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Paper 55
Date: January 12, 2022

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

SAMSUNG ELECTRONICS CO., LTD.,
Petitioner,

v.

ACORN SEMI, LLC,
Patent Owner.

IPR2020-01279
Patent 9,905,691 B2

Before BRIAN J. McNAMARA, JOHN R. KENNY, and
AARON W. MOORE, *Administrative Patent Judges.*

McNAMARA, *Administrative Patent Judge.*

JUDGMENT
Final Written Decision
Determining Some Challenged Claims Unpatentable
Denying Patent Owner's Motion to Exclude Testimony of Dr. Goodnick
Dismissing Patent Owner's Motion to Exclude Testimony of Dr. Kuhn
Denying Petitioner's Motion to Exclude Testimony of Dr. Clifton
35 U.S.C. § 318(a)

I. BACKGROUND

On January 13, 2020, we instituted an *inter partes* review of claims 1–4, 6, 8, 10–13, 15–20, 22, and 25–30 of U. S. Patent No. 9,905,691 B2 (Ex. 1101, "the ' 691Patent"). Paper 20 ("Dec. to Inst."). Patent Owner filed a Patent Owner Response (Paper 28, "PO Resp."), Petitioner filed a Petitioner Reply (Paper 37, "Pet. Reply") and Patent Owner filed a Sur-reply (Paper 43, "PO Sur-reply). A transcript of an oral hearing held on October 13, 2001 (Paper 54, "Hr'g. Tr.") has been entered into the record.

We have jurisdiction under 35 U.S.C. § 6. This Final Written Decision is issued pursuant to 35 U.S.C. §318(a). We base our decision on the preponderance of the evidence. 35 U.S.C. § 316(e); 37 C.F.R. § 42.1(d).

Having reviewed the arguments of the parties and the supporting evidence, we conclude that Petitioner has demonstrated by a preponderance of the evidence that claims 1–4 and 13 are unpatentable.

II. THE '691 PATENT

The '691 patent "relates to a process for depinning the Fermi level of a semiconductor at a metal-interface layer-semiconductor junction and to devices that employ such a junction." Ex. 1101, 1:27–29. The '691 patent explains that Schottky's theory concerning the ability of a junction to conduct current in one direction more favorably than in the other direction, i.e., the rectifying behavior of a metal/semiconductor junction (e.g., an aluminum/silicon junction), depends upon a barrier at the surface of the contact between the metal and the semiconductor. *Id.* at 1:33–48. As the barrier height at the metal/semiconductor interface determines the electrical properties of the junction, controlling the barrier height is an important goal. *Id.* at 3:4–10.

The ’691 patent further explains that Schottky’s theory postulates the height of the barrier, as measured by the potential necessary for an electron to pass from the metal to the semiconductor, is the difference between the work function of the metal (i.e., the energy required to free an electron at the Fermi level (the highest occupied energy state of the metal at T=0)) and the electron affinity of the semiconductor (i.e., the difference between the energy of a free electron and the conduction band of the semiconductor); but experimental results indicate a weaker variation of barrier height with work function than implied by this model. *Id.* at 1:49–2:3.

To explain the discrepancy between the predicted and observed behavior, Bardeen introduced the concept of semiconductor surface states, i.e., energy states within the bandgap between the valence and conduction bands at the edge of the semiconductor crystal that arise from incomplete covalent bonds, impurities, and other effects of termination. *Id.* at 2:4–18, Fig. 1 (showing dangling bonds that may be responsible for surface states that trap electrical charges). Although Bardeen’s model assumes that surface states are sufficient to pin the Fermi level in the semiconductor at a point between the valence and conduction bands, such that the barrier height should be independent of the metal’s work function, in experiments this condition is observed rarely. *Id.* at 2:19–25.

Further, according to the ’691 patent, Tersoff proposed that the Fermi level of a semiconductor is pinned near an effective “gap center” due to metal induced gap states (MIGS), which are energy states in the bandgap of the semiconductor that become populated with metal. *Id.* at 2:35–44. Thus, the wave functions of electrons in the metal do not terminate abruptly at the surface of the metal, but decay in proportion to the distance from the surface, extending inside the semiconductor. *Id.* at 2:44–48.

> To maintain the sum rule on the density of states in the semiconductor, electrons near the surface occupy energy states in the gap derived from the valence band such that the density of states in the valence band is reduced. To maintain charge neutrality, the highest occupied state (which defines the Fermi level of the semiconductor) will then lie at the crossover point from states derived from the valence band to those derived from the conduction band. This crossover occurs at the branch point of the band structure.

Id. at 2:48–56. The ’691 patent also notes one further surface effect on diode characteristics is inhomogeneity, i.e., “if factors affecting the barrier height (e.g., density of surface states) vary across the plane of the junction, the resulting properties of the junction are found not to be a linear combination of the properties of the different regions.” *Id.* at 2:63–67.

According to the ’691 patent, “a classic metal-semiconductor junction is characterized by a Schottky barrier, the properties of which (e.g., barrier height) depend on surface states, MIGS and inhomogeneities.” *Id.* at 2:67–3:3. “Before one can tune the barrier height, however, one must depin the Fermi level of the semiconductor.” *Id.* at 3:10–12. The ’691 patent seeks to depin the Fermi level of the semiconductor while still permitting substantial current flow between the metal and the semiconductor. *Id.* at 3:12–15. The ’691 patent describes depinning the Fermi level as follows:

> By depinning the Fermi level, the present inventors mean a condition wherein all, or substantially all, dangling bonds that may otherwise be present at the semiconductor surface have been terminated, and the effect of MIGS has been overcome, or at least reduced, by displacing the semiconductor a sufficient distance from the metal.

Id. at 3:30–35.

The ’691 patent achieves this goal using thin interface layers disposed between a metal and a silicon based semiconductor to form a “metal-interface layer-semiconductor junction" whose thickness varies with a corresponding minimum specific contact resistance depending on the materials used and allows for depinning the Fermi level while permitting current to flow when the junction is appropriately biased. *Id.* at 3:19–30; *see also id.* at 12:59–14:17, 14:29–52, Figs. 6, 8. "Minimum specific contact resistances of less than or equal to approximately 10 Ω-μm^2 or even less than or equal to approximately 1Ω-μm^2 may be achieved for such junctions in accordance with the present invention." *Id.* at 3:36–39. Such low contact resistances are achieved by selecting a metal with a work function near the conduction band of the semiconductor for n-type semiconductors, or a work function near the valence band for p-type semiconductors. *Id.* at 5:19–23.

Figure 8 of the '691 patent is reproduced below.

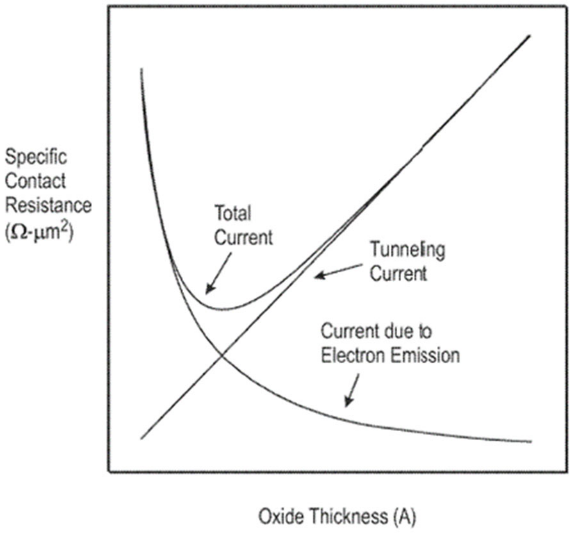

Figure 8 of the '691 patent

Figure 8 of the '691 patent is a graph of interface specific contact resistance versus interface thickness for a structure where the work function of the metal is the same as the electron affinity of the semiconductor, such that the Fermi level of the metal lines up with the conduction band of the semiconductor. *Id.* at 14:29–35. According the ’691 patent, Figure 8 shows that at large thicknesses, the interface layer poses significant resistance to current, but as interface layer thickness decreases, resistance falls due to increased tunneling current. *Id.* at 14:29–38. However, at some point, as the interface layer gets thinner, the effect of MIGS increasingly pulls the Fermi level of the metal down towards the mid-gap of the semiconductor, creating a Schottky barrier and increasing resistance. *Id.* at 14:38–42. Thus, there is an optimum thickness where the resistance is at a minimum and the effect of MIGS has been reduced to depin the metal and lower the Schottky barrier, but the layer is sufficiently thin to allow significant current across the interface layer, such that specific contact resistances of less than or equal to approximately 2500 $\Omega\text{-m}^2$, 1000 $\Omega\text{-m}^2$, 100 $\Omega\text{-m}^2$, 50 $\Omega\text{-m}^2$, 10 $\Omega\text{-m}^2$, or less than 1 $\Omega\text{-m}^2$ can be achieved. *Id.* at 14:45–52.

In one embodiment, the interface layer may be a monolayer or several monolayers of passivating material (e.g., a nitride, oxide, oxynitride, arsenide, hydride and/or fluoride) and may include a separation oxide layer, the specific contact resistance of the electrical device is less than 10 $\Omega\text{-}\mu\text{m}^2$. *Id.* at 3:40–53; *see also* 10:43–54. In another embodiment, the interface layer is made up of a passivation layer fabricated by exposing the semiconductor to nitrogenous material (e.g., ammonia (NH3), nitrogen (N2) or unbound gaseous nitrogen (N) generated from a plasma process) and while heating the semiconductor in a vacuum chamber. *Id.* at 3:44–61. Another embodiment uses an interface layer of passivating material disposed between the surface of a semiconductor and a conductor in which the interface is of sufficient thickness to reduce the effect of MIGs in the semiconductor and passivates the semiconductor but, because the thickness of the interface layer is chosen to provide minimum, or near minimum, specific contact resistance for the junction, significant current may flow between the conductor and the semiconductor. *Id.* at 3:62–4:8. In other embodiments the interface layer is configured to allow a Fermi level of the conductor to (i) align with a conduction band of the semiconductor, (ii) align with a valence band of the semiconductor, and (iii) be independent of the Fermi level of the semiconductor, allowing current to flow between the conductor and the semiconductor when the junction is biased because the thickness of the interface layer corresponds to a minimum or near minimum contact resistance for the junction. *Id.* at 4:8–18. Specific contact resistances of less than or equal to approximately 2500 Ω-m^2, 1000 Ω-m^2, 100 Ω-m^2, 50 Ω-m^2, 10 Ω-m^2, or less than 1 Ω-m^2 can be achieved. *Id.* at 4:19–22, 14:45–52.

III. ILLUSTRATIVE CLAIM(S)

Independent claim 1, reproduced below to include the subject matter of a certificate of correction issued on May 15, 2018 (Ex. 1101, 21), and including claim element designations (i) through (vii) used in the Petition, is representative of the subject matter of the ’691 patent:

> 1. (i) A structure, comprising
>
> (ii) a semiconductor region in a substrate,
>
> (iii) a metal electrical contact to said semiconductor region,
>
> (iv) a metal oxide layer,
>
> (v) a passivating dielectric tunnel barrier layer between said semiconductor region and said metal electrical contact,
>
> (vi) said semiconductor region being electrically connected to said metal electrical contact through said passivating dielectric tunnel barrier layer and said metal oxide layer,
>
> (vii) wherein said passivating dielectric tunnel barrier layer comprises a semiconductor oxide.

