IN THE UNITED STATES COURT OF APPEALS
FOR THE FEDERAL CIRCUIT

TRUSTEES OF BOSTON UNIVERSITY,
Plaintiff-Cross-Appellant

v.

EVERLIGHT ELECTRONICS CO., LTD., EVERLIGHT AMERICAS, INC., EPISTAR CORPORATION, LITE-ON INC., LITE-ON SERVICE USA, INC., LITE-ON TECHNOLOGY CORPORATION, LITE-ON TRADING USA, INC.,
Defendants-Appellants

2016-2576, -2577, -2578, -2579, -2580, -2581, -2582,
-2591, -2592, -2593, -2594, -2595

Appeal from the United States District Court for the District of Massachusetts,
Case No. 1:12-cv-11935-PBS, Hon. Patti B. Saris, Chief District Judge

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BRIEF OF DEFENDANTS-APPELLANTS EVERLIGHT AND LITE-ON

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December 27, 2016

CERTIFICATE OF INTEREST

Counsel for Everlight Americas, Inc., Everlight Electronics Co., Ltd., Lite-On Inc., Lite-On Service USA, Inc., Lite-On Technology Corp., and Lite-On Trading USA, Inc. certifies the following:

1. The full name of every party or amicus represented by me is:

   Everlight Americas, Inc., Everlight Electronics Co., Ltd., Lite-On Inc., Lite-On Service USA, Inc., Lite-On Technology Corp., Lite-On Trading USA, Inc.

2. The name of the real party in interest (if the party named in the caption is not the real party in interest) represented by me is:

   Everlight Americas, Inc., Everlight Electronics Co., Ltd., Lite-On Inc., Lite-On Service USA, Inc., Lite-On Technology Corp., Lite-On Trading USA, Inc.

3. All parent corporations and any publicly held companies that own 10 percent or more of the stock of the party or amicus curiae represented by me are:

   Everlight Electronics Co., Ltd. is a parent corporation that owns 10 percent or more of Everlight America's, Inc.'s stock. Everlight Electronics, Co., Ltd. is publicly listed on the Taiwan Stock Exchange. Lite-On Technology Corp. is a parent corporation that owns 10 percent or more of Lite-On Inc., Lite-On Service USA, Inc., and Lite-On Trading USA, Inc. Lite-On Technology Corp. is publicly listed on the Taiwan Stock Exchange.

4. The names of all the partners or associates that appeared for the party or amicus now represented by me in the trial court or agency or are expected to appear in this court are:

   Finnegan, Henderson, Farabow, Garrett & Dunner, LLP: Christopher S. Schultz, E. Robert Yoches, Jeffrey D. Smyth, Kenneth M. Frankel, MingTao Yang, Tina Hulse

   Hamilton Brook Smith & Reynolds, P.C.: Susan G.L. Glovsky, Lawrence P. Cogswell

Goldstein & Russell P.C.: Kevin K. Russell, Thomas C. Goldstein, Charles H. Davis.

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/s/ Kevin K. Russell
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December 27, 2016

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STATEMENT OF RELATED CASES

This is a consolidated appeal from judgments against co-defendants in a patent infringement suit in the U.S. District Court for the District of Massachusetts. Defendants are unaware of any other related appeal before this or any other appellate court, or any other pending case that will directly affect or be affected by the decision in the pending appeals.

JURISDICTIONAL STATEMENT

The district court exercised jurisdiction under 28 U.S.C. §§ 1331 and 1338(a). This Court has jurisdiction pursuant to 28 U.S.C. § 1295 over Defendant-Appellant Lite-On Inc., Lite-On Service USA, Inc., Lite-On Technology Corp., and Lite-On Trading USA's ("Lite-On") appeal from a final judgment. With respect to Defendant-Appellant Everlight Americas, Inc. and Everlight Electronics Co., Ltd., ("Everlight"), the Court has jurisdiction under 28 U.S.C. § 1292(c)(2) and *Robert Bosch, LLC. v. Pylon Manufacturing Corp.*, 719 F.3d 1305 (Fed. Cir. 2013) (en banc), as Everlight has appealed from a judgment that is final except for a new trial that was granted solely on the issue of damages. All defendants filed timely notices of appeal on August 26, 2016. *See* Appx2523-2536.

