method involves two translations of the coordinate system and requires only the knowledge of the series resistance and the difference in light intensities or short circuit currents. An inversion of this method permits an easy determination of the series resistance, involving measurements at two arbitrary light levels of unknown magnitude. The effects of series resistance consist at high light levels in a flattening of the photovoltaic output characteristic and a related drop in the maximum power point voltage. The resultant decrease in efficiency has to be overcome by series resistance reduction for solar cell applications with optical concentrators or for space missions in closer sun-proximity. In cell portions progressively further distant from the contact strip increasing cell voltages develop, approaching open circuit condition at very high light intensities. This yields a reduction of current contribution from those portions of the cell and a deviation from the normal proportionality between short circuit current and light intensity. The direct measurability of the p-n junction characteristic at high current densities without series resistance effects by the second method provides a powerful tool to the device development engineer, besides yielding a second method for the determination of the series resistance. Results from the application of this method indicate that, in the current density range as used in solar energy conversion, the silicon solar cell characteristic is much more closely described by the diffusion theory for p-n junctions than was previously believed. 1. INTRODUCTION Like all other known generators of electrical power, solar cells possess some internal series resistance. This internal series resistance is so important as to determine the current-voltage characteristic of most of these power generators. This is, however, not the case with the solar cells. Rather a p-n junction, internally contained in the solar cell, determines the current-voltage characteristic of the device, with the series resistance contributing only in a secondary manner. Nevertheless, the internal series resistance is of sufficient importance to have caught the attention of the device development engineers, which led to its reduction through decrease of contact resistance and through application of grid-shaped contacts. Also the power systems engineer concerned with the application of solar cells has to pay attention to the cell series resistance for the proper evaluation of current-voltage characteristics, for the matching of cells and for the prediction of solar cell output at differing light intensities. In order to further spread the knowledge about the various effects of the internal series resistance and about their proper interpretation, a summary of the series resistance effects on solar cell measurements and applications is presented in the following paragraphs. * This paper was presented at the 1961 Pacific General Meeting of the AIEE, Salt Lake City, Utah, August 23-25, 1961. † Heliotek, Division of Textron Electronics, Inc., 12500 Gladstone Avenue, Sylmar, California, U.S.A. 17 455