IV. GROUNDS OF INSTITUTION

Inter partes review was instituted on all the grounds asserted in the Petition as follows:

Claim(s) Challenged	35 U.S.C. §	Reference(s)/Basis
1–3, 13	102(b)	Goodnick[1]
4	103(a)	Goodnick, Jammy[2]
1, 3, 6, 10–13, 15, 16, 19, 20, 22	103(a)	Goodnick, Taubenblatt 1982[3]
8, 17	103(a)	Goodnick, Jammy, Taubenblatt 1982
18, 25–30[4]	103(a)	Goodnick, Jammy, Taubenblatt 1982, Chang[5]

V. CLAIM CONSTRUCTION

In the Decision to Institute, we construed the terms "specific contact resistivity" and "specific contact resistance" to be interchangeable. Dec. to Inst. 12. Neither party disagrees with this construction, and we apply the same construction for purposes of the Decision.

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[1] S.M. Goodnick et al., *Effects of a thin SiO2 layer on the formation of metal-silicon contacts*, 18 J. VAC. SCI. & TECH. 949 (Apr. 1981). (Ex. 1116).

[2] U.S. Patent No. 6,724,088. (Ex. 1115)

[3] M.A. Taubenblatt and C.R. Helms, *Silicide and Schottky barrier formation in the Ti-Si and the Ti-SiOx-Si systems*, 58 J. APPLIED PHYS. 6308 (1982). (Ex. 1117).

[4] Claim 30 has been disclaimed and is no longer a subject of this proceeding.

[5] C.Y. Chang et al., *Specific contact resistance of metal-semiconductor barriers*, 15 SOLID STATE ELECS. 541 (1971)

VI. ANALYSIS OF PRIOR ART CHALLENGES

A. Introduction

"In an [inter partes review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable." *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) (requiring inter partes review petitions to identify "with particularity . . . the evidence that supports the grounds for the challenge to each claim")). This burden of persuasion never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. Nat'l Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015) (discussing the burden of proof in inter partes review).

Anticipation is a question of fact, as is the question of what a prior art reference teaches. *In re NTP, Inc.*, 654 F.3d 1279, 1297 (Fed. Cir. 2011). "A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. Inc., v. Union Oil Co.*, 814 F.2d 628, 631 (Fed. Cir. 1987); *see also Finisar Corp. v. DirecTV Group, Inc.*, 523 F.3d 1323, 1334 (Fed. Cir. 2008) (to anticipate a patent claim under 35 U.S.C. § 102, "a single prior art reference must expressly or inherently disclose each claim limitation"). Moreover, "[b]ecause the hallmark of anticipation is prior invention, the prior art reference—in order to anticipate under 35 U.S.C. § 102—must not only disclose all elements of the claim within the four corners of the document, but must also disclose those elements 'arranged as in the claim.'" *Net MoneyIN, Inc. v. VeriSign, Inc.*, 545 F.3d 1359, 1369 (Fed. Cir. 2008) (quoting *Connell v. Sears, Roebuck & Co.*, 722 F.2d 1542, 1548 (Fed. Cir. 1983)).

Whether a reference anticipates is assessed from the perspective of an ordinarily skilled artisan. *See Dayco Prods., Inc. v. Total Containment, Inc.*, 329 F.3d 1358, 1368 (Fed. Cir. 2003) ("[T]he dispositive question regarding anticipation [i]s whether one skilled in the art would reasonably understand or infer from the [prior art reference's] teaching that every claim element was disclosed in that single reference." (quoting *In re Baxter Travenol Labs.*, 952 F.2d 388, 390 (Fed. Cir. 1991))).

Additionally, under the principles of inherency, if the prior art necessarily functions in accordance with, or includes, the claimed limitations, it anticipates. *MEHL/Biophile Int'l Corp. v. Milgraum*, 192 F.3d 1362, 1365 (Fed. Cir. 1999) (citation omitted); *In re Cruciferous Sprout Litig.*, 301 F.3d 1343, 1349–50 (Fed. Cir. 2002).

As set forth in 35 U.S.C. § 103(a),

> [a] patent may not be obtained . . . if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

The question of obviousness is resolved on the basis of underlying factual determinations including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of ordinary skill in the art; and (4) objective evidence of nonobviousness. *Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966). Additionally, the obviousness inquiry typically requires an analysis of "whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue." *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 418 (2007) (citing *In re Kahn*, 441 F.3d 977, 988 (Fed. Cir. 2006) (requiring "articulated reasoning with some rational underpinning to support the legal conclusion of obviousness")); *see In re Warsaw Orthopedic, Inc.*, 832 F.3d 1327, 1333 (Fed. Cir. 2016) (citing *DyStar Textilfarben GmbH & Co. Deutschland KG v. C. H. Patrick Co.*, 464 F.3d 1356, 1360 (Fed. Cir. 2006)).

An obviousness analysis "need not seek out precise teachings directed to the specific subject matter of the challenged claim, for a court can take account of the inferences and creative steps that a person of ordinary skill in the art would employ." *KSR*, 550 U.S. at 418; *accord In re Translogic Tech., Inc.*, 504 F.3d 1249, 1259 (Fed. Cir. 2007). Petitioner cannot satisfy its burden of proving obviousness by employing "mere conclusory statements." *In re Magnum Oil Tools Int'l, Ltd.*, 829 F.3d 1364, 1380 (Fed. Cir. 2016). Instead, Petitioner must articulate a reason why a person of ordinary skill in the art would have combined the prior art references. *In re NuVasive*, 842 F.3d 1376, 1382 (Fed. Cir. 2016).

A reason to combine or modify the prior art may be found explicitly or implicitly in market forces; design incentives; the "interrelated teachings of multiple patents"; "any need or problem known in the field of endeavor at the time of invention and addressed by the patent"; and the background knowledge, creativity, and common sense of the person of ordinary skill. *Perfect Web Techs., Inc. v. InfoUSA, Inc.*, 587 F.3d 1324, 1328–29 (Fed. Cir. 2009) (quoting *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 418–21 (2007)).

Before determining whether a claim is obvious in light of the prior art, we consider any relevant evidence of secondary considerations of non-obviousness. *See Graham*, 383 U.S. at 17. Notwithstanding what the teachings of the prior art would have suggested to one of ordinary skill in the art at the time of the invention, the totality of the evidence submitted, including objective evidence of non-obviousness, may lead to a conclusion that the challenged claims would not have been obvious to one of ordinary skill. *In re Piasecki*, 745 F.2d 1468, 1471–72 (Fed. Cir. 1984).

We analyze the asserted grounds of unpatentability in accordance with these principles to determine whether Petitioner has met its burden to establish a reasonable likelihood of success at trial.

B. Claims 1–3 as anticipated by Goodnick (Petitioner's Ground 1)

Petitioner contends that Goodnick discloses each and every element of claims 1–3 and 13. Pet. 21–26.

1. Goodnick (Ex. 1116)

Goodnick concerns experiments in which "[t]he focus of the present investigation has been to observe the influence of thin SiO2 layers on the chemical formation of metal-silicon contacts." Ex. 1116, 1. According to Goodnick, a thick interfacial oxide at a metal-silicon interface suppresses current, thereby reducing rectifying characteristics, but a thin oxide layer sustains considerable current via tunneling and reduces the density of interface states by satisfying dangling bonds. *Id.* Goodnick discloses that:

> [a]s a result, the Fermi level at the surface may become unpinned and the barrier height is more directly determined by the metal work function. In addition, a thin interfacial layer may act as a barrier to the chemical reaction and interdiffusion that characterizes the intimate metal silicon contact. Thus, the presence of a thin oxide at the interface acts as a passivating influence, both from an electronic and a chemical standpoint.

Id.

Goodnick discloses experiments with aluminum, platinum, and gold in which thin SiO_2 oxide layers were grown in dry oxygen at 700 degrees Celcius in an open tube furnace to approximately 30Å. *Id.* at 1. The 30Å thermally grown SiO_2 appeared as a complete barrier to the formation of platinum silicide and less of a barrier to the Au-Si reaction, where "widespread dissolution of the SiO_2 layer and reaction between the Au and Si appeared to occur." *Id.* at 5. "Al partially reduces the thin SiO2 layer to form Al_2O_3 and free Si. This reaction appeared to be self-limiting, with SiO_2 still present at the interface, even after heating at 400°C." *Id.* Goodnick concludes:

> a thermally grown SiO2 layer appears effective in preventing or retarding the widespread interdiffusion of elemental Si. However, chemically etched surfaces react readily with the metal overlayer even though a thin native oxide grows prior to deposition. The different chemical nature of room temperature air grown oxides of Si is suggested as an explanation of these results.

Id.

2. *Claim 1*

a) *Preamble 1(i) and claim limitation 1 (ii)*

Petitioner asserts that the preamble is not limiting, but cites Goodnick as disclosing an $Al\text{-}Al_2O3\text{-}SiO_2\text{-}Si$ contact structure. Pet. 22 (citing Ex. 1116 1–2, 5; Ex. 1119, Declaration of Dr. E. Fred Schubert ("Schubert Decl.") ¶ 105).

As to claim limitation 1(ii), "a semiconductor region in a substrate," Petitioner cites Goodnick's silicon substrate doped with phosphorous (an n-type dopant) is an example of a semiconductor. *Id.* (citing Ex. 1116, 1; Ex. 1119, Schubert Decl. ¶ 106). Patent Owner does not present any counterarguments to Petitioner's contentions concerning claim limitations 1(i) and 1(ii).

b) *Claim limitations 1(iii), 1(iv), and 1(v)*

Petitioner identifies claim limitation 1(iii) as reciting "a metal electrical contact to said semiconductor region." *Id.* Petitioner cites

Goodnick's disclosure of an aluminum metal electrical contact formed by evaporating aluminum onto a 30 Å layer of SiO_2 on a cleaned silicon substrate as disclosing this limitation. *Id.* (citing Ex. 1112, 1; Ex. 1119, Schubert Decl. ¶ 107). As to claim limitation 1(iv), "a metal oxide layer," Petitioner cites Goodnick's disclosure of an Al_2O_3 layer. *Id.* (citing Ex. 1116, 5; Ex. 1119, Schubert Decl. ¶ 108). Noting that Goodnick discloses an apparent self-limiting reaction that results in both SiO_2 and Al_2O_3 existing simultaneously at the interface, Petitioner proposes the schematic depiction of the metallization process and the resulting Al-Al_2O_3-SiO_2-Si contact shown below.

Petitioner's Depiction of Goodnick's Metallization Process

Id. at 18 (citing Ex. 1116, 1–2, 5; Ex. 1119 Schubert Decl. ¶¶ 79–85). As illustrated above, Petitioner contends that, after metallization, the contact has a distinct metal contact layer of Al and a metal oxide layer, Al_2O_3. Petitioner's depiction is illustrative and is not reproduced from Goodnick.

