

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

MICRON TECHNOLOGY, INC.,
INTEL CORPORATION, GLOBALFOUNDRIES U.S., INC., and
SAMSUNG ELECTRONICS COMPANY, LTD.,
Petitioner,

v.

DANIEL L. FLAMM,
Patent Owner.

Case IPR2017-00392¹
Patent 5,711,849

Before CHRISTOPHER L. CRUMBLEY, JO-ANNE M. KOKOSKI, and
KIMBERLY McGRAW, *Administrative Patent Judges*.

KOKOSKI, *Administrative Patent Judge*.

FINAL WRITTEN DECISION
35 U.S.C. § 318(a) and 37 C.F.R. §42.73

¹ Samsung Electronics Company, Ltd. was joined as a party to these proceedings via a Motion for Joinder in IPR2017-01747.

I. INTRODUCTION

We have jurisdiction to conduct this *inter partes* review under 35 U.S.C. § 6, and this Final Written Decision is issued pursuant to 35 U.S.C. § 318(a) and 37 C.F.R. § 42.73. For the reasons that follow, we determine that Petitioner has shown by a preponderance of the evidence that claims 1–29 of U.S. Patent No. 5,711,849 (“the ’849 patent,” Ex. 1001) are unpatentable.

A. *Procedural History*

Micron Technology, Inc., Intel Corporation, and GLOBALFOUNDRIES U.S., Inc. (collectively, “the Micron Petitioners”)² filed a Petition (“Pet.”) to institute an *inter partes* review of claims 1–29 of the ’849 patent based on the following grounds:

References	Basis	Challenged Claims
Alkire ³ and Kao ⁴	§ 103	1–29
Alkire, Kao, and Flamm ⁵	§ 103	1–29

² On September 15, 2017, we granted the Motion for Joinder filed by Samsung Electronics Company, Ltd. (“Samsung”) in IPR2017-01747, and authorized Samsung to participate in this proceeding only on a limited basis. See Paper 13. We refer to Micron Technology, Inc., Intel Corporation, GLOBALFOUNDRIES U.S., Inc., and Samsung collectively as “Petitioner” throughout this Decision.

³ *Transient Behavior during Film Removal in Diffusion-Controlled Plasma Etching*, J. Electrochem. Soc.: Solid-State Science and Technology, Vol. 132, No. 3 (1985) 648–656 (Ex. 1005).

⁴ *Analysis of Nonuniformities in the Plasma Etching of Silicon with CF₄/O₂*, J. Electrochemical Soc., Vol. 137, No. 3 (1990) 954–960 (Ex. 1006).

⁵ *The Reaction of Fluorine Atoms with Silicon*, J. Appl. Phys., Vol. 52, No. 5 (1981) 3633–3639 (Ex. 1007).

Paper 1, 5–6. Daniel L. Flamm (“Patent Owner”) filed a Preliminary Response (“Prelim. Resp.”). Paper 9. Pursuant to 35 U.S.C. § 314(a), we instituted an *inter partes* review of claims 1–29 based on our determination that the information presented in the Petition demonstrated a reasonable likelihood that Petitioner would prevail on its challenge that at least one of the challenged claims is unpatentable under 35 U.S.C. § 103 as obvious over the combined teachings of Alkire and Kao. Paper 10 (“Dec. on Inst.”), 19. We subsequently modified our institution decision to include “all of the grounds presented in the Petition.” Paper 32, 2.

After institution of trial, Patent Owner filed a Patent Owner Response (Paper 12, “PO Resp.”), and Petitioner filed a Reply (Paper 14, “Reply”). Petitioner relies on the Declaration of Dr. David Graves (“the Graves Declaration,” Ex. 1003) and the Reply Declaration of Dr. David Graves (“the Graves Reply Declaration,” Ex. 1024). Patent Owner relies on the Declaration of Daniel L. Flamm (“the Flamm Declaration,” Ex. 2003). An oral hearing was held on March 7, 2018. A transcript of the hearing is included in the record. Paper 31.

B. Related Proceedings

The parties indicate that the ’849 patent is at issue in five related patent infringement actions. Pet. 4; Paper 7, 2. The ’849 patent previously was the subject of IPR2016-00466 (filed by Lam Research Corp., institution denied on July 19, 2016), and currently is the subject of IPR2017-00406, also filed by the Micron Petitioners (and joined by Samsung). Pet. 4.

C. The ’849 Patent

The ’849 patent, titled “Process Optimization in Gas Phase Dry Etching,” is directed to “a plasma etching method that includes determining

a reaction rate coefficient based upon etch profile data.” Ex. 1001, 1:51–53. The method “includes steps of providing a plasma etching apparatus having a substrate therein[,]” where the substrate has a film overlaying the top surface, and the film has a top film surface. *Id.* at 1:59–63. It “also includes chemically etching the top film surface to define an etching profile on the film, and defining etch rate data which includes an etch rate and a spatial coordinate from an etching profile.” *Id.* at 1:63–67. Steps of extracting a reaction rate constant from the etch rate data, and using the reaction rate constant to adjust the plasma etching apparatus are also described. *Id.* at 1:67–2:2. According to the ’849 patent, the method “provides for an easy and cost effective way to select appropriate etching parameters such as reactor dimensions, temperature, pressure, radio frequency (rf) power, flow rate and the like by way of the etch profile data.” *Id.* at 1:53–57.

Figure 1A of the ’849 patent is reproduced below:

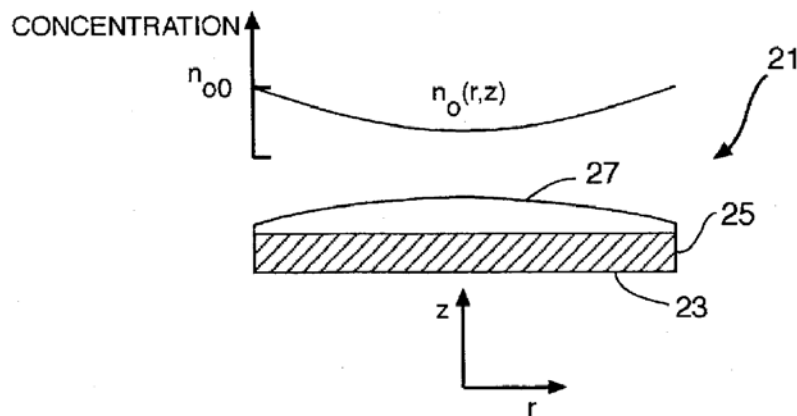


FIG. 1A

Figure 1A is an example of an etched substrate. *Id.* at 3:66–67. Substrate 21 includes bottom surface 23, sides 25, and top surface film 27, and is defined in spatial coordinates z and r . *Id.* at 3:67–4:2. “[T]op surface film [27] includes a convex region, or etching profile.” *Id.* at 4:3–4. “The etching profile occurs by way of different etch rates along the r -direction of

[substrate 21], corresponding to different etchant species concentrations.” *Id.* at 4:4–6. Concentration profile $n_o(r,z)$ shows that “the greatest concentration of reactant species exists at the outer periphery of [] top surface film [27].” *Id.* at 4:6–9.

The '849 patent describes an embodiment of a method of extracting an etch rate constant in which a substrate with an overlying film is placed into a plasma etching apparatus, and the plasma etching step occurs at constant pressure, and, preferably, isothermally. *Id.* at 5:11–19. Plasma etching of the film stops before etching into an etch stop layer underneath the overlying film “[in order] to define a ‘clean’ etching profile.” *Id.* at 5:24–26. The plasma etching step produces an etching profile, which “converts into a relative etch rate, relative concentration ratio, a relative etch depth and the like at selected spatial coordinates.” *Id.* at 5:28–32.

Using x-y-z coordinates, the relative etch rate is in the z-direction, and x-y are the spatial coordinates. *Id.* at 5:38–40. “The etching profile is thereby characterized as a relative etch rate u , [an] x-location, and a y-location $u, (x, y)$,” and an array of data points in the x-y coordinates define the etching profile. *Id.* at 5:40–41, 45–47. An etch constant over diffusivity (k_{vo}/D) and an etch rate at the substrate edge is then calculated, where “[t]he etch constant over diffusivity correlates with data points representing the etch rate profile.” *Id.* at 5:62–65. After the etch rate constant k_{vo} is extracted, the surface reaction rate constant k_s can be determined using the formula $k_s = (k_{vo})d_{gap}$, where d_{gap} is the space above the substrate, between the substrate and the adjacent substrate. *Id.* at 3:35–36, 6:58–62, 9:27–29, Fig 7.

Claims 1, 10, 20, 22, and 26 are the challenged independent claims.

Claim 1 is representative, and is reproduced below.

1. A device fabrication method comprising the steps of:
providing a plasma etching apparatus comprising a substrate therein, said substrate comprising a top surface and a film overlying said top surface, said film comprising a top film surface;
etching said top film surface to define a relatively non-uniform etching profile on said film, and defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile on said substrate, said etching comprising a reaction between a gas phase etchant and said film; and
extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant in the fabrication of a device.

Ex. 1001, 17:35–50.