STATEMENT OF THE ISSUES

1. Whether the district court erred by construing the claim term “grown on” to include deposition of a layer either in direct *or indirect* contact with the underlying layer. [Addressed in co-defendant Epistar’s brief and incorporated by reference here].

2. Whether U.S. Patent No. 5,686,738 (the “’738 Patent”) meets the enablement requirement of 35 U.S.C. § 112(a).

3. Whether the ’738 Patent meets the written description requirement of 35 U.S.C. § 112(a).

INTRODUCTION

This appeal is taken from a judgment in a case with three sets of defendants, Defendant-Appellant Epistar Corp. ("Epistar"), Everlight, and Lite-On (collectively "Defendants"). All three sets of defendants have appealed on overlapping grounds. To avoid unnecessary duplication of briefing in this Court, Everlight and Lite-On file this joint brief incorporating by reference co-defendant Epistar's Introduction and Statement of the Case, as well as Epistar's challenge to the district court's construction of a central claim term, "grown on." *See* Epistar Br. § I; FED. R. APP. P. 28(i) (permitting, but not requiring, appellants to join in a brief or adopt of portion of another brief by reference). In this brief, Everlight and Lite-On challenge the validity of the relevant claim of the underlying Patent, which challenge Epistar joins and incorporates by reference.

STATEMENT OF THE CASE

Everlight and Lite-On adopt in full the Statement of the Case provided in co-defendant Epistar's opening brief.

SUMMARY OF THE ARGUMENT

I. Enablement. Section 112(a) requires that a patent specification enable a person skilled in the art to produce the full scope of the claimed invention without undue experimentation. Plaintiff Trustees of Boston University ("BU") convinced the district court to broadly construe the terms of the '738 Patent, such that it extended to semiconductors with three types of buffer layers (amorphous, polycrystalline, and a mixture of the two) with a monocrystalline growth layer either directly or indirectly above the buffer layer. In so doing, BU put itself "at the peril of losing any claim that cannot be enabled across its full scope of coverage." *Mag Sil Corp. v. Hitachi Global Storage Techs., Inc.*, 687 F.3d 1377, 1380 (Fed. Cir. 2012). In fact, the evidence at trial clearly and convincingly demonstrated that the '738 Patent failed to enable any semiconductor with an amorphous buffer layer. And even if it had, both sides' experts agreed that it is impossible to grow a monocrystalline growth layer directly on top of an amorphous buffer layer through epitaxial methods (which are the only methods described in the specification).

A. *Amorphous Buffer Layer*. The specification describes a "two-step growth process" for creating the patent device's buffer layer. Appx206 abstract. In the first step, an amorphous buffer layer is initially deposited on a substrate at a temperature between 100˚C and 400˚C in the first step (low temperature nucleation step). At the second step (high temperature crystallization step), the substrate is heated to between 600˚C and 900˚C. The specification expressly states that "[a]s the temperature increases to 600˚C, the amorphous film *crystallizes*," Appx214 col. 4 ll. 34-36 (emphasis added), and that the point of the second step is "to *ensure* that the GaN buffer layer *is crystallized*," *id.* col. 4 l. 25 (emphasis added), so that the formation of the growth layer "takes place on the *crystallized* GaN buffer layer." Appx214 col. 4. ll. 36-37 (emphasis added). The Patent itself thus acknowledges that following the specification will result in a crystallized buffer layer, while the defining feature of an *amorphous* buffer layer is that it lacks any crystal structure at all.