Petitioner identifies claim limitation 1(v), as reciting "a passivating dielectric tunnel barrier layer between said semiconductor region and said metal electrical contact." *Id.* at 23. Petitioner identifies the SiO_2 (silicon dioxide) layer as the claimed passivating dielectric tunnel barrier. *Id.* Petitioner notes Goodnick discloses that when thermally evaporating the aluminum metal contact onto the SiO_2 layer grown on the silicon substrate, the aluminum partially reduces SiO_2 to produce Al_2O_3 and some of the SiO_2 layer grown on the silicon surface remained. *Id.* (citing Ex. 1116, 5; Ex. 1119, Schubert Decl. ¶109). According to Petitioner, Goodnick discloses that a layer of SiO_2 grown on the substrate lies between the silicon substrate and the aluminum and is a passivating layer from an electrical and chemical standpoint. *Id.* (citing Ex. 1116, 1; Ex. 1119, Schubert Decl. ¶ 110). Petitioner further asserts that the remaining thin SiO_2 layer grown on the surface of the substrate is a dielectric tunnel barrier. *Id.* at 23–24 (citing Ex. 1105, 7:60–61; Ex. 1101, 1:8–21; Ex. 1116, 1; Ex. 1119, Schubert Decl. ¶ 111).

Patent Owner states that "[a]ll challenges in the petition utilize Goodnick as the primary reference and are based on Goodnick disclosing distinct stratified layers of different material, including a layer of AL_2O_3, as shown in various petitioner-created diagrams in the petition." PO Resp. 52. (citing Pet. 18 and reproducing a portion of Petitioner's metallization diagram shown above).[6] *Id.* Patent Owner argues that, notwithstanding Petitioner's diagrams that purport to illustrate Goodnick teaching clean stratification of distinct layers, Goodnick includes no such diagrams, only uses the term "layer" twice, and does not support the Petition's assertions. *Id.* (citing Ex. 2043, Declaration of Dr. Stephen Goodnick ("Goodnick Decl."); Ex. 2080, Second Declaration of Dr. Stephen M. Goodnick ("2nd Goodnick Decl.")).

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[6] Patent Owner also references its Preliminary Response, which notes that in district court litigation the parties agreed that claim limitation 1(iii) and 1(iv) "require two distinct layers: (1) a passivating dielectric tunnel barrier layer (comprising semiconductor oxide) and (2) a metal oxide layer." *Id.*, Prelim. Resp. 38–39.

Dr. Goodnick, who authored the Goodnick reference, states that Petitioner and Dr. Schubert have "misinterpreted key aspects of my paper." Ex. 2043, Goodnick Decl. ¶ 5. Noting the conventional understanding at the time of his paper was that imperfections in the surface layer, i.e. "dangling bonds," caused the Fermi level to be pinned, Dr. Goodnick states that his reference to the Fermi level becoming unpinned "refer[s] only to the fact that dangling bonds in the silicon are passivated by the oxide layer." *Id.* ¶ 43. Dr. Goodnick also states that, at the time of his paper, the phenomenon of MIGS was poorly understood and "the interaction of pinning due to MIGS and pinning due to dangling surface bonds had not been explored." *Id.* ¶ 44. According to Dr. Goodnick, the inventors "realized that those two pinning mechanisms can be jointly addressed leading to better results . . . they were able to discover that there is an optimum thickness at which the beneficial reduction of pinning by MIGS suppression is negated by the adverse increase in tunneling resistance as the interfacial layer is made thicker." *Id.* ¶ 45 (referring to Figure8 of the '691 patent).

The specific issue before us is what one of ordinary skill in the art would have understood from the Goodnick reference. Dr. Schubert contends that a person of ordinary skill would have understood Goodnick to disclose the claimed layered structure. *See* Ex. 1119, Schubert Decl. ¶¶ 79–85 (at ¶ 80 quoting Goodnick's description of Figure 8(b) that "[i]n contrast to the air exposed sample, an Al_2O_3 layer exists at the Al-SiO_2-Si interface"). Dr. Goodnick states that a person of ordinary skill at the time would not have understood his paper to mean there is a layer of Al_2O_3 on top of a layer of SiO2, but only that Al_2O_3 and SiO_2 were found together in the interface region between the aluminum and the semiconductor. *See* Ex. 2043 ¶¶ 32–40; Ex. 2080, 2nd Goodnick Decl. ¶¶ 8–9.

Figure 8(a) of Goodnick shows "[p]eak to peak Auger sputter profile on room temperature oxidized Si, unheated" and Figure 8(b) of Goodnick shows "[p]eak to peak Auger profile of Al on 30 Å of SiO_2, unheated." Ex. 1116, 5. Responding to Petitioner's assertions concerning the case where 30Å of SiO_2 was first placed on the silicon before depositing the aluminum, Dr. Goodnick refers to Figure 8(b) of his paper, on which the X-axis is sputter time. Ex. 2043, Goodnick Decl. ¶¶ 32–34; Ex. 2080, 2nd Goodnick Decl. ¶ 8. Dr. Goodnick states that, in the period between 0 and 5 minutes, the high levels of Al_2O_3 represent its presence on the top surface of the aluminum, the high level of aluminum between 10 minutes and 30 minutes corresponds to the aluminum deposition, the high level of silicon after 50 minutes corresponds to the silicon substrate, and the high levels of aluminum and silicon between 30 and 50 minutes is the aluminum-silicon interface. Ex. 2043, Goodnick Decl. ¶ 33. According to Dr. Goodnick, Figure 8(b) shows that Al_2O_3 and SiO_2 were present at the aluminum silicon interface, but "it cannot be determined where Al_2O_3 is present with respect to SiO_2." *Id.* at 34. Dr. Goodnick asserts that the presence of a peak in the Al_2O_3 curve at about 40 minutes and the "O" curve (representing SiO_2) between 35 and 40 minutes and the fact that both curves have the same general shape "means that both compounds were found in the same relative quantities in the interface region." *Id.* According to Dr. Goodnick, "[a] POSITA understanding this data would not conclude that there is a layer of Al_2O_3 on top of a layer of SiO_2 as Samsung claims . . . only that both Al_2O_3 and SiO_2 were found together in the interface region between the aluminum and the silicon." *Id.*

Nevertheless, comparing Figures 8a and 8b, the Goodnick reference expressly states:

> Figure 8(a) shows the peak-to-peak profile of an unheated sample with an air grown oxide. It appears that Si has diffused into the Al and collected at the Al_2O_3-Al interface at the surface. No buildup of Al_2O_3 is seen at the Al-Si interface. Figure 8(b) is a profile of an unheated sample with 30Å SiO_2 at the interface. **In contrast to the air exposed sample, an Al_2O_3 layer exists at the Al-SiO_2-Si interface**. This is suggestive of the reduction reaction seen previously, with the presence of SiO_2 necessary for formation of Al_2O_3. Heat treatment of samples resulted in little change in the profiles with the exception of greater concentration of Si at the surface of the unoxidized samples.

Ex. 1116, 5 (emphasis added).

The Goodnick reference further states that, even at elevated temperatures, the reaction is self-limiting "probably [as] a result of the diffusion barrier formed by the Al2O3 layer to the transport of Al to the SiO_2 layer." Ex. 1116, 5 (emphasis added). Dr. Goodnick now states that "[t]his statement was a speculation based on the fact that both SiO_2 and Al_2O_3 were still present at the interface, whereas thermodynamically it was expected that Al would completely reduce SiO_2 to Al_2O_3 and free Si." Ex. 2043 ¶ 39.

Patent Owner emphasizes that Goodnick's two references to an Al_2O_3 layer do not state that the Al_2O_3 layer is distinct from SiO_2 and were not meant to suggest the type of stratified distinct layers in the IPR petitions. PO Resp. 53 (citing Ex. 2080, 2nd Goodnick Decl. ¶¶ 8–9).

Patent Owner contends that the Auger profile data in Figure 8(b) does not support Petitioner's stratified layer arguments. Patent Owner states that, in addition to the Al_2O_3 hump corresponding to 35–55 minutes sputter time indicating an Al_2O_3 layer, the data also shows oxygen of unknown origin rising earlier and peaking to the left of the Al_2O_3 line, as well as aluminum and silicon in the same vicinity. Thus, Patent Owner argues that "according to the Auger profile data, the 'Al_2O_3 layer' is not a stratified distinct layer of Al_2O_3 as the petition asserts." PO Resp. 54 (citing Ex. 1116, 953).

Patent Owner does not explain sufficiently why the data it cites on the Auger profile does not support Petitioner's contentions. The Goodnick reference uses the term "layer" over 40 times and in no case does Goodnick ascribe a meaning to "layer" that is different from one layer being distinct from another.

Patent Owner next argues that XPS measurements reported in Goodnick indicate that both SiO_2 and Al_2O_3 exist simultaneously at the interface, but reveal nothing about the spatial distribution of the Al_2O_3 and SiO_2. PO Resp. 54–55 (citing Ex. 2080, 2nd Goodnick Decl. ¶ 10). Patent Owner also argues that the Goodnick reference speculated an Al_2O_3 diffusion barrier is the probable reason the $4\ Al + 3\ SiO_2 \rightarrow 2Al_2O_3 + 3Si$ reaction is self-limiting, but that speculation is an untested hypothesis insufficient to support Petitioner's contentions. *Id.* at 55 (citing Ex. 2080, 2nd Goodnick Decl ¶¶ 11–13).

Goodnick is entitled "Effects of a thin SiO_2 layer on the formation of metal-silicon contacts" and states "[t]"he reactions that occur between different metals and silicon wafers with a thin oxide layer have been investigated." Ex. 1116. Abstract. Goodnick further states "a thin interfacial layer may act as a barrier to the chemical reaction and interdiffusion that characterizes the intimate metal silicon contact. Thus, the presence of a thin oxide at the interface act as a passivating influence both from an electronic and a chemical standpoint." Ex. 1116, 949.

Taken in context, we agree that a person of ordinary skill would have understood Goodnick to refer to Al_2O_3 as a distinct layer. Referring to Fig. 8(a), Goodnick states that in an unheated sample with an air grown oxide "[i]t appears that Si has diffused into the Al and collected at the Al_2O_3-Al interface at the surface. No buildup of Al_2O_3 is seen at the Al-Si interface." Ex. 1116, 953. Noting that Fig. 8(b) is a profile of an unheated sample with 30Å of SiO_2 at the interface, Goodnick states "[i]n contrast to the air exposed sample, an Al_2O_3 layer exists at the Al-SiO_2-Si interface." *Id.*

Petitioner notes that, on cross examination, Dr. Goodnick acknowledged (i) that the Al metal layer would diffuse into the SiO_2 interface layer and reduce the portion of the SiO_2 layer nearest the Al layer to Al_2O_3, (ii) that once the Al_2O_3 layer forms, it would be difficult for aluminum atoms to diffuse through the Al_2O_3 layer to continue reaction with the SiO_2 layer, and (iii) because the reaction is self-limiting, a portion of the original SiO_2 layer would remain once the reaction forming the Al_2O_3 layer stopped. Pet. Reply 5–6 (citing Ex. 1168, Goodnick Tr. 55:5–25, 57:19–58:8, 59:24–60:7). In view of, *inter alia*, Dr. Goodnick's cross examination testimony, we are persuaded by Dr. Schubert's testimony that a person of ordinary skill would have understood that distinct layers of Al_2O_3 and SiO_2 are formed. Ex. 1173 ¶¶ 85–98.

As to Patent Owner's arguments concerning speculation (PO Sur-reply), we note that our inquiry is what Goodnick would have disclosed to a person of ordinary skill. Goodnick's comments, even if they are now deemed by Dr. Goodnick to be speculative, are consistent with the physical evidence and even Dr. Goodnick considers the process is to this day the best and only understanding of the structure formed. *See* Pet. Reply 7 (citing Ex.