II. ANALYSIS

A. *Level of Ordinary Skill in the Art*

Petitioner argues that a person of ordinary skill in the art at the time of the '849 patent would have had “a Bachelor of Science degree in chemical engineering, electrical engineering, material science, chemistry, or physics or a closely related field, along with at least 3–4 years of experience in the development of plasma etching or chemical vapor deposition.” Pet. 19. Petitioner further argues that a person with a master’s degree “would require 2–3 years of experience in the development of plasma etching or chemical vapor deposition,” and a person with a Ph.D. “would not require additional experience.” *Id.* (citing Ex. 1003 ¶ 73). Patent Owner does not dispute Petitioner’s assessment in its Response.

Petitioner's assessment appears consistent with the level of ordinary skill in the art at the time of the invention as reflected in the prior art in this proceeding. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (explaining that specific findings regarding ordinary skill level are not required "where the prior art itself reflects an appropriate level and a need for testimony is not shown" (quoting *Litton Indus. Prods., Inc. v. Solid State Sys. Corp.*, 755 F.2d 158, 163 (Fed. Cir. 1985))). Accordingly, we adopt Petitioner's assessment of the level of ordinary skill in the art.

B. Claim Interpretation

The '849 patent has expired. Ex. 1001, [22] (application filed on May 3, 1995); *see* Pet. 15. For claims of an expired patent, the Board's claim interpretation is similar to that of a district court, i.e., consistent with *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). *See In re Rambus, Inc.*, 694 F.3d 42, 46 (Fed. Cir. 2012). Under the *Phillips* standard, claim terms are given their ordinary and customary meaning as would be understood by a person of ordinary skill in the art at the time of the invention, and in the context of the entire patent disclosure and prosecution history. *Phillips*, 415 F.3d at 1312–14. Only those terms in controversy need to be construed, and only to the extent necessary to resolve the controversy. *See Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017) ("we need only construe terms 'that are in controversy, and only to the extent necessary to resolve the controversy'") (quoting *Vivid Techs., Inc. v. Am. Sci. & Eng'g, Inc.*, 200 F.3d 795, 803 (Fed. Cir. 1999)).

For purposes of the Decision on Institution, we interpreted "surface reaction rate constant" as set forth in claims 1, 5, 10, 14, 20, 22, 26, 27, and

29 to mean “a temperature-dependent reaction rate constant for the chemical reaction between a gas phase etchant and the surface of an etchable material.” Dec. on Inst. 7. The parties do not contest our interpretation of this term, and we see no reason to modify it in light of the record developed at trial.

C. *Principles of Law*

To prevail on its challenges to the patentability of the claims, a petitioner must establish facts supporting its challenge by a preponderance of the evidence. 35 U.S.C. § 316(e); 37 C.F.R. § 42.1(d). “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 the patent owner. *See Dynamic Drinkware, LLC v. Nat’l Graphics, Inc.*, 800 F.3d 1375, 1378–79 (Fed. Cir. 2015) (discussing the burdens of persuasion and production in *inter partes* review).

A claim is unpatentable under 35 U.S.C. § 103 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 to a person having ordinary skill in the art to which the subject matter pertains. *KSR Int’l Co. v. Teleflex, Inc.*, 550 U.S. 398, 406 (2007). 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. *See Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966).

A patent claim “is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art.” *KSR*, 550 U.S. at 418. An obviousness determination requires finding “both ‘that a skilled artisan would have been motivated to combine the teachings of the prior art references to achieve the claimed invention, and that the skilled artisan would have had a reasonable expectation of success in doing so.’” *Intelligent Bio-Sys., Inc. v. Illumina Cambridge Ltd.*, 821 F.3d 1359, 1367–68 (Fed. Cir. 2016) (citation omitted); *see KSR*, 550 U.S. at 418 (for an obviousness analysis, “it can be important to identify a reason that would have prompted a person of ordinary skill in the relevant field to combine the elements in the way the claimed new invention does”). 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. Info USA, Inc.*, 587 F.3d 1324, 1329 (Fed. Cir. 2009) (quoting *KSR*, 550 U.S. at 418–21).

D. Overview of the Prior Art

1. Overview of Alkire

Alkire is directed to the formulation of a mathematical model “to analyze transient behavior during film removal from closely spaced wafers

in a barrel plasma etching reactor.” Ex. 1005, 1.⁶ “The analysis relates the effect of geometric and operating variables to process characteristics such as etch uniformity, over-etch exposure, and throughput.” *Id.* “Regions of operating conditions that permit etch uniformity within specified tolerances are found, and optimum settings for inter-wafer spacing and reactor pressure to achieve maximum throughput are calculated.” *Id.* Alkire teaches that “[e]tch uniformity and throughput are of particular importance in any plasma etching process,” and that “[p]arameters that affect uniformity and throughput include RF power input, chamber pressure, gas flow rate and distribution, wafer spacing, wafer diameter, and temperature.” *Id.* at 1–2.

Alkire Figure 2 is reproduced below.

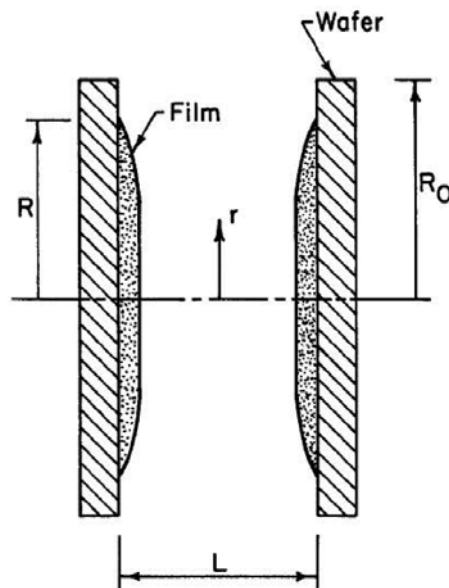


Figure 2 is a schematic of the radially symmetric region between two successive wafers that are facing each other. *Id.* at 2. Before etching begins, a uniform-thickness film exists on the wafer surface. *Id.* “To an extent that

⁶ The cited page numbers in Ex. 1005 refer to the numbers added by Petitioner in the bottom right corner of the page.

depends upon operating conditions, the etch rate is highest on the periphery of the wafer,” and, therefore, film in this region clears first. *Id.* Figure 2 illustrates this, showing that the “film has been cleared entirely from the outer portion of the wafer, while the inner region is yet to clear.” *Id.*

Alkire makes several assumptions to “preserve the salient features of the system and also streamline the task of computation,” including that “[t]he spacing between the adjacent wafers is sufficiently smaller than the wafer radius so that significant concentration variations occur only in the radial direction,” “the etching reaction is first order” and “proceeds to completion at or near the film surface,” and “[t]he concentration of etchant at the wafer remains constant during the etch cycle.” *Id.* Alkire provides two governing equations: Equation [1] that gives “the thickness of etchable material left at a certain location and time,” and Equation [2] that is the conservation equation for the etching species, as set forth below.

$$h(r, t) = h_o - \int_0^t \frac{k_2}{x} c(r, t) dt \quad [1]$$

$$D \frac{1}{r} \frac{d}{dr} \left(r \frac{dc}{dr} \right) = \frac{2k_2}{L} c + 2k_1 c^2 [A_2] + \frac{v_o w}{2L} c \quad [2]$$

with the boundary conditions

$$c = c_o \text{ at } r = R_o$$

$$\frac{dc}{dr} = 0 \text{ at } r = 0$$

Id. Alkire defines h_o as the initial film thickness (cm), k_2 as the etch rate constant (cm/s), X as the moles of etchant species consumed per cm³ of film etched (mol/cm³), c as the etchant concentration (mol/cm³), h as the film thickness (cm), r as the radial position (cm), t as time (s), D as the etchant diffusivity (cm²/s), L as the wafer separation distance (cm), k_1 as the volume

recombination reaction rate constant ($\text{cm}^6/(\text{mol})^2/\text{s}$), A_2 as the parent molecule, v_o as the random thermal velocity of etchant species (cm/s), w as the wall recombination coefficient, c_o as the etchant concentration at the wafer edge (mol/cm^3), and R_o as the wafer radius (cm). *Id.* at 8–9.

Alkire then “rewrite[s] the governing equations in terms of dimensionless quantities” that it defines, resulting in dimensionless Equations [6] and [7]. *Id.* at 3. According to Alkire, “[b]y solving Eq. [6] and [7], the effect of process parameters (c_o , P , D , k ’s) and of geometric factors (L , R_o) on etch uniformity, overetch exposure, and total etch time can be determined,” and, “[i]n particular, optimum conditions for high throughput can be identified.” *Id.* Alkire states that these “[d]imensionless groupings of system parameters were used to compile behavior and to reveal scale-up principles,” and that “[t]he model can be extended without much difficulty to handle more complex situations.” *Id.* at 8. Alkire concludes that “[t]he use of mathematical models can assist in organizing scientific concepts into strategies for engineering design.” *Id.*

2. Overview of Kao

Kao describes experimental and modeling work that “examine[s] the effect of reactor pressure, etchant gas flow rate, and wafer location on the uniformity of plasma etching silicon using CF_4/O_2 in a parallel-plate-radial flow reactor.” Ex. 1006, 1.⁷ Kao “presents the results of a series of experiments aimed at quantifying the dependencies of etch uniformity on process parameters,” and develops a quantitative model that “helps explain several trends in the data.” *Id.*

⁷ The cited page numbers in Ex. 1006 refer to the numbers added by Petitioner in the bottom right corner of the page.