BU's attempts to nonetheless show that the patent enabled an amorphous buffer layer were grossly insufficient. First, BU suggested that a person skilled in the art might just skip the second step. The only support for that facially implausible suggestion was a sentence in the specification which stated that at step two the "amorphous film *can* be crystallized by heating at 600˚C - 900˚C," Appx213 col. 2 ll. 41-42 (emphasis added), which BU's expert read to indicate that the step was optional. But the word "can" is incapable of bearing the weight BU must place on it. At best, it might suggest that there are other ways to crystalize the buffer layer, but even then, it would still indicate that the buffer must be crystalized by some method in order to create the claimed invention. Moreover, the greater context of the specification makes clear that the advertised two-step process requires both steps be followed.

BU's expert also suggested that even if one followed the second step, the buffer layer might not crystallize *all the way through*. But that would simply mean the buffer layer was a mixture of amorphous and polycrystalline, which is a separate permutation of the device. It would not mean that the partially crystalized layer was somehow amorphous. And, in any event, the specification itself declares that the end result of the second step should be a crystallized layer. Moreover, even if the second step did not crystallize the buffer layer, the process of creating the *growth* layer on top of it would. That is, the growth layer is rendered monocrystalline by heating the substrate to a sufficient degree that the topmost layer in the stack (at that point, the growth layer) crystallizes completely. Because the process calls for heating the substrate in order to "cook" the top growth layer, the buffer layer – made of the same material and even closer to the heated substrate – would necessarily crystalize as well.

Finally, the district court simply misunderstood the inventor's testimony in finding that Dr. Moustakas had claimed to have made an amorphous buffer layer.

B. *Monocrystalline Growth Layer Directly On An Amorphous Buffer Layer*. Even if the Patent had enabled creation of an amorphous buffer layer, it did not enable a semiconductor with a monocrystalline growth layer grown directly on top of an amorphous buffer layer.

The district court erred first in holding that the Patent was not required to enable this version of the claimed device. The court reasoned that it would be "unreasonable" to require the inventor to enable every permutation of the multiple versions of the device he laid claim to. But this Court's precedents are unambiguous that enablement of the full scope of the claim is required as the quid pro quo of the patent monopoly.

The district court was further wrong in finding that even if the Patent was required to enable a semiconductor with a monocrystalline growth layer grown directly on top of an amorphous buffer layer, a reasonable jury could find this version of the device enabled. In fact, both sides' experts agreed that it is impossible to epitaxially grow a monocrystalline layer directly on an amorphous layer, given that the lower layer's lack of crystallinity will prevent the upper layer from achieving a monocrystalline structure.

None of the testimony cited by the district court in upholding the jury verdict remotely overcomes this clear and convincing consensus. BU's experts testified that it is *possible* to put a monocrystalline growth layer on top of an amorphous buffer layer through non-epitaxial methods. But the enablement question is not whether the claimed invention is *possible* to create, but whether the written specification tells a person skilled in the art how to create it without undue experimentation. Here, BU's experts did not claim that they had created the claimed device by following the specification in this Patent. Indeed, the district court acknowledged that the experts did not manage to create the device until *years* after the patent application was filed, rendering the evidence irrelevant as a matter of law. Moreover, the experts did so using an entirely different technology than is taught in the patent, which teaches exclusively epitaxy. BU's contrary argument that the Patent is not limited to epitaxy is unconvincing. It is also beside the point because even if the Patent left open some other method, it certainly does not *teach* the reader how to use that method to create a semiconductor with a monocrystalline growth layer directly on an amorphous buffer layer.

II. **Written Description.** Even if the Patent were sufficiently enabled, asserted Claim 19 is invalid for the distinct failure to include a written description reasonably conveying that the inventor actually had possession of the claimed invention at the time of the application. This "written description" requirement of Section 112(a) ensures that that in addition to enabling others to make the patented invention, the inventor actually invented the full scope of what the Patent claims as of the time of the application.