1168, Goodnick Tr. 129:19–130:7; Ex. 1173, Schubert Decl. 2 ¶ 99). Moreover, no one has argued that it was beyond the skill of a person of ordinary skill in the art to create the described layer of Al_2O_3.

c) Claim limitations 1(vi) and 1 (vii)

Petitioner identifies claim limitation 1(vi) as reciting "said semiconductor region being electrically connected to said metal electrical contact through said passivating dielectric tunnel barrier layer and said metal oxide layer." Pet. 24. Petitioner cites Goodnick as investigating "the influence of thin SiO2 layers on the chemical formation of metal-silicon contacts." *Id.* (citing Ex. 1116, 1). Petitioner also cites Goodnick as describing its interfacial oxide layers as thin and stating "an oxide layer that is sufficiently thin may sustain considerable current via tunneling." *Id.* at 24–25 (citing Ex. 1116, 1; Ex. 1119, Schubert Decl. ¶ 112).

Petitioner identifies claim limitation 1(vii), as reciting "wherein said passivating dielectric tunnel barrier layer comprises a semiconductor oxide." *Id.* at 25. Referencing its earlier discussion of Goodnick, Petitioner cites that reference as describing a SiO_2 passivating dielectric tunnel barrier layer. *Id.* at 25 (citing Ex. 1116, 1–2, 5).

Other than asserting that Goodnick fails to disclose distinct layers, as discussed in detail above, Patent Owner does not respond to Petitioner's contentions concerning claim limitations 1(vi) and 1(vii).

In consideration of the above, we find that Petitioner has demonstrated by a preponderance of the evidence that Goodnick discloses all of the limitations of claim 1.

3. Claims 2–3 and 13

Claim 2 depends from claim 1 and recites the additional limitation that "the semiconductor oxide comprises an oxide of the semiconductor region." Petitioner cites Goodnick as disclosing thermally growing a layer of SiO_2 on a silicon substrate, that some of the SiO_2 layer is reduced by aluminum to produce Al_2O_3, and that a layer of SiO_2 remaining on the silicon substrate is an oxide of the silicon substrate. Pet. 25.

Claim 3 depends from claim 1 and recites the additional limitation that "the semiconductor oxide of the dielectric tunnel barrier has a thickness of approximately 0.1 nm to 5 nm." Petitioner cites Goodnick as disclosing thermally growing a 30Å (3 nm) thick layer of SiO_2 on a silicon substrate that is reduced partially by aluminum to produce Al_2O_3 with a remaining layer of SiO_2, whose minimum thickness, i.e. the thickness of a monolayer (a layer one molecule thick), is 2 Å (0.2 nm). Pet. 26 (citing Ex. 1116, 1–2; Ex. 1119, Schubert Decl. ¶ 119).

Claim 13 depends from claim 3 and recites the additional limitation that "the semiconductor oxide comprises an oxide of silicon." Noting that SiO_2 is an oxide of silicon, Petitioner cites Goodnick as disclosing this feature. Pet. 27 (citing Ex. 1116, 5).

Patent Owner does not present any counterarguments concerning the additional limitations recited in claims 2–3 and 13. In consideration of the above, we find that Petitioner has demonstrated by a preponderance of the evidence that Goodnick discloses all of the limitations of claims 2–3 and 13.

C. Claim 4 as obvious over Goodnick in view of Jammy (Petitioner's Ground 2)

1. Jammy (Ex. 1115)

Jammy discloses "improved contact between conductive studs and shallow diffusion regions by incorporation of a quantum conductive barrier layer at the interface between the conductive stud and shallow diffusion region." Ex. 1115, 3:18–21. An annotated version of Figure 1 of Jammy is shown below.

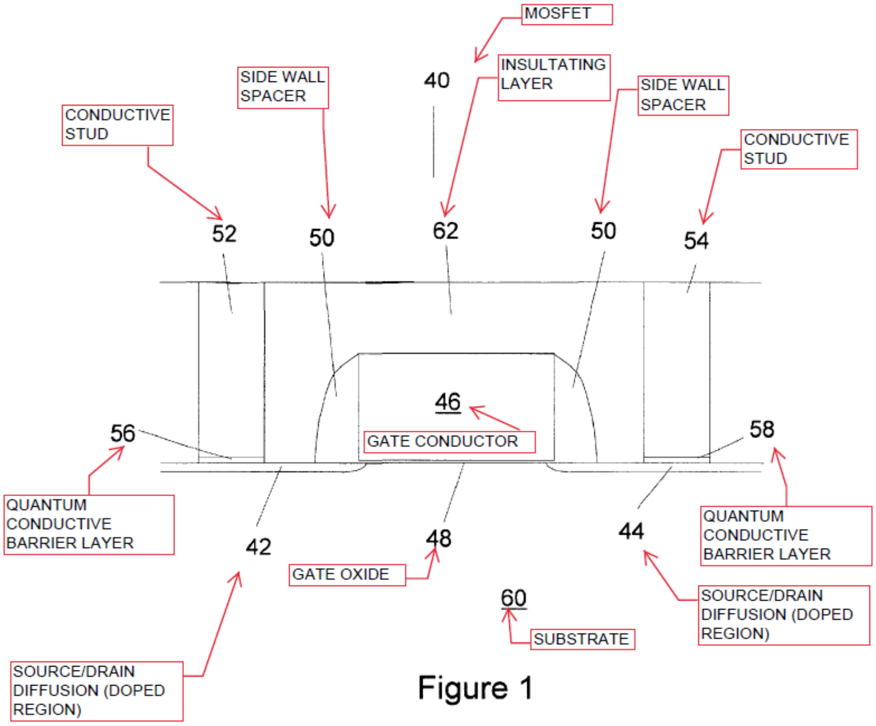


Figure 1

Ex. 1115, Fig. 1. Annotated Figure 1 shows MOSFET 40 in which shallow source/drain diffusions, i.e., doped regions 42, 44, formed in substrate 60 contact conductive studs 52, 54 through quantum conductive barriers 56, 58. *Id.* at 4:9–18. Jammy's quantum conductive layers are thin films of less than 50Å (more preferably about 5–30 Å, most preferably about 5–15 Å) of materials that in their bulk properties would be considered dielectrics, but in thin layers become electrically conductive, such that resulting layers preferably have a film resistance of less than about 1 K-ohm-µm^2, more preferably less than about 100 ohm-µm^2. *Id.* at 3:23–40. Jammy's thin layers also prevent or slow diffusion of chemical species from one side of the layer to the other.

1. Claim 4

Claim 4 depends from claim 3 and recites the additional limitation that "the semiconductor region comprises an n-typed doped source or drain of a transistor." Acknowledging that Goodnick "does not expressly disclose that its n-doped silicon semiconductor region 'comprises an n-type source or drain of a transistor,'" Petitioner cites Jammy as disclosing this feature. Pet. 27. According to Petitioner, a person of ordinary skill would have combined the teachings of Goodnick and Jammy because Goodnick describes contact metallization processes for semiconductor devices and Jammy describes a semiconductor device. *Id.* at 28.

Patent Owner asserts that Petitioner's challenge to claim 4 based on the combined teachings of Goodnick and Jammy fails because it is premised on Goodnick teaching a stratified layer of Al_2O_3 distinct from SiO_2. PO Resp. 60. As discussed above, we find that a person of ordinary skill would have understood Goodnick to disclose this feature. *See* Section VI.B. In consideration of the above, we find that Petitioner has demonstrated by a preponderance of the evidence that a person of ordinary skill would have had reason to combine the teachings of Goodnick and Jammy and that the combined teachings of Goodnick and Jammy would have suggested the limitations of claim 4 to a person of ordinary skill in the art.

As Patent Owner's contentions concerning objective considerations of non-obviousness apply to all the claims challenged on that basis, we address objective considerations further in Section VI.G.

D. Claims 1, 3, 6, 10–13, 15, 16, 19, 20, 22 as obvious over Goodnick and Taubenblatt (Petitioner's Ground 3)

1. Taubenblatt

Noting the importance of silicides as Schottky barriers, ohmic contacts, and low resistivity interconnects in integrated circuits, Taubenblatt states that "[m]any silicides are commonly formed by the deposition of a metal layer on silicon via e-beam evaporation, chemical vapor deposition, or sputtering, and the reaction of the metal layer with the underlying silicon at 400-600 °C." Ex. 1115, 1. Taubenblatt concerns experiments "to characterize silicide formation for the Ti-Si system under ultrahigh vacuum (UHV) conditions with the controlled addition of surface oxides." *Id.* Taubenblatt's "results show that the presence of SiO_2 at the Si surface, prior to Ti deposition, has a significant effect on the reaction of Ti and Si and that the thickness of the SiO_2 layer is especially important in determining the reaction end products." Ex. 1117, 8. According to Taubenblatt:

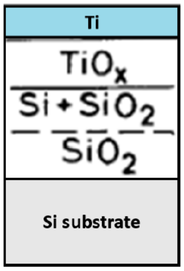
> in the manufacture of circuit elements employing titanium disilicide, Ti will react through a thin silicon dioxide layer with the SiO2 remaining at the surface. But in the reaction of Ti with a thicker SiO2 layer, Ti oxide forms, which can act as a diffusion barrier to prevent further reduction of the oxide by unreacted Ti metal or in the formation of silicide.

Id.

2. Motivation to combine the teachings of Goodnick and Taubenblatt

Petitioner argues that Goodnick discloses an interface layer that includes a metal oxide layer (aluminum oxide (Al_2O_3)), but acknowledges that Goodnick does not expressly describe a metal oxide layer that comprises an oxide of titanium, as recited explicitly in claims 6, 10–12, and 15–16. Pet. 29. Petitioner states that, because Taubenblatt teaches that

(i) depositing titanium on a layer of SiO_2 thicker than 20 Å (2nm) and (ii) annealing at temperatures between 700ºC–900ºC forms a TiO_x–SiO_2 interface layer, a person of ordinary skill would have understood that by depositing titanium on Goodnick's 30 Å (3 nm) thick layer of thermally grown SiO_2, "all it would have taken to form a TiO_x–SiO_2 interface layer is annealing at 700ºC–900ºC, as described in Taubenblatt 1982." *Id.* at 31 (citing Ex. 1117, 7–8; Ex. 1119, Schubert Decl. ¶ 137). Petitioner contends that the combined teachings of Goodnick and Taubenblatt would have resulted in the structure shown below.



Pet. 31–32 (citing Ex. 1115, 1–2; Ex. 11117, 7–8; Ex. 1119, Schubert Decl. ¶ 138). The structure Petitioner postulates a person of ordinary skill would have known includes a SiO_2 layer on top of a silicon substrate, a $Si+SiO_2$ layer over the SiO_2 layer, a TiO_x layer on top of the $Si+SiO_2$ layer and a Ti layer over the TiO_x layer. *Id.* at 32; *see also* Ex. 1117, Fig. 11, 8 (discussing Fig. 11, row 3, concerning the behavior of thin layers of SiO_2).

According to Petitioner, an ordinarily skilled artisan would have had reason to provide Goodnick with an interface layer that includes both titanium oxide and silicon dioxide "because that interface layer would have been expected to reduce the specific contact resistivity of that junction." *Id.* at 32 (citing, e.g., Ex. 1119, Schubert Decl. ¶ 39). Petitioner argues it was known that a SiO_2 interface layer grown on silicon would passivate the surface of the silicon and "[t]hat passivation would have reduced the barrier height of a titanium to n-type silicon junction, such as the junction between Taubenblatt's titanium and Goodnick's n-type source drain/drain silicon substrate." *Id.* at 33 (citing Ex. 1115, 31; Ex. 1116, 1–2; Ex. 1119, Schubert Decl. ¶ 141). Petitioner further states that, for a junction between titanium and n-type silicon with a SiO_2 interface layer, the SiO_2 interface layer reduces the barrier height more than 0.1 eV" and that "reducing the barrier height of a junction reduces its specific contact resistivity." *Id.* (citing Ex. 1119, Schubert Decl. ¶ 141; Ex. 1118 (Chang)[7], 5–6).