Kao measured etch depths at various stages of the experimental process, including prior to etching (to measure the initial film thickness) and immediately after etching (to measure the amount of film removed), and calculated etch rates as etch depth divided by etch time. *Id.* at 2. Etch rate profiles were measured from the point closest to the reactor exit to the point closest to the reactor entrance, and plotted as (i) average absolute etch rate at any position across the wafer and (ii) etch rates normalized to the minimum etch rate over the wafer in order “to indicate the degree of nonuniformity across the wafer.” *Id.*

Kao’s model “takes a simplified approach to the plasma etching system,” and “assume[s] that plasma etching occurs via three lumped reaction steps: (i) dissociation of etchant gas molecules by electron bombardment (or chemical reaction with free radicals),” “(ii) a surface reaction between the substrate atoms and the reactive etching species produced in the plasma, and (iii) chemically reactive species (free radicals) recombining to form a nonreactive species through loss reactions.” *Id.* at 3. “Designating k_d^* to be the rate constant for the dissociation of CF_4 , k_e to the rate constant for the surface etching reaction, and k_l to be the loss reaction rate constant,” Kao gives the rate of reaction in the gas phase for fluorine, CF_4 , and silicon, and the component continuity equations for CF_4 and F. *Id.* at 4. Kao ultimately presents its model in dimensionless form in Equations [8a-b], which “were solved using the finite element program TWODEPEP.” *Id.* at 5.

Kao explains that “[t]he unknown reaction rate constants, k_l , k_d , and k_e were varied in each call to TWODEPEP to allow minimizing the error between the observed and the calculated etch rate.” *Id.* “The three runs

which varied flow rate (data of Fig. 3) were used to determine the set of three constants.” *Id.* Kao states that “[t]he agreement is good” between observed etch rates and predicted etch rates “at 60 and 80 sccm flow rates, with a small deviation observed at 100 sccm near the center of the wafer.” *Id.* Kao observes that “decreasing flow rate enhances the etch rate,” “higher pressures resulted in higher etch rates,” and “the location of the wafer has only a small effect on etch uniformity.” *Id.* at 6.

Kao concludes that its experimental results “show a large degree of nonuniformity in etch rate when etching silicon with CF_4/O_2 .” *Id.* According to Kao, “[a]n approximate kinetic model coupled with a radial flow reactor model shows promise in predicting the etch rate nonuniformities and the magnitude of the etch rate,” and “[r]ate parameters determined by best fitting the model to the experimental data are of reasonable magnitudes compared to those reported elsewhere.” *Id.* at 7.

3. *Overview of Flamm*

Flamm describes an investigation in which “the etching of silicon by F atoms and intensity of concomitant luminescence were measured as a function of temperature (223–403K) and F-atom concentration ($n_F = 1.6 \times 10^{15} - 7.7 \times 10^{15} \text{ cm}^{-3}$).” Ex. 1007, 1.⁸ Flamm reports that the saturated intensity “was measured as a function of temperature,” and provides “a typical data set taken at constant pressure and mole fraction of F atoms (constant discharge power), which has been corrected for the effect of temperature on the gas-phase F-atom density.” *Id.* at 3. Flamm explains

⁸ The cited page numbers in Ex. 1007 refer to the numbers added by Petitioner in the bottom right corner of the page.

that “[t]he intensity is well described by an Arrhenius expression” using a factor that “corrects for the temperature dependencies of atom concentration and atom flux to the surface.” *Id.*

Flamm also “shows the temperature dependence of etch rates similarly corrected for the effect of temperature on atom density,” where the “etch rates are described by the regression equation $R_{(Si)} = 2.91 \pm 0.20 \times 10^{-12} n_F T^{1/2} e^{-E_{\text{etch}}/kT}$.” *Id.* Flamm reports that “[w]ithin experimental error the etch rate and chemiluminescent intensity have the same activation energy.” *Id.* Flamm concludes that “[t]he present rates and activation energy are consistent with those reported for *in situ* etching of Si and SiO₂ in F atoms containing plasmas at 0.3–0.5 Torr” and, consequently, “the F atom solid reaction alone can generally account for these data.” *Id.* at 6.

E. Obviousness over Alkire and Kao

Petitioner contends that the subject matter of claims 1–29 is unpatentable under 35 U.S.C. § 103(a) as having been obvious over the combined teachings of Alkire and Kao. Pet. 34–77; Reply 4–29. Petitioner relies on the Graves Declaration and the Graves Reply Declaration in support of its contentions. *Id.* Patent Owner disagrees with Petitioner’s assertions. PO Resp. 2–19, 21–32.

1. Motivation to Combine Alkire and Kao

Petitioner contends that a person having ordinary skill in the art (“PHOSITA”) “would have combined Alkire and Kao in order to improve the theoretical model of Alkire with the use of experimental data in order to test and validate Alkire’s theoretical model, as taught in Kao.” Pet. 30 (citing Ex. 1003 ¶ 114). Petitioner contends that Kao discloses, “and a PHOSITA would have recognized, that Alkire provides a robust model for

the reaction between a gas phase etchant and a substrate film, but that no experimental data to support or inform that model was provided,” and that “[a] PHOSITA would have been motivated to improve the model disclosed in Alkire by using experimental data to provide independent confirmation of the accuracy of the model as taught in Kao.” *Id.* at 30–31 (citing Ex. 1006, 1; Ex. 1003 ¶ 115). According to Petitioner, “a PHOSITA would have been motivated to combine the teachings of Kao with those of Alkire in order to increase the predictive capability of Alkire’s model to better drive process development and reactor design to improve throughput and yield while avoiding costly trial and error.” *Id.* at 31 (citing Ex. 1003 ¶ 116).

Petitioner also contends that “both Alkire and Kao disclose the known technique of modeling a plasma etching reaction between a gas-phase and substrate,” and “Kao further teaches measuring the etch rate profile of the substrate and using that etch rate data to calculate a surface reaction rate constant by performing a best-fit calculation on the etch rate data.” Pet. 31 (citing Ex. 1003 ¶ 117; Ex. 1006, 3–5). Petitioner contends that “Alkire and Kao are both directed to plasma etching reactors for manufacturing semiconductor devices and address non-uniformity in semiconductor plasma etching.” *Id.* at 32 (citing Ex. 1005, 1–2, Fig. 1; Ex. 1006, 1–2, Fig. 1; Ex. 1003 ¶ 119). Petitioner further contends that “Kao teaches that its experiments were intended to build upon the earlier work of Alkire in analyzing the use of a barrel plasma etcher to etch a film in an ashing model.” *Id.* (citing Ex. 1006, 1; Ex. 1003 ¶ 119).

Patent Owner argues that “[i]t would not have been obvious for a PHOSITA to combine Alkire with the experimental measurement of reaction rate and the use of that data in modeling as taught by Kao.” PO Resp. 6.

Patent Owner argues that “Kao emphasizes solving his model for the radius of the reactor, which is completely different from the model of Alkire, which solves for the radius of the wafer.” *Id.* Patent Owner argues that “[t]he twelve distinct etch rate measurements plotted in Figures 8 through 11 of Kao are not symmetrical across the wafer” and a PHOSITA would not use these measurements “due to the lack of symmetry for analysis of a plasma etching model to the plasma etching techniques and model of Alkire.” *Id.* at 7.

Patent Owner further argues that “Alkire specifically teaches away from the use of ‘purely empirical programs of development’ (Ex. 1005 at 1), which would teach away from the use of the etch rate data disclosed by Kao.” PO Resp. 9. According to Patent Owner, “Alkire’s statement that ‘purely empirical programs of development can be time consuming’ does criticize, discredit, or disparage the use of empirical data to improve the fabrication of a device.” *Id.* Patent Owner also argues that Kao “emphasizes that ‘the model predicts a larger effect of pressure on etch rate than observed,’ which confirms incompatibility to discredit or discourage investigation,” and “admits that ‘the pressure dependence of k_i is unknown and further work is warranted’ tacitly acknowledging that a PHOSITA could not rely on his models or data and further discredits or discourages investigation.” *Id.* at 9–10 (internal citation omitted).

Patent Owner additionally argues that “a PHOSITA would never use the actual experimental data or related techniques reported by Kao in combination with any modeling technique or with any other re[a]ctor design and related process” because “Kao was etching wafers in a tragically deficient geometry using a feed gas mixture known to generate a complex

product composition that shifts widely responsive to variations in flow, pressure, and electrical discharge parameters.” PO Resp. 14. Patent Owner argues that “Kao did not measure chemical composition or *any* products of his complex plasma chemistry, the identity, relative concentrations, and spatial distributions of species interacting with his silicon wafers were unknown,” and “[a]ccordingly, a PHOSITA could not combine the etching data from Kao with Alkire or any other reference in view of established knowledge that Kao’s chemistries and reactor design would yield a wide range of variation.” *Id.* at 16.