Here, even if some future scientists could, with reasonable experimentation, create a semiconductor with an amorphous layer (with and without a monocrystalline growth layer directly on top of it), there is clear and convincing evidence in the specification itself that Dr. Moustakas had not achieved those results by the time he filed his application. That truth is confirmed by the fact that BU's best evidence of enablement is Dr. Moustakas' claim to have created such devices, but only *seven years* after submitting the parent application.

III. Claim Construction. For the reasons set forth in Epistar's brief, incorporated into this brief by reference, the district court wrongly construed the claim term "grown on."

STANDARD OF REVIEW

This Court reviews the denial of motion for judgment as a matter of law ("JMOL") or for a new trial according to the law of the regional circuit. *LifeNet Health v. LifeCell Corp.*, 837 F.3d 1316, 1322 (Fed. Cir. 2016). The First Circuit "review[s] the district court's denial of a motion for judgment as a matter of law, including legal decisions made therein, de novo." *Mass. Eye & Ear Infirmary v. QLT Phototherapeutics, Inc.*, 552 F.3d 47, 57 (1st Cir. 2009). Courts may grant a JMOL when the evidence "points so strongly and overwhelmingly in favor of the moving party that no reasonable jury could have returned a verdict adverse to that party," *Marcano Rivera v. Turabo Med. Ctr. P'ship*, 415 F.3d 162, 167 (1st Cir. 2005) (internal quotation marks omitted), "or if the legal conclusions implied from the jury's verdict cannot in law be supported by those findings," *Cybor Corp. v.*

FAS Techs, Inc., 138 F.3d 1448, 1454 (Fed. Cir. 1998) (en banc). The First Circuit reviews the grant or denial of a motion for new trial for abuse of discretion. *Jennings v. Jones*, 587 F.3d 430, 435 (1st Cir. 2009). "A trial court may grant a new trial on the basis that the verdict is against the weight of the evidence." *Id.* at 436.

"Enablement is a question of law that we review without deference, based on underlying factual inquiries that we review for clear error." *Cephalon, Inc. v. Watson Pharms., Inc.*, 707 F.3d 1330, 1336 (Fed. Cir. 2013). "[B]ecause a patent is presumed to be valid, the evidentiary burden to show facts supporting a conclusion of invalidity is one of clear and convincing evidence." *AK Steel Corp. v. Sollac & Ugine*, 344 F.3d 1234, 1238-39 (Fed. Cir. 2003) (internal citations omitted).

Compliance with the written-description requirement of Section 112 is a question of fact. *Ariad Pharms., Inc. v. Eli Lilly & Co.*, 598 F.3d 1336, 1351 (Fed. Cir. 2010) (en banc). The court reviews a jury's verdict on written description to determine if it is supported by substantial evidence. *Martek Biosciences Corp. v. Nutrinova, Inc.*, 579 F.3d 1363, 1369 (Fed. Cir. 2009). Although the defendant must present clear and convincing evidence that the patent is invalid, a patent may be held invalid on its face under the written description requirement. *Univ. of Rochester v. G.D. Searle & Co.*, 358 F.3d 916, 927 (Fed. Cir. 2004).

ARGUMENT

Defendants were found liable for infringing the ’738 Patent, which claims a particular kind of semiconductor used in light emitting diodes (LEDs). *See* Epistar Br. 4-5. Asserted Claim 19, however, is invalid under 35 U.S.C. § 112(a) for lack of enablement and for failing to provide an adequate written description. Thus, because no reasonable jury could find that Claim 19 meets either the enablement or the written description requirements, this Court should find Claim 19 invalid and order judgment be entered in the Defendants’ favor. FED. R. CIV. P. 50(a). Even if the Court concludes that JMOL is not appropriate, the Court should at least order a new trial on invalidity as the clear weight of the evidence shows that the Claim 19 of the ’738 Patent is invalid. FED. R. CIV. P. 59, 60. Finally, as argued in Epistar’s brief, the district court wrongly construed the claim term “grown on,” requiring a new trial on infringement if this Court upholds the Patent’s validity.