In summarizing what would have been known to one of ordinary skill at the relevant time, Petitioner's expert, Dr. Schubert, cites another Taubenblatt reference, i.e., Taubenblatt 1984[8]. Petitioner notes that Taubenblatt 1984 references teachings in Turner and Rhoderick[9] as disclosing that an interfacial oxide reduces the pinning ability of the interface states in silicon, so that the barrier behaves more like an ideal Schottky barrier. Ex. 1119, Schubert Decl. ¶ 54 (citing Ex. 1123, 3). Dr. Schubert also states "it was well known before 2002 that interposing an interface layer between a metal and a semiconductor at a metal-semiconductor junction could reduce specific contact resistance." *Id.* ¶ 55; *see also id.* ¶ 56 (citing Schroen[10], issued in 1976 (Ex. 1124, Abstract) as disclosing the specific contact resistance obtained by using a thin insulating

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[7] Chang is not a reference cited in this ground. Chang is cited in another ground.

[8] M.A. Taubenblatt et al., *Interface effects in titanium and hafnium Schottky barriers on silicon*, 44 APPLIED PHYS. LETTERS 895 (Ex. 1123, "Taubenblatt 1984").

[9] Ex. 1123, fn 18 (citing M. J. Turner and E. H. Rhoderick, Solid State Electron. II, 291, (1968)); *see also* Ex. 1117, fn 1.

[10] U.S. Patent No. 3,983,264 (Ex. 1124, "Schroen").

interfacial layer between a metal and a semiconductor is far smaller than the resistance observed in a structure of only a semiconductor and a metallization layer), *id.* ¶ 59 (quoting Iwaguro[11] (Ex. 1127) ¶ 6, which states "[b]y bringing a metal film into contact with this sub-silicon oxide film, an ohmic junction exhibiting favorable low contact resistance can be obtained.").

As to the use of titanium, Dr. Schubert cites a 1989 patent by Kim[12] (Ex. 1125) as describing an interface layer formed by titanium reducing silicon dioxide to achieve a specific contact resistance as low as 8Ω-μm^2. Ex. 1119, Schubert Decl. ¶¶ 57–58 (citing Ex. 1125, 5:27–30). In its discussion of Ground 5, Petitioner also cites Kim as evidence that ordinarily skilled artisans had achieved contact resistivity below 10 Ω-μm^2 using an interface layer, stating Kim "describes obtaining a specific contact resistance (resistivity) as low as 8 Ω-μm^2 for a junction between a Ti-W (titanium-tungsten) alloy and n-type silicon with an interfacial oxide layers that includes titanium dioxide therebetween. Pet. 54–55 (citing Ex. 1125, 4:63–5:1, 5:27–30).

In the Decision to Institute, we noted that Kim discloses the use of an alloy of tungsten and titanium, and specifically identifies disadvantages to the use of aluminum and titanium alone. Dec to Inst. 44–45 (citing Ex. 1025, 1:12–30. We found that Petitioner had not demonstrated a person of ordinary skill would have had reason to combine the teachings in Goodnick and Taubenblatt concerning experiments about the behavior of aluminum and titanium on silicon, as proposed by Dr. Schubert. *See* Dec. to

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[11] Certified Translation of Japanese Laid-Open App. No. JPH11162874A (June 18, 1999) (Ex. 1127, "Iwaguro").
[12] U.S. Patent No. 4,845,050 (Ex. 1125, "Kim").

Inst. 44–45. We agreed with Patent Owner that Dr. Schubert's assertions that a person of ordinary skill would replace Goodnick's aluminum with Taubenblatt's titanium is inconsistent with Kim's disclosures concerning the use of a tungsten-titanium alloy consisting mostly of tungsten by weight. *Id.* at 45; *see also* PO Resp. 14–16. Although that issue remains before us, as discussed below, based on the evidence developed at trial, we further consider the presence of a titanium oxide and its effect on resistance.

Noting that Goodnick does not mention resistivity and Taubenblatt mentions resistivity only once, the Patent Owner Response contends that a person of ordinary skill would not have been motivated to combine the teachings of Goodnick and Taubenblatt in the manner proposed by Petitioner. PO Resp. 8–9 (citing Dec. to Inst. 42). Patent Owner emphasizes that Goodnick "presents experimental results of research into the effects of a layer of silicon dioxide between silicon and three metals (gold, platinum, and aluminum), none of which is titanium," that Taubenblatt "reports the results of several experiments depositing titanium on silicon under various conditions," and that neither reference is concerned with building a low resistance junction. *Id.* at 9. Patent Owner further argues that "[n]othing in Goodnick suggests any reason to study titanium" and "[n]othing in Taubenblatt suggests studying aluminum." *Id.*

According to Patent Owner, Petitioner's reference to the teachings in other documents, such as Kim, is unavailing because the Petition fails to establish a link between the subject matter cited by Dr. Schubert and his assertion that a person of ordinary skill would have substituted Taubenblatt's titanium for Goodnick's aluminum. *Id.* at 10.

Patent Owner further argues that the bulk resistivity of titanium is about 16 times that of aluminum, suggesting that a person of ordinary skill would not have looked to replace aluminum with titanium. *Id.* at 11. Patent Owner notes Dr. Schubert's testimony that the resistivity of the metal in the metal-insulator-semiconductor stack is insignificant when compared to the much larger resistivity of insulators (PO Resp. 12 (citing Ex. 2076, Transcript of Deposition of Dr. Schubert ("Schubert Tr."), 65:21–67:9)). Patent Owner also cites its own expert, Dr. Kuhn, who testified that bulk resistivity of an insulator is irrelevant when it is used as a tunneling interface layer, i.e., because tunneling is a property of the barrier height at the junction and the physical thickness, not the material's bulk resistivity. *Id.* (citing Ex. 2070, Declaration of Dr. Kelin Kuhn ("Kuhn Decl.") ¶ 117). According to Dr. Kuhn,

> [I]t is not correct to say that a POSITA would ignore the bulk resistivity of the metal in a metal - insulator semiconductor stack of the type of interest here. That is especially true if the choice is between aluminum and titanium because, as I mentioned, aluminum is a significantly better electrical conductor than titanium (by a factor of about 16X).

Ex. 2070, Kuhn Decl. ¶ 120. In addition, "considerable research in the semiconductor industry has been (and currently is) conducted to try to find conductors that have marginally lower resistivity." *Id.* ¶ 119.

Petitioner's Reply counters that Patent Owner fails to consider the resistivity of the entire structure, not just the metal layer. *See* Pet. Reply 9. Petitioner notes that "[t]he proposed combination substitutes the Al-Al_2O_3 (in Goodnick) for Ti-TiO_x (in the proposed combination) (with the SiO_2 and Si layers the same in both structures)." *Id.* Petitioner acknowledges that the semiconductor's bulk resistivity far outweighs the bulk resistivity of the metal layer, regardless of whether aluminum or titanium is used in the metal layer, and notes that, because the bulk resistivity of the semiconductor is largely fixed based on the doping concentration, the contributions from the SiO_2-Si would be similar in both structures. *Id.* According to Petitioner "that is precisely why a POSITA would have sought other means for reducing the junction's ***overall*** resistivity, such as by reducing the resistivity of the interface layer by substituting TiO_2 for Goodnick's higher-resistivity Al_2O_3 layer." Pet. Reply 10 (citing Ex. 1173, Schubert Decl. 2 ¶¶ 107-108). According to Petitioner "an ordinarily skilled artisan would have sought to provide an interface layer that reduces specific contact resistivity to reduce the power consumption of a device incorporating a contact with that interface layer." Pet. 35 (citing Takeshiu, 4:57–58; Ex. Schubert Decl. ¶ 149).

Responding to Dr. Kuhn's assertion that the bulk resistance of the material is irrelevant because the interface layer is used as a tunneling interface layer, Dr. Schubert states that Dr. Kuhn fails to consider tunneling barrier differences. *See* Pet. Reply 10 (citing PO Resp. 12; Ex. 2070, Kuhn Decl. ¶ 117). Dr. Schubert asserts that by substituting TiO_x for Al_2O_3 the tunneling probability in the proposed combination is nearly 30 times higher than the tunneling probability between Al and Al_2O_3, thereby reducing the structure's resistivity more than the 16 fold increase in resistivity attributable to the Ti in the Al metal layer. Ex. 1173, Schubert Decl. 2 ¶¶ 108, 114–121. According to Petitioner, TiO_x is substantially more conductive than Al_2O_3 because current can flow through TiO_x via electron tunneling and via conduction bands, but in the case of Al_2O_3, the tunneling barrier is higher, and current does not flow through Al_2O_3's conduction bands. Pet. Reply 11–12 (citing Ex. 1173, Schubert Decl. 2 ¶¶ 109–111).

Patent Owner contends that Dr. Schubert's tunneling analysis cited in the Petitioner Reply is a new theory not discussed in the Petition. PO Sur-reply 11, 14–15. We consider the arguments in the Petitioner Reply to the extent Petitioner and Dr. Schubert offer an analytical reply to arguments in the Patent Owner Response, i.e., Dr. Kuhn's testimony that bulk resistivity of the metal is irrelevant because tunneling is a property of barrier height. PO Resp. 12 (citing Ex. 2070, Kuhn Decl. ¶ 117).

As discussed above, Petitioner cites Goodnick as recognizing a thick interfacial oxide at a metal-silicon interface suppresses current, thereby reducing rectifying characteristics, but a thin oxide layer sustains considerable current via tunneling and reduces the density of interface states by satisfying dangling bonds. *See* Section VI.B. The Petition also states that "reducing the barrier height of a junction reduces its specific contact resistivity" and that "for a junction between titanium and n-type silicon with an SiO_2 interface layer, the SiO_2 interface layer produces a net reduction of barrier height of more than 0.1 eV owing to the passivation that the SiO_2 interface layer provides." Pet. 33 (citing Ex. 1118, 5–6; Ex. 1119, Schubert Decl. ¶ 141; Ex. 1123, 3).

The issue presented in this challenge is whether a person of ordinary skill would have had reason to replace Goodnick's aluminum with titanium. Patent Owner disputes Dr. Schubert's tunneling analysis concerning the use of titanium. PO Sur-reply 10–11. Patent Owner argues that Dr. Schubert's 30 times improvement factor is wrong because Dr. Schubert uses a calculated electron affinity of 3.28 eV for Al_2O_3, rather than a measured value of 3.71 eV to determine the improvement. *Id.* at 10–11. According to Patent Owner, using the formulas in paragraph 116–121 of Dr. Schubert's 2nd Declaration and applying an electron affinity of 3.71eV, "[t]his tunneling probability for Al_2O_3 based on the measured electron affinity is only a factor of 1.66 greater than that of TiO_2." *Id.* at 11. Patent Owner further argues that Dr. Schubert's analysis is based on documents and data dated after the 2002 effective filing date of the application of the subject patent, that Petitioner's reply fails to show "tunneling probability" translates to resistance, that Petitioner's reply fails to establish a baseline from which the significance of a factor of 30 increase in tunneling probability can be determined, and that Petitioner's tunneling argument in its reply is an improper new theory. *Id.*

In this context the arguments in the Petitioner Reply are responsive to issues raised by Dr. Kuhn. The Petition cites Kim's disclosure that an alloy of 10% titanium and the remainder of tungsten by weight forms a stable low resistance ohmic contact to silicon conduction members and a strong bond to a thick layer of silicon. Pet. 33.