Based on our review of the record, we find that Petitioner has established that a PHOSITA would have had reason to combine the teachings of Alkire and Kao to achieve the claimed subject matter. Alkire discloses that the mathematical model developed therein “represents a simplified view by virtue of several assumptions,” but “can serve as a basis for studying more complex systems.” Ex. 1005, 8. Alkire also states that “[e]xperimental work aimed at testing the model predictions is currently in progress in our laboratory.” *Id.* Kao identifies Alkire as one of “[s]everal papers [that] have been published which discuss the problem of etch nonuniformities,” noting that Alkire “examined the nonuniform stripping of photoresist with O₂ in a barrel reactor,” which “results in a depletion of the etching species across the wafer, thus causing nonuniform etching.” Ex. 1006, 1. Kao goes on to present “the results of a series of experiments aimed at quantifying the dependencies of etch uniformity on process parameters.” *Id.* In this regard, we credit Dr. Graves’s testimony that

[o]ne of ordinary skill in the art would have understood that one could, and would have been motivated to, improve the theoretical model of Alkire with the use of actual experimental data as

disclosed in Kao. Kao specifically discusses Alkire, and discloses that while Alkire provides a robust model for the reaction between a gas phase etchant and a substrate film, no experimental data to support or inform the model was provided. See Ex. 1006 at p. 1 (discussing the model of Alkire and recognizing that “only model results were given with no experimental data”). The use of actual experimental data to extract the surface reaction rate constant would provide independent confirmation of the accuracy of Alkire’s model. A person of ordinary skill in the art would have been motivated to test and validate the model of Alkire with actual data, as taught in Kao.

Ex. 1003 ¶ 115.

We have considered Patent Owner’s arguments to the contrary and do not agree with them for the following reasons. Patent Owner contends that Alkire and Kao solve for different radii using different models, i.e., Alkire solves for the radius of the wafer and Kao solves for the radius of the reactor. PO Resp. 6. Petitioner, however, shows that Kao’s Figure 8 “teaches three sets of measurements (circles, squares, and triangles) taken at twelve distinct positions across each wafer.” Reply 18 (citing Ex. 1003 ¶ 143; Ex. 1006, 5). With respect to Figure 8, Kao explains that the data of Figure 3 “were used to determine the set of three constants,” and that Figure 8 shows “[o]bserved etch rates (data points) vs. predicted etch rates (lines) . . . for the single wafer case at three different flow rates.” Ex. 1006, 5. Kao explains that the etch rate profiles shown in Figure 3 were the result of experiments involving “the etching of a single wafer at a time,” with the wafer “placed in the center radial location” of the reactor. *Id.* at 2. We also credit Dr. Graves’s testimony that “[t]he caption below Figure 8 teaches that the x-axis represents the position across the wafer at which each data point was taken,” and that “[t]hese etch rate data points were used to determine the

rate constants disclosed in Kao, including the surface reaction rate constant, k_e .” Ex. 1024 ¶ 24 (citing Ex. 1006, 5; Ex. 1003 ¶ 143).

Patent Owner also contends that “[t]he twelve distinct etch rate measurements plotted in Figures 8 through 11 of Kao are not symmetrical across the wafer as shown,” and could not be used “for analysis of a plasma etching model to the plasma etching techniques and model of Alkire” (PO Resp. 7), but does not provide sufficient analysis or objective evidence demonstrating why symmetry is required. In particular, we note that Patent Owner states that it has “supplemented” its Patent Owner Response with the Flamm Declaration (*id.* at 2, 13), but does not provide any citations to or discussion of the Flamm Declaration in its Response. It is improper to incorporate by reference arguments from one document into another. 37 C.F.R. § 42.6(a)(3); *see also DeSilva v. DiLeonardi*, 181 F.3d 865, 866–67 (7th Cir. 1999) (“A brief must make all arguments accessible to the judges, rather than ask them to play archaeologist with the record.”); *Cisco Sys., Inc. v. C-Cation Techs., LLC*, Case IPR2014-00454, slip op. at 7–10 (PTAB August 29, 2014) (Paper 12) (informative) (discussing incorporation by reference).

Nevertheless, we have reviewed the Flamm Declaration and determine that it is virtually identical to Patent Owner’s arguments as they appear in the Patent Owner Response, and does not provide any additional explanation or objective evidence in support of those arguments. *See Ashland Oil, Inc. v. Delta Resins & Refractories, Inc.*, 776 F.2d 281, 294 (Fed. Cir. 1985) (stating a lack of objective support for an expert opinion “may render the testimony of little probative value in [a patentability] determination”). In contrast, Dr. Graves persuasively testifies that “the

claims of the '849 Patent do not have a symmetry requirement, and the specification of the '849 Patent does not disclose or suggest that symmetry is relevant to the disclosed methods.” Ex. 1024 ¶ 25.

Next, we do not agree with Patent Owner that Alkire “teach[es] away from the use of etch rate data as disclosed in Kao.” PO Resp. 9. We credit Dr. Graves’s testimony that

Alkire encourages testing and validating a model with empirical data, as does Kao, and describes an ongoing effort to do so, stating that “[e]xperimental work aimed at testing the model predictions is currently in progress in our laboratory.” Ex. 100[5] at 8. In addition, I do not see any criticism in Alkire of empirical programs such as Kao’s. At most, Alkire merely acknowledges what was well known to a PHOSITA: that “it is invariably difficult to translate successful experience with one system to a new system on the basis of intuition alone” and “purely empirical programs of development can be time consuming.” Ex. 1005 at 1. Accordingly, Alkire proposed using mathematical models “to assist in organizing scientific concepts into strategies for engineering design” (*id.* at 8), but did not eschew validating, testing, and improving a model with experimental data. Rather, Alkire expressly stated that his laboratory would undertake experimental work to test his model. Ex. 100[5] at 8.

Ex. 1024 ¶ 33; *see also In re Fulton*, 391 F.3d 1195, 1201 (Fed. Cir. 2004) (“The prior art’s mere disclosure of more than one alternative does not constitute a teaching away from any of these alternatives because such disclosure does not criticize, discredit, or otherwise discourage the” claimed solution.). We also find persuasive Petitioner’s argument that “Kao teaches that the use of empirical data in testing and validating a mathematical model can reveal areas for improvement in the model and better inform reactor design,” and thus “the alleged deficiencies in the accuracy of Kao” would not discourage a PHOSITA from using experimental data to test and validate

its mathematical model. Reply 24–25; *see also* Ex. 1003 ¶ 116 (Dr. Graves testifying that a PHOSITA “would also have been motivated to combine the teachings of Kao with Alkire in order to increase the predictive capability of Alkire’s model to better drive process development and reactor design to improve throughput and yield while avoiding costly trial and error.”).

Lastly, we do not agree with Patent Owner that a PHOSITA would not use Kao’s “actual experimental data or related techniques” with “any modeling technique or with any other re[a]ctor design and related process” and, therefore, would not combine Alkire and Kao as proposed by Petitioner. PO Resp. 14. As Petitioner reiterates in its Reply, it has “never suggested incorporating Kao’s model or data into the model of Alkire,” but instead has “consistently argued that a PHOSITA would have been motivated to combine the model of Alkire with the specific teachings of Kao.” Reply 26; Ex. 1024 ¶ 34; *see also* Reply 18 (A “PHOSITA would have been motivated to combine the mathematical model of Alkire with Kao’s teaching to use empirical etch rate data to validate and test a mathematical model and to use uniformity values to adjust etching parameters.”); Pet. 30–31 (“A PHOSITA would have been motivated to improve the model disclosed in Alkire by using experimental data to provide independent confirmation of the accuracy of the model as taught by Kao.”); *id.* at 45 (A PHOSITA “would find it obvious to use the empirical analysis of Kao in the similar plasma etching reaction of Alkire to test and validate the model of Alkire.”); Ex. 1003 ¶ 136 (The combination of Alkire and Kao “would connect the purely mathematical model of Alkire to empirical data for the etch rate data to extract the surface reaction rate for defined process conditions to test, validate, and improve Alkire’s model.”).

Moreover, Patent Owner's arguments regarding the alleged deficiencies of Kao's model are unsupported by the evidence of record. For example, Patent Owner argues that "Kao was etching wafers in a tragically deficient geometry using a feed gas mixture known to generate a complex product composition that shifts widely responsive to variations in flow, pressure, and electrical discharge parameters" but does not provide adequate explanation or objective evidence demonstrating why a PHOSITA would understand Kao in that way. PO Resp. 14. We do not find Patent Owner's conclusory arguments to be persuasive. Instead, we credit Dr. Graves's testimony that Kao

was the first publication to model two-dimensional (radial-azimuthal) etch chemistry profiles in a plasma reactor. This allowed Kao to predict non-uniform profiles of reactant and etch rate on a single wafer and compare them to measurements. These results offered valuable insights into reactant transport and concentration spatial non-uniformities as a function of gas pressure and flowrate. The type of reactor Kao used in the study admittedly had limitations, but the key aspect of the paper was in its coupling of a new mathematical analysis of the process with etch rate measurements. Although Kao's model results in only approximately matched experimental measurements, that is true of all models of plasma etch reactors, even by the standard of the present literature.