I. The ’738 Patent Fails The Enablement Requirement of Section 112(a).

Pursuant to 35 U.S.C. § 112(a), “the specification shall contain a written description . . . of the manner and process of making and using [the invention], in such full, clear, concise, and exact terms as to enable any person skilled in the art . . . to make and use the same . . . .” If, “by following the steps set forth in the specification, one of ordinary skill in the art is not able to replicate the claimed invention without undue experimentation, the claim has not been enabled,” and is therefore invalid. *Nat'l Recovery Techs., Inc. v. Magnetic Separation Sys., Inc.*, 166 F.3d 1190, 1196 (Fed. Cir. 1999).

The evidence at trial clearly and convincingly established that if a person of skill in the art follows the teachings of the '738 Patent, she will not be able to make the full scope of the invention claimed by Claim 19.

A. The Specification Of The '738 Patent Fails To Enable An Amorphous Buffer Layer.

Claim 19 claims a semiconductor that has, among other things, a "non-single crystalline buffer layer." Appx216 col. 8 l. 5. During claim construction, BU proposed an expansive definition of "non-single crystalline" that encompassed devices having any one of three different crystalline structures: "polycrystalline, amorphous, or a mixture of polycrystalline and amorphous." Appx253-256; *see* Epistar Br. 6-7 (describing various crystalline states). The district court accepted that construction over Defendants' objection. *Id.* "Although BU was entitled to request a changed claim construction up until the jury verdict . . . it pressed the tripartite definition throughout trial," insisting that it "would deem an amorphous buffer layer infringing of the '738 Patent." Appx12. However, the Patent does not enable a semiconductor with an amorphous GaN buffer layer.

1. As A Simple Matter Of Physics, Following The Specification Will Not Produce An Amorphous Buffer Layer.

The ’738 Patent describes a “two-step growth process” for producing the claimed invention. Appx206 abstract; *see also* Appx213 col. 2 ll. 14-17 (“A film is epitaxially grown in a two step process comprising a low temperature nucleation step and a high temperature growth step.”). In the first step, a molecular beam source of gallium and activated nitrogen are mixed in an epitaxy growth chamber, then exposed to the substrate for deposition while the substrate is kept at a temperature between 100˚C and 400˚C. Appx213 col. 2 ll. 9-20, Appx214 col. 4 ll. 12-15. In the preferred embodiment, the substrate is exposed to the molecular GaN for 3 to 15 minutes, during which time an amorphous film is deposited on the substrate surface. Appx213 col. 2 ll. 39-41. In the second step, the substrate is then heated to between 600˚C and 900˚C in order to crystallize the amorphous GaN film. *Id.* col. 2 ll. 19-21, 41-42. After the second step is completed, GaN is further deposited on the crystallized GaN buffer layer at high temperature, which results in a monocrystalline growth layer of GaN. *Id.* col. 2 ll. 43-67.

As the Patent itself acknowledges, in the second step, “[a]s the temperature increases to 600˚C, the amorphous film crystallizes,” Appx214 col. 4 ll. 34-36, necessarily producing a non-amorphous buffer layer.[1] *See also id.* col. 4 ll. 23-25.

[1] We use the term “non-amorphous” to mean any state other than purely amorphous (*e.g.*, polycrystalline, or a mixture of polycrystalline and amorphous).

Indeed, the specification explains that the whole point of the second step is "to *ensure* that the GaN buffer layer *is crystallized*," *id.* (emphasis added), so that the formation of the growth layer "takes place on the *crystallized* GaN buffer layer." *Id.* col. 4. ll. 36-37 (emphasis added).

Defendants' expert likewise confirmed that heating the buffer layer to 600˚C will cause the layer to crystallize to some extent as a simple matter of physics. Appx2308-2311 (Trial Tr. 6 at 223-26). As a consequence, following the specification of the '738 Patent *will not* produce an amorphous buffer layer.