Petitioner cites Kim (Ex. 1125) as evidence that a person of ordinary skill would have had reason to substitute Goodnick's aluminum with Taubenblatt's titanium and Dr. Schubert cites Kim as describing an interface layer formed by titanium reducing silicon dioxide to achieve a specific contact resistance as low as 8 Ω-μm^2. Ex. 1119, Schubert Decl. ¶¶ 57–58 (citing Ex. 1125, 5:27–30). According to Kim

> It is believed that during the sintering step titanium in the conductor 27 at the interface between the conductor 27 and the silicon conductive members 15, 17 and 16 reacts with native silicon dioxide present on the exposed portions of these conductors to form silicon and titanium dioxide, a semi-conductor, thereby reducing the interface resistance.

Ex. 1025, 4:63–5:1. Kim further states that "Alloys in the range of about 10% to 40% by weight of titanium and the remainder tungsten are particularly suitable for providing low resistance contacts to silicon." *Id.* at 5:2–4. Although Kim concerns alloys of tungsten and titanium, it is the formation of the titanium dioxide documented in Kim that we understand to be the basis of Dr. Schubert's assertions concerning reduced ohmic resistance. The Petition points out that a person of ordinary skill would have recognized the existence of a relationship between barrier height and resistance for the device as a whole, stating

> [w]hile titanium oxides modestly passivate silicon surfaces—and therefore modestly reduce the junction's barrier height—they present less resistance to current than SiO_2 does. Thus, converting some of the interface layer's SiO_2 to a titanium oxide would have decreased specific contact resistivity further. But an ordinarily skilled artisan would have found it beneficial to leave *some* SiO_2 remaining in the interface layer to obtain the barrier-height reducing benefits of a passivating layer of SiO_2.

Pet. 33 (citing Ex. 1125, 4:63–5:1; Ex. 1119, Schubert Decl. ¶¶ 142–143; Ex. 1123, 3; Ex. 1130, 2–3). According to Petitioner, a TiO_x-SiO_2 interface layer combines the barrier-height-lowering of a passivating layer of SiO_2 with the lower resistance of a layer of titanium oxide." Pet. 35 (citing Ex. 1117, 7-8; Ex. 1125, 4:63-5:1; Ex. 1119, Schubert Decl. ¶ 145). As discussed above, even Patent Owner's electron affinity analysis recognizes at least some improvement in tunneling probability when using titanium instead of aluminum. PO Sur-reply 14. Goodnick demonstrates the effect of tunneling on specific resistance. *See* Section VI.B. Petitioner concludes that "an ordinarily skilled artisan would have expected that TiOx – SiO2 interface layer to present less electrical resistance than that presented by Goodnick's Al_2O_3 – SiO_2 interface layer. *Id* (citing Ex. 1119, Schubert Decl. ¶¶ 147–148.)

Petitioner does not cite Kim as part of this challenge, but as background art that reflects the knowledge of a person of ordinary skill. We addressed the disclosures of Kim in IPR2020-01264. There we determined that Petitioner had not shown that Kim teaches a metal oxide layer or a layer of titanium dioxide. *See Samsung v. Acorn*, IPR2020-01264, Paper 18–20 at 17–19 PTAB (Jan. 13, 2021) (Decision Denying Institution). There we noted that "[t]he reference [Kim] simply says 'to form silicon and titanium dioxide, a semiconductor, thereby reducing the interface resistance,' with nothing to indicate that formation takes place as a layer."). *Id*. at 18. Consistent with this finding, we are not persuaded that Kim would have suggested to a person of ordinary skill replacing Goodnick's aluminum with Taubenblatt's titanium in a layered structure. Notwithstanding the bulk resistivity and tunneling effect evidence discussed above, there is insufficient evidence to conclude that a person or ordinary skill would have combined the teachings of Goodnick and Taubenblatt as proposed by Petitioner.

In consideration of the above, we find that Petitioner has not demonstrated by a preponderance of the evidence that a person of ordinary skull would have combined the teachings of Goodnick and Taubenblattt as proposed by Petitioner.

3. Claims 1, 3, 6, 10–12, 13, 15, 16, 19, 20, and 22

Citing its discussion of Goodnick, Petitioner contends that, if one of ordinary skill had reason to combine their teachings, Goodnick and Taubenblatt teach a Ti-TiO_x-SiO_2-Si contact, as recited in claim 1 (Pet. 36–41) with a tunnel barrier thickness of 0.1 nm to 5nm, as recited in claim 3 (*id.* at 42–43), wherein the metal oxide comprises an oxide of titanium, as recited in claim 6, the semiconductor oxide comprises an oxide of silicon, as recited in claim10, and the semiconductor oxide of the dielectric tunnel barrier is adjacent the semiconductor region, as recited in claim 11 (*id.* at 43–44). Noting that claim 13 depends from claim 3, which depends from claim 1, Petitioner contends that the combined teachings of Goodnick and Taubenblatt teach a structure with the semiconductor oxide comprises an oxide of silicon, as recited in claim 13, that the metal oxide layer comprises an oxide of titanium, as recited in claim 15, and the metal electrical contact comprises titanium, as recited in claim 16. Pet. 44–45.

Claim 19 depends from claim 1 and recites the added limitations that "the semiconductor region comprises silicon, the semiconductor oxide comprises an oxide of silicon, the metal oxide of the dielectric tunnel barrier layer comprises an oxide of titanium, and the metal electrical contact comprises titanium." In support of its argument that Goodnick and Taubenblatt disclose this combination of features, Petitioner cites its earlier discussion of these individual features. Pet. 46–47.

Claim 20 depends from claim 1 and recites the added limitations that "the dielectric tunnel barrier layer is configured to reduce a height of a Schottky barrier between the metal electrical contact and the semiconductor region from that which would exist at a contact junction between the metal electrical contact and the semiconductor region without the dielectric tunnel barrier layer disposed therebetween." In support of its argument that Goodnick and Taubenblatt disclose this combination of features, Petitioner cites its earlier discussion of claim limitation 1(vii) and argues that the SiO_2 layer also reduces the Schottky barrier height between the titanium (the metal electrical contact) and the n-type silicon substrate (the semiconductor region) from the barrier height that would have existed without the SiO_2 layer disposed between them. Pet. 47–48.

Claim 22 recites "the dielectric tunnel barrier layer is configured to reduce contact resistivity between the metal electrical contact and the semiconductor region from that which would exist at a contact junction between the metal electrical contact and the semiconductor region without the dielectric tunnel barrier layer disposed therebetween." In support of its argument that Goodnick and Taubenblatt disclose this combination of features, Petitioner cites its earlier discussion of claims 1 and 20, citing Carver (Ex. 1128, 2)[13], contends the terms "contact resistivity" and "specific contact resistivity" are interchangeable, and, citing Chang,[14] argues "[s]pecific contact resistivity depends on barrier height, so decreasing the barrier height between the metal electrical contact (titanium) and the semiconductor region (n-type silicon) would have decreased specific contact resistivity. Pet. 48–49 (citing Ex. 1119, Schubert Decl. ¶ 1119; Ex. 1118, 5–6).

Petitioner's challenges to each of these claims relies upon the combination of Goodnick and Taubenblatt in a layered structure with titanium as the metal oxide. Having determined that Petitioner has not demonstrated that a person of ordinary skill would have had reason to combine these teachings, we find that Petitioner has not demonstrated by a preponderance of the evidence that claims 1, 3, 6, 10–12, 13, 15, 16, 19, 20, and 22 are unpatentable.

E. Claims 8 and 17 as obvious over Goodnick in view of Jammy and Taubenblatt (Petitioner's Ground 4)

Claim 8 depends from claim 6, and claim 17 depends from claim 15; claim 6 and 15 recite that the metal oxide layer of the dielectric tunnel barrier layer comprises an oxide of titanium. Claim 8 and 17 recite that the semiconductor comprises an n-type doped source or drain of a transistor. Petitioner contends that a person of ordinary skill would have had reason to

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[13] Carver is not cited as a reference in this ground.
[14] Chang is not cited as a reference in this ground.

grow Goodnick's 30 Å layer on Jammy's n-type doped source or drain of a transistor in a silicon substrate and then deposit aluminum. Pet. 49. Petitioner cites Taubenblatt as teaching depositing titanium instead of aluminum, arguing that swapping Goodnick's silicon substrate for Jammy's source or drain of a transistor and performing conventional processing steps, an ordinarily skilled artisan would have had a reasonable expectation of success in combining the teachings of the references. *Id.* at 49–50 (citing Ex. 1119, Schubert Decl. ¶¶ 203–204). Petitioner further argues that because Jammy discloses depositing conductive studs on its quantum conductive barrier and incorporates by reference Cote,[15] which teaches titanium conductive studs, depositing Jammy's conductive stud would have been equally suitable and would have yielded the same TiO_x-SiO_2 interface layer owing to the formation of the TiO_x diffusion barrier during Taubenblatt's annealing process. *Id.* at 50 n.3 (citing Ex. 1115, 4:5–8, Fig.1; Ex. 1129, 8:24–28; Ex. 1119, Schubert Decl. ¶ 202 n.13).

Petitioner's challenges to each of these claims relies upon the combination of Goodnick and Taubenblatt in a layered structure with titanium as the metal oxide. Having determined that Petitioner has not demonstrated that a person of ordinary skill would have had reason to combine these teachings, we find that Petitioner has not demonstrated by a preponderance of the evidence that claims 8 and 17 are unpatentable over Goodnick in View of Jammy and Taubenblatt.

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[15] U.S. Patent No. 5,216,282 (Ex. 1129).

F. Claims 18 and 25–29 as obvious over Goodnick in view of Jammy, Taubenblatt, and Chang (Petitioner's Ground 5)

1. Chang (Ex. 1118)

Chang concerns the specific contact resistance of metal-semiconductor barriers. *See* Ex. 1118. Noting that the specific contact resistance at zero bias, R_c, is important as a measure of the ohmic or rectifying behavior of a metal-semiconductor barrier under operating conditions, Chang calculates R_c for metal-Si and metal-GaAs barriers on p-type and n-type samples. *Id.* at 1. According to Chang, R_c decreases exponentially with increasing temperatures and with decreasing barrier height. *Id.* Chang also states that for higher dopings where tunneling dominates, R_c decreases rapidly with increasing doping. *Id.*

2. Claims 18 and 25–29

Claim 18 depends from claim 17 and recites the additional limitation that "a specific contact resistivity between the n-type doped source or drain and the metal electric contact is less than 1 Ω-μm^2." Independent claim 25 recites an electrical junction having an interface layer, comprising a metal oxide separation layer and a semiconductor passivation layer, between a contact metal and a semiconductor comprising a transistor having a source and drain, in which the specific contact resistivity between the contact metal and the semiconductor is less than 1 Ω-μm^2. Claims 26–29 depend directly or indirectly from claim 25 and recite additional features. Claim 26 recites the metal oxide comprises an oxide of titanium; claim 27 recites the semiconductor oxide passivation layer comprises an oxide of the semiconductor; claim 28 recites the semiconductor oxide passivation layer is between 0.1µm and 5nm thick; claim 29 recites that the semiconductor oxide passivation layer is adjacent the semiconductor.