Ex. 1024 ¶ 29 (internal citations omitted). Dr. Graves also notes that "Dr. Flamm himself has acknowledged the utility of modeling despite its inability to perfectly describe a system," and that although the authors of a reference cited by Patent Owner (Ex. 2002) "acknowledged '[a]n important assumption' in their model and 'some discrepancy' between predicted and measured values (Ex. 2002 at Abstract), they reported their model was 'able

to predict the trend of the experimental results’ (Ex. 2002 at 226).” *Id.* (citing Ex. 2001, 1522).

2. *Claim 1*

Petitioner contends that the combination of Alkire and Kao discloses or suggests all of the elements of claim 1. Pet. 34–47. The parties focus their arguments on two elements in claim 1: (1) “etching said top film surface to define a relatively non-uniform etching profile on said film, and defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile on said substrate;” and (2) “extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant in the fabrication of a device.” As to the other elements of claim 1, we have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that those elements are disclosed and arranged as in the claim. Pet. 34–37. We address the arguments regarding the disputed elements in turn.

- a. *etching said top film surface to define a relatively non-uniform etching profile on said film, and defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile on said substrate*

Petitioner contends that Alkire discloses “etching the top surface to define a relatively non-uniform etching profile” because it teaches that “the rate of film removal depends on the concentration distribution in the interwafer gap” and “[t]he etch rate is highest on the periphery of the wafer.” Pet. 38 (quoting Ex. 1005, 2). Petitioner contends that Alkire discloses “defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile”

because “[t]he thickness of etchable material as a function of time disclosed in Alkire is etch rate data, where the change in $h(r,t)$ as a function of time is an etch rate at a spatial coordinate (given by r in cylindrical coordinates) over time (t).” *Id.* at 39 (citing Ex. 1005, 2).

Petitioner acknowledges that “Alkire does not explicitly disclose measuring the etch rate data at any spatial coordinates.” Pet. 39. In that regard, Petitioner contends that “Kao teaches measuring the etch rate data for an etching reaction between a gas-phase plasma and a substrate at twelve spatial coordinates,” and “describes measuring the etch depths ‘at various stages of the experimental process.’” *Id.* (citing Ex. 1006, 1–2). According to Petitioner, “[a]pplying Kao’s empirical etch rate measurement at twelve spatial coordinates for analysis of a plasma etching model to the plasma etching techniques and model of Alkire would allow a person having ordinary skill in the art to use empirical data to improve the Alkire model for plasma etching.” *Id.* at 41 (citing Ex. 1003 ¶ 136).

Patent Owner argues that “Alkire merely disclosed a uniform etching profile, which was facing another uniform etching profile, each of which is flat, although there is some curvature at the edges, which exists for any film material.” PO Resp. 21. Patent Owner also argues that “[n]o etch rate data, including the etch rate and spatial coordinate, were disclosed by Alkire.” *Id.* Patent Owner argues that “a PHOSITA would not combine Kao with Alkire,” and that “Kao is riddled with deficiencies including the absence of meaningful data and no operable model for the analysis of non-uniformities.” *Id.* at 22. Patent Owner argues that a PHOSITA would not use Kao’s experimental data “in combination with any other modeling technique or with any other reactor design related process” and “would not

be able to extract any extensible etch rate from profile or etch rate data measured” in Kao. *Id.* at 22–23. According to Patent Owner, “a PHOSITA would recognize that the validity of Kao’s data is highly suspect.” *Id.* at 23.

Petitioner replies that “Alkire discloses that ‘the etch rate is highest on the periphery of the wafer,’ thereby expressly teaching that the etch rate across the wafer is non-uniform.” Reply 6–7 (citing Ex. 1005, 2). Petitioner asserts that “Alkire discloses an equation for the thickness of the film as a function of the radial distance and time,” which “provides the thickness of the film at a given spatial coordinate at a given time” and therefore defines etch rate data. *Id.* at 11 (citing Ex. 1003 ¶ 133; Ex. 1005, 2). Petitioner further asserts that Patent Owner’s arguments that Kao is “deficient” are unsupported and unexplained. *Id.* at 22–24.

Based on our review of the record, we find Petitioner’s argument that the combination of Alkire and Kao discloses the “etching said top film surface to define a relatively non-uniform etching profile on said film, and defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile on said substrate” limitation of claim 1 to be persuasive. Pet. 38–41; Reply 5–11, 22–24; Ex. 1003 ¶¶ 92, 130–136; Ex. 1024 ¶¶ 12–17, 28–30. Alkire teaches that Figure 2, which is “not drawn to scale, is a schematic representation of the radially symmetric cell formed by two wafers facing each other,” and, “[p]rior to the onset of etching, a film of uniform thickness exists on the wafer surfaces.” Ex. 1005, 2. Alkire further teaches that “the etch rate is highest on the periphery of the wafer” and “[f]ilm in this region thus clears first.” *Id.* Alkire explains that “Figure 2 illustrates the situation

part way through the process, where film has been cleared entirely from the outer portion of the wafer, while the inner region is yet to clear.” *Id.*

Moreover, Dr. Graves testifies that “a profile that tapers at the edges, as shown in Alkire Figure 2, is by definition non-uniform” and that “Alkire makes clear that Figure 2 is meant to represent a diffusion-limited regime in which etching occurs at variable rates along the wafer radius, the highest rate being at the wafer’s edge.” Ex. 1024 ¶ 14. We further credit Dr. Graves’s testimony that

a person of ordinary skill at the time of the alleged invention considering Alkire would be aware not only of Figure 2 but also of Figure 6, which also shows a non-uniform thickness profile:

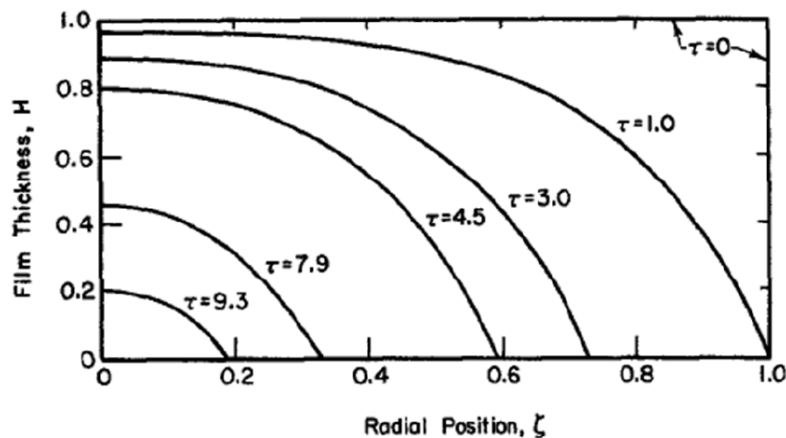


Fig. 6. Film thickness distribution at different cumulative etch times τ ($\alpha = -1, \beta = 10, \gamma = 0, \phi_o^2 = 25$ and total etch time $\tau_o = 10.1$).

Figure 6 shows the “film thickness distribution” as a function of radial position on the wafer for five different etch times ($\tau = 1.0$ through 9.3). Ex. 1005 at 6. The film initially has a uniform thickness (shown by the horizontal and vertical line segments labeled “ $\tau = 0$ ”). During etching, as the radial position on the wafer increases from the center of the wafer (0 on the ζ -axis) toward the edge of the wafer (positive values on the ζ -axis), the thickness of the film decreases as shown by the five curves corresponding to five different etch times. *Id.* Each curve represents the non-uniform etching profile on the film at a

particular time. *Id.* at 2, 6; *cf.* Ex. 1001 at 3:66–4:9, Fig. 1A; Ex. 1003 ¶ 92. Accordingly, Alkire teaches a non-uniform film and etch profile, contrary to Dr. Flamm’s statements.

Ex. 1024 ¶ 15. That a PHOSITA would understand Alkire to be teaching a non-uniform etch profile is further confirmed by Kao, which identifies Alkire as a published paper that discusses “the problem of etch nonuniformities,” and recognizes that Alkire “examined the *nonuniform* stripping of photoresist with O₂ in a barrel reactor” wherein the transport of etching species to the wafer “relies predominately on diffusion, with little convective influences,” which “results in a depletion of the etching species across the wafer, thus causing *nonuniform* etching.” Ex. 1006, 1 (emphasis added). Accordingly, the evidence of record supports Petitioner’s contention that Alkire discloses a non-uniform etch profile.

We also agree with Petitioner that “Alkire discloses ‘defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said relatively non-uniform etching profile on said substrate.’” Pet. 39. In particular, Alkire teaches that “[d]uring etching, the thickness of the etchable material left at a certain location and time will be given by

$$h(r, t) = h_o - \int_0^t \frac{k_2}{x} c(r, t) dt \quad [1]$$

The concentration distribution $c(r, t)$ varies with time during the etching process and is calculated by application of transport laws to the movement of etchant species.” Ex. 1005, 2. Dr. Graves explains that “the thickness of etchable material as a function of time disclosed is etch rate data, where $h(r, t)$ is an etch rate at a spatial coordinate (given by r in cylindrical coordinates) and a time (t).” Ex. 1003 ¶ 133. In contrast, Patent Owner’s

argument that “[n]o etch rate data, including the etch rate and spatial coordinate, were disclosed by Alkire” is conclusory and not supported by any evidence of record. *See* PO Resp. 21.