These acknowledgments in the specification itself may call into doubt whether the inventor actually intended to claim devices with an amorphous buffer layer. But having persuaded the district court to adopt a broader claim construction that entitles it to a monopoly over devices containing amorphous buffer layers, BU put itself "at the peril of losing any claim that cannot be enabled across the full scope of its coverage." *Mag Sil*, 687 F.3d at 1380; *see also Liebel-Flarsheim Co. v. Medrad, Inc.*, 481 F.3d 1371, 1380 (Fed. Cir. 2007) ("The irony of the situation is that Liebel successfully pressed to have its claims include a jacketless system, but having won that battle, it then had to show that such a claim was fully enabled, a challenge it could not meet. The motto 'beware of what one asks for,' might be applicable here.").

2. *The District Court's Contrary Reasons For Nonetheless Upholding The Patent's Validity Are Meritless.*

The district court nonetheless denied JMOL on the ground that there was "competing testimony from multiple qualified experts as to whether the patent enabled an amorphous buffer layer." Appx16. But BU's testimony was grossly insufficient to counter the plain import of the specification and undisputed testimony that exposing the buffer layer to the temperatures described therein will at least partially crystalize the buffer layer and render it non-amorphous.

a. *The Specification Does Not Suggest Skipping The Second Step.*

The district court first cited the testimony of BU expert, Dr. Piner, who stated that in "this part of the embodiment of the patent it talks about forming an amorphous film to begin with, and then can be, *meaning can or cannot be as well*, crystallized, meaning formed polycrystalline material . . . but doesn't necessarily have to be." Appx2268 (Trial Tr. 4 at 49) (emphasis added); Appx15 (district court quoting Dr. Piner's testimony). What, exactly, Dr. Piner meant by his emphasis on "can" is not entirely clear. It is possible that he meant (or the district court understood him to mean) that a person skilled in the art would understand that the second step is optional. And if the second step is not followed, the buffer layer (which everyone agrees is amorphous during the first step) will not be exposed to the higher, crystallizing temperatures at step two, leaving the amorphous buffer layer intact. Any such argument, however, would be completely baseless.

First, even standing alone, the sentence is not susceptible to BU's apparent interpretation. To say that a film *can* be crystallized in a particular way simply conveys that the film *must* be crystallized if the description is to be followed, and that the result *can* be achieved by the prescribed method. If a two-step recipe for Jello calls for mixing gelatin with water, then states the "mixture can be turned solid by chilling it to 40 degrees," no one would read the word "can" to suggest skipping the chilling step or putting the Jello in the oven. Here, even if the word "can" may suggest that there are other undisclosed ways to crystallize the buffer layer,[2] it still conveys that the buffer layer is to be crystallized. And even a partially crystallized buffer layer is not an amorphous buffer layer. Appx2240-2243 (Trial Tr. 2 at 78-81) (Dr. Moustakas discussing how even small crystals within a layer will render the layer non-amorphous).

Second, the word "can" must, in any event, be read in context. *Application of Johnson*, 558 F.2d 1008, 1017 (C.C.P.A. 1977) (Markey, J.) ("[W]e note that the specification as a whole must be considered in determining whether the scope of

[2] For example, the layer may perhaps be crystallized by changing pressure or mixing in an additive during the deposition process.

enablement provided by the specification is commensurate with the scope of the claims.”). Dr. Moustakas described his discovery as “the two-step temperature process,” Appx2260 (Trial Tr. 3 at 65), and the specification describes both steps without ever suggesting either step is optional. *See, e.g.*, Appx213 col. 2 ll. 36-47 (describing the two step approach in a preferred embodiment); Appx214 col. 4 ll. 11-39 (describing the “typical process” set forth by the specification as having two steps). By expressly advertising a two-step process, the Patent unambiguously instructs that both steps must be followed to create the claimed invention.