In support of its challenges to claims 25–29, Petitioner references its discussion of Goodnick, Jammy, Taubenblatt, and Chang concerning Grounds 1–4. Pet. 56–63. As discussed above, we are not persuaded that Petitioner has demonstrated a person of ordinary skill would have combined the references as proposed in Petitioner's challenges to each of these claims, i.e., the combination of Goodnick and Taubenblatt in a layered structure with titanium as the metal oxide. Having determined that Petitioner has not demonstrated that a person of ordinary skill would have had reason to combine these teachings, we find that Petitioner has not demonstrated by a preponderance of the evidence that claims 18 and 25–29 are unpatentable over Goodnick in View of Jammy Taubenblatt and Chang.

G. Objective indicia of non-obviousness of claim 4

1. Introduction

As discussed above, we find that Petitioner has demonstrated that a person of ordinary skill would have had reason to combine the teachings of Goodnick and Jammy and that their combined teachings would have suggested the limitations of claim 4 to a person of ordinary skill in the art. Before determining whether claim 4 is obvious in light of the prior art, we consider any relevant evidence of secondary or objective considerations of non-obviousness, as such evidence may lead to a conclusion that the challenged claim would not have been obvious to one of ordinary skill. *See Graham*, 383 U.S. at 17; *In re Piasecki*, 745 F.2d 1468, 1471–72 (Fed. Cir. 1984). Objective criteria constitute independent evidence of nonobviousness and may include any of the following: long-felt but unsolved needs, failure of others, unexpected results, commercial success, copying, licensing, and praise. *See Mintz v. Dietz & Watson, Inc.*, 679 F.3d 1372, 1378 (Fed. Cir. 2013).

Patent Owner contends that the invention reduces contact resistance, even for claims that do not specifically recite specific contact resistance values, and that the Petition acknowledges the tangible benefits of such reduced contact resistance. PO Sur-reply 20. According to Patent Owner, "[t]he objective evidence of non-obviousness overwhelmingly weighs in favor of the '691 Patent claims." PO Resp. 30 (citing Ex. 2090, Declaration of Dr. Paul Clifton ("Clifton Decl.") ¶¶ 8–102).

2. *Presumption of Nexus*

It is well established that to accord substantial weight to secondary considerations in an obviousness analysis, the evidence of secondary considerations must have a nexus to the challenged claim, i.e., there must be a legally and factually sufficient connection between the evidence and the patented invention. *Fox Factory, Inc. v. SRAM, LLC,* 944 F.3d 1366, 1373 (Fed. Cir. 2019). A patentee is entitled to a presumption of nexus when the patentee shows that the asserted objective evidence is tied to a specific product and that product embodies the claimed features and is coextensive with them. *Id.* Even where nexus cannot be presumed, "the patent owner is still afforded an opportunity to prove nexus by showing that the evidence of secondary considerations is the 'direct result of the unique characteristics of the claimed invention.'" *Id.* (quoting *In re Huang*, 100 F.3d 135, 140 (Fed. Cir. 1996)).

3. *Commercial Success*

Patent Owner argues that the products accused of infringement (and found to infringe) in the related litigation have been commercially successful. PO Resp. 41. Patent Owner argues that Petitioner has stipulated to commercial success (*id.*), and Petitioner, in fact, made the following stipulation in this proceeding:

> Samsung stipulates, solely for the purpose of, and for use in, this IPR proceeding, that the products accused of infringement in *Acorn Semi, LLC v. Samsung Electronics Co., Ltd. et al.*, No. 2:19-cv-00347-JRG (E.D. Tex.) have been commercially successful. Samsung disputes, however, that any commercial success achieved by the accused products is attributable, in any way, to the challenged claims of the Acorn patents

Ex. 2116, 2.

In the Patent Owner Response, Patent Owner argued that infringement of the '691 patent was being tried in the Related Litigation and that the verdict that the jury would reach would likely establish infringement of the challenged claims, thus establishing that the accused products embody the claimed features and are coextensive with them. PO Resp. 38 (citing Ex. 1150 as evidence that the jury would address infringement of the '691 claims). After the Patent Owner Response was filed, the jury issued verdict. Ex. 2121. That verdict did not, however, address alleged infringement of claim 4. *Id.* at 4. Thus, the verdict did not establish any presumption of nexus between any commercial success of accused products and claim 4. Patent Owner has not presented evidence in this proceeding that the accused products in the litigation embodies the features of claim 4—district court infringement contentions are not evidence. Thus, Patent Owner has not established a presumption of nexus between claim 4 and the accused products in the Related Litigation. Nor has nexus been established by any other means.

4. Long felt need

According to Patent Owner, although Goodnick and Taubenblatt were available in prominent journals for over 20 years, the inability of others to produce the claimed invention during that time "is consistent with the fact that those references do not, in fact, actually suggest the claimed invention."

PO Resp. 31. Petitioner cites *Iron Grip Barbell Co. v. USA Sports, Inc.*, 392 F.3d 1317, 1325 (Fed. Cir. 2004), for the proposition that "[a]bsent a showing of long-felt need or the failure of others, the mere passage of time without the claimed invention is not evidence of nonobviousness." Pet. Reply 28.

Patent Owner cites multiple assertions from the International Technology Roadmap for Semiconductors (ITRS) concerning the incentive to reduce the contact resistance at metal-semiconductor junctions and notes that the 2001 ITRS stated achieving this goal via conventional approaches "May also require that the metal/semiconductor barrier height be reduced." *Id.* at 32 (quoting Ex. 2093, 28). We note that this quotation indicates a person of ordinary skill would have understood the relationship between ohmic resistance and barrier height.

Citing Dr. Clifton's testimony that ITRS Roadmap represents an opinion and that many of its statements may not turn out to be correct, Petitioner argues that we cannot rely upon such conjecture. Pet. Reply 23–24 (citing Ex. 1172, Transcript of Deposition of Dr. Paul Clifton ("Clifton Tr.") 274:24–275:6, 276:20–277:2). Citing testimony by Dr. Clifton that technology categories mentioned in the 2001 and 2003 ITRS do not anticipate that invention, Petitioner further notes that the 2001 and 2003 ITRS lays out a broad industry strategy out to 2019 to achieve lowered contact resistance using technologies that are different from those of the challenged patents. *Id.* at 24 (citing Ex. 1172, Clifton Tr., 272:14–21).

Petitioner asserts that the reference to other technologies indicates an absence of a specific long felt need or the absence of existing solutions to the problem of reducing specific resistance. *Id.* On this record Patent Owner has not provided sufficient evidence of a nexus between the long felt and the specific limitations recited in claim 4, i.e., the structure recited in claim 1, in which the oxide of the tunnel barrier layer has a thickness between 0.1 nm and 5 nm (claim 3) and the semiconductor region is an n-type source or drain of a transistor (claim 4).

5. Unexpected results

Patent Owner contends that, prior to the invention claimed in the ’691 patent, the conventional approach to achieving low ohmic resistivity contacts was to remove the oxide layer and use metals capable of reacting with the native oxide during the sintering or bonding step—thereby removing the native oxide from the metal-silicon interface. PO Resp. 32–33. Patent Owner contends that its introduction of an interface oxide layer, i.e., inserting a dielectric into a metal-semiconductor contact in order to reduce resistivity was hailed as counter-intuitive. *Id.* at 33–34 (citing Ex. 2095, 2928; Ex. 2096, 3; Ex. 2097, 5; Ex. 2070, Kuhn Decl. ¶49); *see* PO Sur-reply 23–24).

Petitioner notes that Patent Owner’s expert, Dr. Kuhn, testified she had not studied whether the concepts in Patent Owner’s inventions were unique or novel and had not considered background prior art references, such as Kim (Ex. 1125), Schroen (Ex. 1124), and Iwaguro (Ex. 1127), that Dr. Schubert asserts disclose inserting an insulating layer between a metal and semiconductor contact to achieve a low contact resistance. Pet. Reply 26–27 (citing Ex. 1169, Transcript of Deposition of Dr. Kelin Kuhn (“Kuhn Tr.”) 237:19–24, 254:4–9; Ex. 1119, Schubert Decl. ¶¶ 55–59). According to Petitioner, in view of Dr. Schubert’s unrebutted testimony that using an interface layer to achieve low contact resistance was known, there is no nexus between the claims and any purported unexpected results. *Id.*

Patent Owner notes that Petitioner was unsuccessful in relying on Kim in related IPR2020-01264 and has not tried to rely on Schroen and Iwagaro in this proceeding or the district court litigation. PO Sur-reply 21–22. Patent Owner characterizes Schroen and Iwagaro as marginally relevant references that fail to disclose a two layer interface layer with a metal oxide layer, and, even if they disclose limited aspects of the invention, they do not suggest the inventors' novel combination. PO Sur-reply 22 (citing *Henny Penny Corp. v. Frymaster LLC*, 938 F.3d 1324, 1333 (Fed. Cir. 2019); Ex. 1169, Kuhn Tr. 87:16–88:1). Patent Owner emphasizes that it "was the first to understand, explain, and control the unexpected reduced-resistance effect. [Patent Owner] had the insight; Kim, Schroen, and Iwaguro had none." *Id.* Patent Owner does not identify how the unexpected results relate specifically to claim 4. On this record, therefore, Patent Owner has not provided sufficient evidence of a nexus between any unexpected results and the limitations of claim 4.

6. Industry praise

Patent Owner notes that in 2004 and 2006, the inventors published two papers describing the invention (Exs. 2045, 2046 (collectively "the Connelly Papers")) that have been cited over 270 times in the professional literature. PO Resp. 34. On this record, Patent Owner has not demonstrated a sufficient nexus between any praise in these papers and specific limitations of claim 4. Patent Owner does not identify how the structures described in those papers relate to claim 4. Further, Petitioner provides evidence of the contrary. Claim 4, via its dependency from claim 1, recites a structure comprising a metal oxide layer. The Connolly papers disclose only a silicon nitride interface layer, which is not a metal oxide interface layer. Ex. 1171, 172:2–10, 175:19–25; Ex. 1173 ¶ 139. Thus, praise for the Connelly Papers does not constitute objective evidence of nonobviousness for claim 4.

7. Alleged suspicious behavior

Patent Owner alleges that, in an abstract in 2017, Petitioner's researchers cited the Connelly papers as a basis for their work, but removed the citation when the paper was published in full in 2018. *See* PO Resp. 47–51 (citing Ex. 2047, 1; Ex. 2048, 4879). According to Patent Owner, Petitioner's abstract focused on how contact resistance limits performance in scaling silicon MOSFETs and states that, instead of increased doping, the researchers studied an alternate option, i.e. a metal-interface-semiconductor (MIS) structure that mirrors the challenged independent claims. *Id.* at 48. Patent Owner states that the paper published by Petitioner's researchers in 2018 that did not cite the Connelly Papers "describes in positive terms reducing ρ_c, reducing the height of the Schottky barrier, depinning the Fermi level, and tuning the SBH (Schottky barrier height) between a low work-function metal and n-type silicon." *Id.* at 49. According to Patent Owner, there is a nexus between Petitioner's actions and claim 4, which recites a structure comprising a semiconductor oxide and metal oxide layers that together depin the Fermi level and recite an n-type semiconductor. *Id.* Patent Owner also alleges that Petitioner filed its own patent applications based on Patent Owner's technology. *Id.* at 49–51 (noting the similarity between a graph showing the thickness of the insulating mater and contact resistivity in Petitioner's patent a graph showing oxide thickness and specific contact resistance in Patent Owner's patents).