We further find that “Kao teaches measuring the etch rate data for an etching reaction between a gas-phase plasma and a substrate at twelve spatial coordinates” as Petitioner asserts. Pet. 39 (citing Ex. 1006, 1–2). As Dr. Graves explains:

Kao describes measuring the etch depths “at various stages of the experimental process” to conduct the experiments. [Ex. 1006, 2]. “The etch depths were measured using a Sloan Dektak surface profile measuring system.” *Id.* “Etch rates were calculated as etch depth of silicon divided by etch time.” *Id.* Kao charts the etch rate as a function of location, as well as “the degree of nonuniformity across each wafer” for a variety of etch parameters, in several plots . . .

Ex. 1003 ¶ 135 (citing Ex. 1006, Figs. 3–6). We also credit Dr. Graves’s testimony that

[i]t would have been understood by one of ordinary skill that applying Kao’s empirical etch rate measurement at twelve distinct spatial coordinates for analysis of a plasma etching model to the plasma etching techniques and model of Alkire to validate and test Alkire’s model for plasma etching with empirical data. Kao explains that it was intended to improve on existing models, including Alkire, by using experimental data to extract reaction rate constants to quantify and validate the model. One of ordinary skill in the art would have recognized that one could refine the method of Alkire in view of Kao by conducting experiments to determine etch rate data in Alkire’s reactor and extracting a surface reaction rate constant from that data, as taught by Kao. This combination would connect the purely mathematical model of Alkire to empirical data for the etch rate data to extract the surface reaction rate for defined process conditions to test, validate, and improve Alkire’s model.

Id. ¶ 136 (internal citations omitted).

Furthermore, as set forth above, we disagree with Patent Owner's contention that a PHOSITA would not combine Kao with Alkire. See supra Section II.E.1. Additionally, with respect to Patent Owner's argument that a PHOSITA would not use Kao's experimental data in Alkire's model, we note that an obviousness analysis does not require bodily incorporation of one reference into another. *Allied Erecting & Dismantling Co. v. Genesis Attachments, LLC*, 825 F.3d 1373, 1381 (Fed. Cir. 2016) ("[I]t is not necessary that [the cited references] be physically combinable to render obvious [the challenged patent]. The test for obviousness is not whether the features of a secondary reference may be bodily incorporated into the structure of the primary reference. . . ." (internal quotations omitted)). Rather, the test for obviousness is "whether 'a skilled artisan would have been motivated to combine the teachings of the prior art references to achieve the claimed invention.'" *Id.* As Petitioner reiterates in its Reply, it is not arguing that Kao's model or data would be incorporated into the model of Alkire, but "that a PHOSITA would have been motivated to combine the model of Alkire with the specific teachings of Kao" in order to test and validate Alkire's theoretical model. Reply 26; see Pet. 30–32; Ex. 1003 ¶¶ 114–119; Ex. 1024 ¶ 34. We also find, for the reasons set forth above, that Patent Owner's arguments regarding the alleged deficiencies of Kao's model are unsupported by the evidence of record. See supra Section II.E.1.

Accordingly, we determine that the combined teachings of Alkire and Kao disclose "etching said top film surface to define a relatively non-uniform etching profile on said film, and defining etch rate data comprising an etch rate and a spatial coordinate which defines a position within said

relatively non-uniform etching profile on said substrate” as recited in claim 1.

- b. *extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant in the fabrication of a device*

Petitioner contends that “Alkire in view of Kao discloses ‘extracting a surface reaction rate constant from said etch rate data’” because “[b]oth Alkire and Kao disclose a ‘reaction rate constant for the surface etching reaction’ (k_2 in Alkire, k_e in Kao) that is a temperature-dependent reaction rate constant for the chemical reaction between a gas phase etchant and the surface of an etchable material.” Pet. 42 (citing Ex. 1005, 3–4; Ex. 1006, 4, 7). Petitioner contends that Kao teaches an etching reaction model “that describes ‘the rate of reaction of the gas phase . . . of each major component’ as separate equations using the reaction rate constant for ‘the dissociation of CF_4 ,’ the ‘loss reaction rate constant,’ and the reaction ‘rate constant for the surface etching reaction.’” *Id.* (citing Ex. 1006, 4) (emphasis omitted).

Petitioner also contends that “Kao further discloses using the experimentally measured-etch rate data to extract the reaction rate constants, including the surface reaction rate constant” and “discloses equations for ‘the rate of the reaction in the gas phase . . . of each major component’ that are dependent on the disclosed reaction rate constants.” *Id.* at 43 (citing Ex. 1006, 4).

Petitioner further contends that “Alkire and Kao teach ‘using said surface reaction rate constant in the fabrication of the device.’” Pet. 45. Petitioner contends that “Alkire teaches the use of a mathematical model using an etch rate constant to analyze the effect of etching parameters ‘on etch uniformity, overetch exposure, and throughput [and to identify] optima.’” *Id.* (quoting Ex. 1005, 8). Petitioner contends that Alkire teaches

using this analysis “to find ‘[r]egions of operating conditions that permit etch uniformity within specified tolerances,’ and to calculate ‘optimum settings for interwafer spacing and reactor pressure to achieve maximum throughput’ in fabricating devices in a plasma etcher.” *Id.* at 45–46 (quoting Ex. 1005, 1). Petitioner also contends that “Kao’s experimental and modeling work, including the extraction of a surface reaction rate constant, is directed at ameliorating a serious problem in device fabrication: the negative effect of intrawafer nonuniformities on circuit yields.” *Id.* at 46 (citing Ex. 1006, 1; Ex. 1003 ¶ 146). According to Petitioner, it would have been obvious to a PHOSITA “to use Kao’s surface reaction rate constant in the fabrication of a device in order to decrease intrawafer nonuniformities and improve circuit yields.” *Id.* (citing Ex. 1003 ¶ 146).

Patent Owner makes three arguments in response to Petitioner’s contentions. First, Patent Owner argues that “Alkire is silent on extracting a surface reaction rate constant from the etch rate data, and using the surface reaction rate constant in the fabrication of a device.” PO Resp. 24. Petitioner, however, does not rely on Alkire as disclosing the extraction of the surface reaction rate constant from the etch rate data. *See, e.g.*, Pet. 45 (“A PHOSITA would find it obvious to use the teaching of Kao of extracting the surface reaction rate constant from the experimental etch rate data to improve Alkire’s theoretical model.”). Petitioner relies on Alkire with respect to its mathematical model for the etch rate reaction, and its disclosure of a reaction rate constant for the surface etching reaction. *See id.* at 42. Petitioner contends that Kao “discloses using the experimentally measured-etch data to extract reaction rate constants, including the surface reaction rate constant.” *Id.* at 43. Moreover, Patent Owner’s arguments in

this regard generally attack Alkire individually, rather than in combination with Kao. PO Resp. 24. Nonobviousness cannot be established by attacking the references individually when the ground of unpatentability is predicated upon a combination of prior art disclosures. *See In re Merck & Co., Inc.*, 800 F.2d 1091, 1097 (Fed. Cir. 1986); *see also In re Keller*, 642 F.2d 413, 426 (CCPA 1981) (“But one cannot show non-obviousness by attaching references individually where, as here, the [grounds of unpatentability] are based on combinations of references.”).

Second, Patent Owner argues that “Alkire’s model lacks any temperature dependence, express or otherwise, to extract the claimed surface reaction rate constant, which is temperature dependent.” PO Resp. 5. Patent Owner argues that “Alkire assumes ‘operation is isothermal,’” “excludes any temperature dependence from his model,” and, “[a]t most, Alkire mentions in his conclusion section that because ‘chemical reactions are affected by temperature, the rate constant (k_2) may not be a constant.’” *Id.* Dr. Graves convincingly explains, however, that Patent Owner bases this argument on a partial quote in Alkire, and that

Alkire’s full condition (“Operation is isothermal with no spatial variations of diffusivity or reaction rate constants”) is correctly understood as a simplifying assumption that there is no spatial (or temporal) temperature variation in Alkire’s barrel etcher *at the particular temperature selected for the single etch operation simulated by the model* (which Alkire sets at 400K, *see* Ex. 1005 at 6, Table I). In other words, once the temperature for an etch operation at 400K is set, Alkire assumes that the temperature everywhere in the diffusion region of the reactor remains 400K throughout the duration of the etch operation. . . . Alkire expressly acknowledges that this assumption is “a simplified view” given the real-world temperature dependence of chemical reactions, including the etching reaction at the surface of an etchable film on a wafer: “Since chemical reactions are affected

by temperature, the reaction rate constant (k_2) may not be constant.” Ex. 1005 at 8.

Ex. 1024 ¶¶ 19–20. We also credit Dr. Graves’s testimony that “[i]sothermal operation during a single etch operation is consistent with a surface reaction rate constant, and an overall model, that is temperature dependent, as Alkire’s model shows,” and “[t]he surface reaction rate constant will in general depend on temperature, but other factors in the model also depend on temperature,” and, therefore, temperature is “one of the parameters used in extracting the surface reaction rate constant from the overall model, as in the ’849 Patent.” *Id.* ¶ 21.