If that implicit direction were not enough, the Patent goes on to explain why: step one creates an amorphous buffer layer and step two crystallizes it so it can act as a template for monocrystalline growth in the succeeding layers. *See, e.g.*, Appx214 col. 4 ll. 36-37 (explaining that “[a]ny further growth” of the growth layer “takes places on the crystallized GaN buffer layer”); Appx2274-2275 (Trial Tr. 4 at 137-38) (BU’s expert agreeing that it is not possible to epitaxially deposit a monocrystalline growth layer on a buffer layer if the buffer layer is not at least partially crystalized). The specification thus explains that the substrate is kept at 600˚C “to *ensure* that the GaN buffer layer had crystallized,” Appx214 col. 4 ll. 24-25 (emphasis added), and only *after* crystallization has occurred should the Ga shutter be opened to allow for deposition of the monocrystalline growth layer, *id.* col 4 ll. 25-27; *see also Id.* col. 4 ll. 34-37 (noting that “[a]s the temperature increases 600˚C, the amorphous film crystallizes"). The use of words like "ensure" and "after" makes clear that the inventor intended for a person of skill in the art to crystallize the buffer layer in step two.[3]

b. Following The Two-Step Process Does Not Create The Purely Amorphous Buffer Layer Claimed By The Patent.

It is also possible that Dr. Piner's emphasis on the word "can" was meant to suggest that even if step two *is* followed, the buffer layer may *or may not* fully crystallize. The district court thus quoted Dr. Piner's testimony asserting that even if the second step is followed, the "crystallization process . . . . doesn't necessarily have to occur throughout the entirety of the thickness of the buffer layer." Appx15 (quoting Appx2269 (Trial Tr. 4 at 50)). But that theory does not save Claim 19 either.

[3] Although the district court did not rely on it, Dr. Piner also seemingly suggested that a person of skill in the art could create an amorphous buffer layer by using a temperature lower than the 600˚C minimum prescribed in step two. Appx2268-2269 (Trial Tr. 4 at 49-50). But the Patent expressly states that the "high temperature growth step is preferably carried out in the temperature range of 600˚C-900˚C." Appx213 col. 2 ll. 19-21; *see also* Appx214 col. 4 ll. 11-19 (stating that the "typical process" involves bringing the substrate to 600˚C during the second step), col. 4 ll. 34-36 (noting that "[a]s the temperature *increases to* 600˚C, the amorphous film crystallizes" (emphasis added)). No reasonable reader of the specification could come away with the impression that the very specific temperature range identified in step two must sometimes be disregarded if the reader actually wants to create all the devices covered by Claim 19.

First, saying that the process may result in a buffer layer with only *some* crystallization is simply to say that it results in a layer that is mixed amorphous and polycrystalline, not the purely amorphous buffer layer BU persuaded the district court is also claimed. Appx2240-2243 (Trial Tr. 2 at 78-81) (Dr. Moustakas explaining that, once heat is added after the initial low temperature deposition step, the amorphous GaN layer begins to crystallize in part, forming a "mixture of amorphous and a polycrystalline material").

Second, the specification itself plainly states on multiple occasions that the buffer layer is crystallized once it is heated to 600˚C. *See, e.g.*, Appx214 col. 4 l. 25 (noting that second step "ensure[s]" that the layer is crystallized); *id.* col. 4 ll. 34-36 (noting that "[a]s the temperature increases 600˚C, the amorphous film crystallizes"); *id.* col. 4 ll. 36-37 (formation of the growth layer "takes place on the crystallized GaN buffer layer."). Accordingly, a person of skill in the art would understand, as Dr. Piner himself elsewhere stated, Appx2269-2270 (Trial Tr. 4 at 50-51), that following the two-step procedure described in the specification results in at least a buffer layer with mixed crystallinity.