Noting that the sentence citing the Connelly Papers in the abstract is not present in the final published paper, Petitioner contends that "[o]mitting a citation when there is no longer relevant information in a paper is ***not*** evidence of any suspicious behavior—it is what authors routinely do" and "even Dr. Kuhn did not cite to the Connelly Papers in her related work," even though she was aware of the Connelly Papers. Pet. Reply 30 (citing Ex. 1169, Kuhn Tr., 34:4–23). Petitioner further points out that its "graph merely presents what was known in the literature long before [Patent Owner's] patents." *Id.* at 31.

The alleged suspicious behavior is not an objective criteria cited in Federal Circuit precedent. Patent Owner provides no testimony concerning the motivations of the authors of the abstract or the published paper and we make no inferences from the difference in the citations concerning the Connelly Papers.

8. Summary

In consideration of the above, we do not find that the objective evidence supports a conclusion of nonobviousness. Thus, we determine that claim 4 would have been obvious over Goodnick and Jammy.

VII. PATENT OWNER'S MOTIONS TO EXCLUDE

Patent Owner filed a Motion to Exclude. Paper 44 ("PO Mot. To Exclude"). Petitioner filed an Opposition to Patent Owner's Motion. Paper 48 (Pet. Opp."). Patent Owner filed a Reply. Paper 49 ("PO Reply)

A. Motion to exclude Goodnick cross examination testimony

Patent Owner moves to exclude portions of the deposition testimony of its own expert, Dr. Stephen Goodnick, as outside the scope of the challenged claims. PO Mot. To Exclude, 1. In particular, Patent Owner moves to exclude testimony elicited on cross examination concerning whether certain metal oxides fall within the scope of the challenged claims. *Id.* (citing Ex. 1168, Transcript of Deposition of Dr. Stephen Goodnick

(“Goodnick Tr.”) 65:20–66:17, 113:20–117:23, and 137:17–141:10 (collectively, the “Goodnick Metal-Oxide Testimony”)). Patent Owner argues that “nothing in Dr. Goodnick’s declaration even remotely addresses the interpretation of ‘metal oxide’ in the challenged claims, what is or is not a ‘metal oxide,’” but that his “declaration instead concerns primarily the Goodnick paper, particularly whether a person of ordinary skill in the art (POSITA) would understand it as disclosing distinct stratified layers of Al_2O_3 and SiO.” *Id.* at 2.

Petitioner argues that Dr. Goodnick’s first declaration (Ex. 2043), which in its entirety is incorporated by reference in Dr. Goodnick’s second declaration (Ex. 2080), includes statements directed to the composition of the various layers in a prior art structure, including a metal oxide layer. Pet. Opp. 2 (citing Ex. 2043, Goodnick Decl. ¶ 53). Noting Dr. Goodnick’s testimony that the Goodnick Paper does not teach distinct layers, but instead that Al_2O_3 and SiO_2 form a “checkerboard” pattern, Petitioner asserts that questioning Dr. Goodnick on what constitutes a distinct metal oxide layer was proper. *Id.* at 2–3.

Although Patent Owner contends Dr. Goodnick’s declaration did not open the door for general questioning about metal oxides (PO Opp. 2–3), we agree with Petitioner that the proper scope of cross examination includes Dr. Goodnick’s understanding of what constitutes a distinct layer. A primary issue raised by Patent Owner against Petitioner’s challenge that Goodnick anticipates is that, notwithstanding its use of the term layer, Goodnick does not teach distinct layers that are required by the claim. *See* Section VI.B. One of those layers is a metal oxide layer (Ex. 1101, claim 1), in particular a titanium oxide layer (claim 6). In view of Dr. Goodnick’s checkerboard analogy in his declaration, it was proper for Petitioner to question Dr.

Goodnick about the extent of materials in the checkerboard. Both parties argue there may be implications of Dr. Goodnick's testimony for purposes of infringement litigation. *See* Pet. Opp. 4–6; PO Reply 3–4. We do not address those implications. The issue before us is whether Goodnick would have taught or suggested to a person of ordinary skill the limitations of the claims, which the parties agree include distinct layers of metal oxide and other semiconductor oxide. *See* Section VI.B. As Dr. Goodnick testified that his article did not teach such distinct layers, it was proper for Petitioner to explore Dr. Goodnick's views concerning the composition of a layer during cross examination.

In consideration of the above, Patent Owner's motion to exclude the Goodnick Metal Oxide testimony is denied.

B. Motion to exclude Kuhn cross examination testimony

Patent Owner also moves to exclude deposition testimony of its expert, Dr. Kuhn, about claim limitations that recite an "oxide of titanium." PO Mot. To Exclude 7. Patent Owner asserts that "the 'oxide of titanium' limitation was not substantively addressd in this or any other IPR petition, and Dr. Kuhn never addressed it in her declaration (Ex. 2070)." *Id.* Claim 6, which depends from claim 3, which depends from claim 1, recites that the metal oxide, which finds its antecedent in claim 1, is an oxide of titanium.

In combination with Goodnick's disclosure of an interface layer, Petitioner cited Taubenblatt as describing the formation of a titanium oxide layer. Pet. 30–31. As discussed extensively above, however, Petitioner was unable to demonstrate that a person of ordinary skill would have had reason to substitute Taubenblatt's titanium for Goodnick's aluminum. Therefore, we do not address specifically claims drawn to an oxide of titanium and do not consider the testimony Patent Owner seeks to exclude concerning the titanium oxide genus and various species of titanium oxide. *See* PO Mot. To Exclude 8–11. For purposes of this proceeding, we determine that Patent Owner's Motion to Exclude the Kuhn oxide of titanium testimony is dismissed moot.

VIII. PETITIONER'S MOTION TO EXCLUDE

Petitioner filed a Motion to Exclude. Paper 45 ("Pet. Mot. To Exclude"). Patent Owner filed an Opposition. Paper 47 ("PO Opp."), and Petitioner filed a Reply. Paper 49 ("Pet. Reply").

Petitioner moves to exclude certain direct testimony of Dr. Paul Clifton, i.e., paragraphs 8–15, 19–25, 36–45, 47–50, 52–63, 67, 69–70, 72, 76–77, and 81–107 of the Clifton Declaration, becasue "during Dr. Clifton's deposition, it became clear that Acorn was offering Dr. Clifton only as a fact witness, not an expert witness and, accordingly, it became apparent that the expert opinions offered in Dr. Clifton's declaration are improper." Pet. Mot. To Exclude 3. Patent Owner offered Dr. Clifton's testimony in support of its objective considerations arguments. *See* Section VI.G.

Patent Owner contends that Petitioner misconstrues comments made by Patent Owner's counsel during Dr. Clifton's deposition indicating that Dr. Clifton was a fact witness, that Dr. Clifton testified as a hybrid fact-expert witness, that Petitioner failed to timely object to Dr. Clifton's testimony and that Petitioner's motion is mostly moot because the objective indicia that was the subject of Dr. Clifton's testimony is established independently from the documentation in evidence. *See generally* PO Opp.

Patent Owner asserts that, in *inter partes* reviews, the Board's rules do not specifically distinguish between experts and fact witnesses and that all witnesses (whether fact witnesses or expert witnesses) provide their direct testimony in the form of declarations. PO Opp. 2. This is in contrast to procedures in district courts, where expert witnesses must be designated and special discovery procedures apply. *Id.* (citing Fed. R. Civ. P. 26(a)(2)). Although as a procedural matter, Patent Owner correctly characterizes the difference between district court proceedings and those before the Board, we do not endorse a standard that would allow a party to re-characterize a witness's testimony after the fact. In this case, however, we need not decide that issue.

At his deposition, Dr. Clifton stated that he understood himself to be testifying as a fact witness, not an expert (Pet. Reply 1, citing Ex. 1117, Clifton Tr. 100:2–12) and Dr. Clifton's declaration includes information that demonstrates sufficient knowledge of facts for admissibility (Ex. 2090 ¶¶ 3–6 (describing his education, his technical research in MIS junctions (although not specifically concerning contact resistance), his years of experience, his employment by Patent Owner since 2004, and his current role as Vice President of Semiconductor Technologies)). We do not agree with Petitioner that Dr. Clifton's occasional use of the expression "I believe" itself transforms his testimony from fact to opinion concerning the objective criteria. *See* Pet. Mot. To Exclude 6. Much of the testimony in Dr. Clifton's declaration concerning the long felt need in the industry, what the patents describe, the Connelly papers, the work that led up to the structures Patent Owner developed, the reactions of other researchers in the field, and the unexpected nature of the results, is based on events that occurred shortly before or while Dr. Clifton was employed by Patent Owner and derive from Dr. Clifton's personal knowledge. In light of his background and the largely factual nature of his testimony, Petitioner's arguments for excluding Dr. Clifton's testimony concern the weight that we should accord his testimony, rather than its admissibility.

Petitioner's Motion to Exclude is therefore denied.

IX. CONCLUSION[16]

In consideration of the above we find that Petitioner has demonstrated by a preponderance that claims 1–3 and 13 are unpatentable as anticipated by Goodnick and that claim 4 is unpatentable as obvious over the combined teachings of Goodnick and Jammy.

In summary:

Claims	35 U.S.C. §	Basis	Claims Shown Unpatentable	Claims Not shown Unpatentable
1–3, 13	102	Goodnick	1–3, 13	
4	103	Goodnick, Jammy	4	
1, 3, 6, 10–13, 15, 16, 19, 20, 22	103	Goodnick, Taubenblatt		1, 3, 6, 10–13, 15, 16, 19, 20, 22
8, 17	103	Goodnick, Jammy, Taubenblatt		8, 17
18, 25–29	103	Goodnick, Jammy, Taubenblatt, Chang		18, 25–29
Overall Outcome			1–4, 13	6, 8, 10–12, 15–20, 22, 25–29

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[16] Should Patent Owner wish to pursue amendment of the challenged claims in a reissue or reexamination proceeding subsequent to the issuance of this decision, we draw Patent Owner's attention to the April 2019 *Notice Regarding Options for Amendments by Patent Owner Through Reissue or Reexamination During a Pending AIA Trial Proceeding. See* 84 Fed. Reg. 16,654 (Apr. 22, 2019). If Patent Owner chooses to file a reissue application or a request for reexamination of the challenged patent, we remind Patent Owner of its continuing obligation to notify the Board of any such related matters in updated mandatory notices. *See* 37 C.F.R. § 42.8(a)(3), (b)(2).

X. ORDER

In consideration of the above it is:

ORDERED that claims 1–4 and 13 are unpatentable;

FURTHER ORDERED that Petitioner's Motion to Exclude certain declaration testimony of Dr. Clifton is DENIED;

FURTHER ORDERED that Patent Owner's Motion to Exclude certain portions of the Goodnick deposition testimony is DENIED;

FURTHER ORDERED that Patent Owner's Motion to Exclude certain portions of the Kuhn deposition testimony is DIMISSED as moot; and

FURTHER ORDERED that, because this is a Final Written Decision, parties to the proceeding seeking judicial review of the decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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