We also find persuasive Petitioner’s argument that “[t]he fact that the temperature does not change during etching (i.e. isothermal operation) says nothing about whether the surface reaction rate constant is dependent on the temperature at which the etch is performed.” Reply 13 (citing Ex. 1024 ¶ 22). As Petitioner notes, the ’849 patent “states that the plasma etching of the disclosed invention ‘preferably . . . occurs isothermally at temperature T_1 ’” and also “discloses a model for solving the surface reaction rate constant that assumes a constant temperature, T , during the etch process (i.e. isothermal operation).” *Id.* (citing Ex. 1001, 5:16–20, 5:62–6:61). In this regard, we credit Dr. Graves’s testimony that because the ’849 patent teaches that the steps of the claimed method “can be repeated ‘at different temperatures $T_2, T_3 . . . T_n$ to calculate additional reaction rate constants,’” “the ’849 patent itself teaches that a temperature-dependent surface reaction rate constant can be determined from etch operations that are themselves isothermal.” Ex. 1024 ¶ 22 (quoting Ex. 1001, 6:63–64).

Third, Patent Owner argues that “Petitioner ‘misinterprets the significance of Kao’s k_e , which is not a determined reaction rate constant’

but instead ‘arises as one of three empirical fitting parameters, each of which alone or in combination, fails to reasonably fit Kao’s experimental results’” (PO Resp. 13 (quoting Prelim. Resp. 7)), and that “[n]o PHOSITA would consider Kao’s data, modeling, or associated techniques useful for anything, never mind a surface reaction rate constant that could be useful for the fabrication of a device” (*id.* at 26). As Petitioner notes, however, Patent Owner offers no “explanation for [its] argument that the surface reaction rate constant cannot be determined with empirical fitting parameters” such as Kao’s k_e . Reply 21.

In contrast, Petitioner persuasively argues, with supporting testimony from Dr. Graves, that “the 849 Patent expressly teaches ‘a more robust procedure’ to solve for the surface reaction rate constant is to use empirical fitting parameters to fit the constant to the measured rate data,” which “is the exact solution used in Kao.” *Id.* at 22 (citing Ex. 1003 ¶¶ 58–61, 138–144; Ex. 1024 ¶¶ 26–29; Pet. 6–13, 42–47). We also credit Dr. Graves’s testimony that

[a]lthough Kao reported some difficulties in fitting his model to the data in some instances, the fit is rather good in other instances. For example, as shown in Figure 8 below, Kao’s model fits the etch rate data at the two lower flow rates (60 sccm and 80 sccm) quite well:

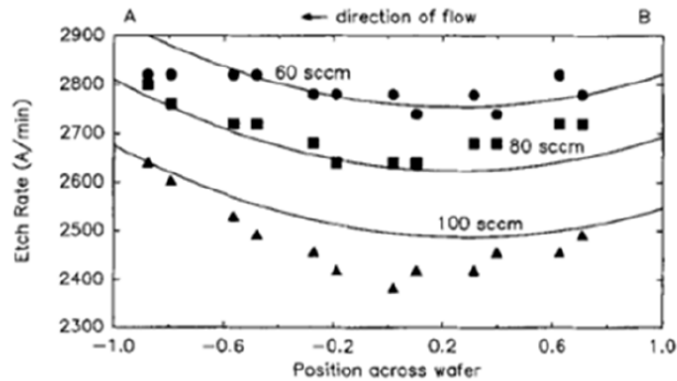


Fig. 8. Model (curves) vs. data (points) for the effect of flow rate on etch rate. Pressure = 150 mtorr, temperature = 70°C, RF power = 750W.

Ex. 1006 at 5–6. Moreover, a PHOSITA would understand that because chemical reaction systems, including plasma etchers, are so complex, modeling chemical reactions necessarily involves simplifying assumptions and approximations, as Kao, Alkire, and the '849 Patent all acknowledged, and therefore typically result in only an approximate fit to measured data. Ex. 1005 at 2; Ex. 1006 at 3; Ex. 1001 at 3:17–41. Such models are nevertheless useful in providing insight into the underlying chemical and physical processes at work in the studied system.

Ex. 1024 ¶ 27.

Accordingly, we determine that the combined teachings of Alkire and Kao disclose “extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant in the fabrication of a device” as required by claim 1.

c. *Conclusion*

After considering Petitioner’s and Patent Owner’s positions, as well as their supporting evidence,⁹ we determine that Petitioner has shown, by a

⁹ Patent Owner did not introduce any evidence of objective indicia of nonobviousness.

preponderance of the evidence that independent claim 1 would have been obvious over the combined teachings of Alkire and Kao.

3. *Claims 2–9 and 14*

Claims 2–9 and 14 depend, directly or indirectly, from independent claim 1. Patent Owner does not address separately Petitioner’s explanations and supporting evidence as to how the teachings of Alkire and Kao account for all of the limitations of these dependent claims. *See generally* PO Resp. We have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that the combined teachings of Alkire and Kao account for all the limitations recited in claims 2–9 and 14. Pet. 61–70; Ex. 1003 ¶¶ 180–197.

4. *Claims 10–13 and 15–19*

The limitations of independent claim 10 are substantially similar to those in independent claim 1. *Compare* Ex. 1001, 18:4–18 *with id.* at 17:35–50. As a result, Petitioner relies on the same disclosures in Alkire and Kao and makes similar arguments with respect to the elements of claim 10 as it does with respect to the elements of claim 1. Pet. 48–50. Patent Owner argues that the combination of Alkire and Kao does not disclose “extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant in designing a second plasma etching apparatus” as recited in claim 10. PO Resp. 26. In particular, Patent Owner reiterates its argument that “no etch rate data or use of the surface reaction rate constant is shown or suggested by Alkire alone, or in combination with Kao,” and that “[n]o PHOSITA would even think about using any of the data from Kao that teaches non-uniformities in etch rate, leading to Kao’s own notation that: ‘further work is warranted.’” *Id.* at 27 (quoting Ex. 1006,

6). For the reasons set forth above with respect to claim 1, we do not find Patent Owner's arguments to be persuasive. *See supra* Sections II.E.1, II.E.2. Accordingly, after considering Petitioner's and Patent Owner's positions, as well as their supporting evidence, we determine that Petitioner has shown, by a preponderance of the evidence that independent claim 10 would have been obvious over the combined teachings of Alkire and Kao.

Claims 11–13 and 14–19 depend, directly or indirectly, from independent claim 10. Patent Owner does not address separately Petitioner's explanations and supporting evidence as to how the teachings of Alkire and Kao account for all of the limitations of these dependent claims. *See generally* PO Resp. We have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that the combined teachings of Alkire and Kao account for all the limitations recited in claims 11–13 and 14–19. Pet. 61–73; Ex. 1003 ¶¶ 180–195, 198–201.

5. *Claims 20 and 21*

Petitioner contends, with supporting testimony from Dr. Graves, that the combined teachings of Alkire and Kao disclose all of the elements of independent claim 20. Pet. 50–52; Ex. 1003 ¶¶ 156–161. Patent Owner responds that the combination of Alkire and Kao does not disclose “extracting a surface reaction rate constant from said etch rate data, and using said surface reaction rate constant” as required by claim 20. PO Resp. 28. Patent Owner again argues that “Kao concludes by disclosing irregularly shaped data curves, and that ‘further work is warranted,’” and “by stating that the ‘Experimental results presented here show a large degree of nonuniformity in etching rate. . .’” *Id.* (quoting Ex. 1006, 6). Therefore,

according to Patent Owner, “[a] PHOSITA would not combine Alkire and Kao, or ever use both of them due to the nonuniformity of etching rate in Kao.” *Id.*

For the reasons set forth above, we determined that a PHOSITA would have had reason to combine the teachings of Alkire and Kao to achieve the claimed subject matter. *See supra* Section II.E.1. We also determined that the combined teachings of Alkire and Kao disclose extracting a surface reaction rate constant from etch rate data and using that surface reaction rate constant. *See supra* Section II.E.2.b. Accordingly, after considering Petitioner’s and Patent Owner’s positions, as well as their supporting evidence, we determine that Petitioner has shown, by a preponderance of the evidence that independent claim 20 would have been obvious over the combined teachings of Alkire and Kao. *See* Pet. 50–52; Ex. 1003 ¶¶ 156–161.

Claim 21 depends from claims 1, 10, or 20. Ex. 1001, 18:60–62. Patent Owner does not address separately Petitioner’s explanations and supporting evidence as to how the teachings of Alkire and Kao account for all of the limitations of dependent claim 21. *See generally* PO Resp. We have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that the combined teachings of Alkire and Kao account for all the limitations recited in claim 21. Pet. 73–75; Ex. 1003 ¶¶ 202–206.

6. *Claims 22–25*

Petitioner contends, with supporting testimony from Dr. Graves, that the combined teachings of Alkire and Kao disclose all of the elements of independent claim 22. Pet. 52–59; Ex. 1003 ¶¶ 162–173. For example,

Petitioner contends that Kao teaches the “defining etching parameters providing said uniformity value” element of claim 22 because “Kao discloses in figure 3 a uniformity value greater than 95% for all measured values at a gas flow of 60 sccm at a variety of wafer positions within the reactor” and that “this uniformity value was achieved using the etching parameters of a ‘reactor pressure of 150 mtorr, [and] an electrode temperature of 70°C.’” Pet. 54–55 (citing Ex. 1006, 2). Petitioner further contends that Kao “discloses a series of experiments defining etch parameters flow rate, reactor pressure, wafer position, and wafer loading providing a number of uniformity values,” the results of which, along with the corresponding etching parameters, are shown in Kao Figures 4, 5, and 6. *Id.* at 55 (citing Ex. 1006, 2–3).

Patent Owner makes three arguments in response to Petitioner’s contentions. First, Patent Owner argues that the combined teachings of Alkire and Kao do not disclose a method of fabricating an integrated circuit using a plasma etch apparatus as recited in claim 22, because “Alkire merely discloses a ‘mathematical model’” and “[a] PHOSITA would not use the techniques disclosed by Alkire to manufacture any integrated circuit and, even if Alkire’s techniques were used, no integrated circuit could be manufactured.” PO Resp. 28–29. Patent Owner further argues that “Kao produces data, models, and techniques that are not consistent, and plagued with problems, as described above” and, “[a]ccordingly, a PHOSITA would not use either technique and would not combine Kao and Alkire for the reasons noted above.” *Id.* at 29. We have already considered Patent Owner’s arguments regarding Kao’s alleged problems, as well as Patent

Owner's arguments that a PHOSITA would not combine Alkire and Kao, and did not find them to be persuasive. *See supra* Sections II.E.1, II.E.2.

We further find that Petitioner's argument that the combination of Alkire and Kao teaches fabricating an integrated circuit is supported by the evidence of record. As Petitioner notes, "Figure 2 of Kao illustrates the pattern of the device that was fabricated through the etch process disclosed in Kao," and "[t]his portion of an integrated circuit device was fabricated by etching the silicon substrate patterned with a silicon dioxide film in order to measure the etch depths of the etching process in the experiments disclosed in Kao." Pet. 35–36 (citing Ex. 1006, 1–2); *see* Reply 26–27. Moreover, Kao states that "[i]ntrawafer nonuniform etching in plasma and reactive ion etching systems is a major problem in current [integrated circuit] processing technology," "the inability to etch consistent circuits on each chip of a wafer will continue unless the causes of the bullseye effect are better understood and corrections made," and that it "presents the results of a series of experiments aimed at quantifying the dependencies of etch uniformity on process parameters." Ex. 1006, 1. Patent Owner does not address these disclosures in Kao. We also credit Dr. Graves's testimony that "[t]he mask pattern transfer by dry etching disclosed in Kao was a well-known feature of integrated circuit device fabrication, as described in a 1983 prior art treatise on Very Large Scale Integration techniques" (Ex. 1003 ¶ 126 (citing Ex. 1020, 4–6)), and that "the fabrication of a semiconductor substrate is one step in the fabrication of an integrated circuit device would have been common knowledge to a person of ordinary skill in the art in 1995" (*id.* ¶ 162).

Second, Patent Owner argues that neither Alkire nor Kao disclose “providing a uniformity value and surface reaction rate constant for an etching reaction.” PO Resp. 29. In particular, Patent Owner argues that Kao “does not teach any uniformity value by teaching ‘nonuniform etching,’ which is contrary to the claimed uniformity value.” *Id.* (citing Ex. 1006, 1). Patent Owner, however, does not provide sufficient explanation or evidence demonstrating that a PHOSITA would understand Kao in this manner. In contrast, Petitioner and Dr. Graves provide sufficient explanation supported by the evidence of record showing that Kao “discloses ‘providing a uniformity value’ based on surface reaction rate.” Pet. 53. Petitioner points to Figure 3 in Kao, which discloses “a nonuniformity value of less than 1.05 for all measured values at a gas flow of 60 sccm.” *Id.* Petitioner notes that Kao states that “[t]he relative difference between the highest and lowest etch rate across each wafer dropped from 15 to 3% as the flow rate was decreased from 100 to 60 sccm” and that “[t]his nonuniformity value is a uniformity value of greater than 95%.” *Id.* at 54 (quoting Ex. 1006, 2; citing Ex. 1003 ¶ 164). Again, Patent Owner does not address these disclosures in Kao.

Third, Patent Owner argues that neither Alkire nor Kao discloses “adjusting at least one of said etching parameters using said surface reaction rate constant to produce a selected etching rate wherein said etching rate providing an etching condition for fabrication of an integrated circuit device” limitation of claim 22. PO Resp. 29–30. Patent Owner argues that “Alkire is silent about the use” of any surface reaction rate constant, and “does not show or suggest that these process parameters can be adjusted to produce a selected etching rate.” *Id.* at 30 (citing Ex. 1005, 3). Patent Owner also argues that “Kao fails to disclose” this element of claim 22

because it “concludes by disclosing irregularly shaped data curves and expressly stating that ‘further work is warranted’” and “that the ‘[e]xperimental work presented here show a large degree of nonuniformity in etching rate.’” *Id.* at 30–31 (citing Ex. 1006, 6).

We disagree with Patent Owner. Alkire teaches that its models can be used to determine “the effect of process parameters (c_0 , P , D , k ’s) and of geometric factors (L , R_0) on etch uniformity, overetch exposure, and total etch time,” and, “[i]n particular, optimum conditions for high throughput can be identified.” Ex. 1005, 3. Alkire further states that “the efficient design and scale-up of plasma systems is usually difficult to accomplish by intuition alone,” and “[t]he use of mathematical models can assist in organizing scientific concepts into strategies for engineering design.” *Id.* at 8. Kao describes using its surface reaction rate constants to calculate model curves illustrating the effect of flow rate, pressure, wafer location, and wafer loading on etch rate, as shown in Figures 8–11. Ex. 1006, 5–6. Kao goes on to state that “[s]everal observations from this modeling-experimental study give insight into the controlling rates in this plasma etching system,” including that “decreasing flow rate enhances the etch rate,” “higher pressure resulted in higher etch rates,” and that “the location of the wafer had only a small effect on etch uniformity.” *Id.* at 6.

After considering Petitioner’s and Patent Owner’s positions and their supporting evidence, we determine that Petitioner has shown, by a preponderance of the evidence, that independent claim 22 would have been obvious over the combined teachings of Alkire and Kao. *See* Pet. 52–59; Ex. 1003 ¶¶ 162–173. Claims 23–25 depend directly from independent claim 22. Patent Owner does not address separately Petitioner’s

explanations and supporting evidence as to how the teachings of Alkire and Kao account for all of the limitations of these dependent claims. *See generally* PO Resp. We have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that the combined teachings of Alkire and Kao account for all the limitations recited in claims 23–25. Pet. 75–76; Ex. 1003 ¶¶ 207–208.

7. *Claims 26–29*

The limitations of independent claim 26 are substantially similar to those in independent claim 1, and Petitioner largely relies on the same disclosures in Alkire and Kao and makes similar arguments with respect to the elements of claim 26 as it does with respect to the elements of claim 1. Pet. 59–61. Patent Owner repeats its arguments that: (1) “Alkire does not show or suggest any etching rate data and, therefore, cannot show or suggest extracting the surface reaction rate constant for the temperature;” (2) “Kao merely disclosed curve fitting parameters, which were not constants at all, as noted;” and (3) “[a] PHOSITA would never combine these two references, or even use Kao for any meaningful process.” PO Resp. 31. We have already considered these arguments, and do not agree with them for the reasons set forth above. *See supra* Sections II.E.1, II.E.2. As to the other elements of claim 26, we have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that those elements are disclosed and arranged as in the claim. Pet. 59–61; Ex. 1003 ¶¶ 174–179.

Claims 27–29 directly depend from independent claim 26. Patent Owner does not address separately Petitioner’s explanations and supporting evidence as to how the teachings of Alkire and Kao account for all of the

limitations of these dependent claims. *See generally* PO Resp. We have reviewed the evidence and arguments presented in the Petition and find that Petitioner has shown sufficiently that the combined teachings of Alkire and Kao account for all the limitations recited in claims 27–29. Pet. 73–77; Ex. 1003 ¶¶ 202–206, 209–210.

F. Obviousness over Alkire, Kao, and Flamm

Petitioner contends that the subject matter of claims 1–29 is unpatentable under 35 U.S.C. § 103(a) over the combined teachings of Alkire, Kao, and Flamm. Pet. 32–34, 77–79. Petitioner presents this ground in the alternative to the first ground in the event that the Board adopts a construction of “surface reaction rate constant” that requires that it be defined by an Arrhenius relationship. *Id.* at 77. As set forth above, we do not construe “surface reaction rate constant” to include this requirement. *See supra* Section II.B. Furthermore, we have already determined claims 1–29 to be unpatentable under another of Petitioner’s grounds of unpatentability. Therefore, we need not reach Petitioner’s alternative challenge to claims 1–29 based on the combined teachings of Alkire, Kao, and Flamm.

III. CONCLUSION

After reviewing the record and weighing the evidence offered by both parties, we determine that Petitioner has shown, by a preponderance of the evidence, that claims 1–29 of the ’849 patent would have been obvious over the combined teachings of Alkire and Kao.

IV. ORDER

In consideration of the foregoing, it is

ORDERED that claims 1–29 of the '849 patent are determined to be *unpatentable*; 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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