Third, even if the described process for creating the buffer layer itself did not result in a non-amorphous buffer layer, the disclosed process for creating the monocrystalline *growth* layer will necessarily crystallize the *buffer* layer as well, rendering the buffer layer non-amorphous. As Dr. Fitzgerald explained, in the

ECR-MBE system described in the specification, the semiconductor is heated like a griddle—the *substrate* is heated to 600˚C and that heat is transferred through the layers that sit on the substrate. Appx214 col. 4 ll. 11-25; Appx2317-2318 (Trial Tr. 6 at 232-33) (contrasting cooking in an oven, in which case the entire container is heated, thereby cooking from the outside in).[4] It necessarily follows that if the growth layer is heated to a temperature that would crystallize it (as required by the specification), the underlying buffer layer must be at *least* as hot, necessarily crystallizing it as well. And when that happens, the resulting semiconductor will no longer have an amorphous (*i.e.*, uncrystallized) growth layer underneath the crystallized growth layer. *See* Appx2309-2311 (Trial Tr. 6 at 224-26).

c. Dr. Moustakas Did Not Testify It Was Possible To Grow An Amorphous Buffer Layer Following The Directions In The Specification.

The district court's reliance on Dr. Moustakas's testimony is likewise misplaced. The district court first stated that "Dr. Moustakas testified that when he grew a 'gallium nitride buffer, that material was amorphous. It didn't have any crystalline structure.'" Appx16 (quoting Appx2238 (Trial Tr. 2 at 76)). But Dr.

[4] Likewise, the specification explains that the *substrate* is cooled to 270˚C during step one then heated to 600˚C in step two once the buffer layer has been deposited. Appx214 col. 4 ll. 12-19 ("The *substrate* was cooled down to 270˚C in the presence of the nitrogen plasma. A Ga shutter was then opened to deposit the initial buffer layer of GaN. . . . The *substrate* was then brought slowly to 600˚C." (emphasis added))

Moustakas was not claiming that he had created an amorphous buffer layer by following the specification. Instead, he was simply describing the result of following *step one* of the process which, no one disputes, results in an amorphous buffer layer prior to heating to a higher temperature at step two. Appx2242-2243 (Trial Tr. 2 at 80-81) (explaining that, as heat is added after the initial deposition step, crystallization begins). Dr. Moustakas then continued by saying "[n]ow, when we heat this material to higher temperatures . . . some of the amorphous material will undergo what is known as crystallization." Appx2238 (Trial Tr. 2 at 76). Dr. Moustakas himself described the resulting material as a "mixture of amorphous and a polycrystalline material," not a purely amorphous buffer layer. Appx2243 (Trial Tr. 2 at 81).

The district court next quoted Dr. Moustakas's testimony that a monocrystalline layer "will cover underneath material which is still either amorphous or polycrystalline." Appx16 (quoting Appx2250-2251 (Trial Tr. 2 at 88-89)). But the court's reliance on this statement was misplaced as well. The quotation was taken from a portion of Dr. Moustakas's testimony describing a phenomenon he termed "lateral epitaxial overgrowth." Appx2246 (Trial Tr. 2 at 84). He explained that this overgrowth occurs when a small seed within a mixed polycrystalline and amorphous structure grows laterally and vertically, "becom[ing] larger and larger," and eventually overtaking the structure, producing a monocrystalline layer above the buffer layer. Appx2250-2251 (Trial Tr. 2 at 88-89). Dr. Moustakas expressly stated, however, that for this to happen, there must be some sort of crystalline seed to begin this process. Appx2246 (Trial Tr. 2 at 84) (noting that "if you take that particular crystal, that crystal, as we keep sending to the gallium and nitrogen atom[s], it will grow to be thicker, but also grows laterally . . . ."). Indeed, Dr. Moustakas explained that the originally amorphous buffer layer deposited at step one will begin to crystallize as heat is added during step two, and "start forming nuclei" that then began to grow larger until lateral epitaxial overgrowth eventually occurs. Appx2242-46 (Trial Tr. 2 at 80-84).

Accordingly, Dr. Moustakas did *not* state that a GaN growth layer can form above an amorphous layer following the written description. He instead testified that the two-step process described in the Patent would take an amorphous buffer layer and heat it *in order to partially crystalize it*, after which those crystals would seed further crystalline growth to produce a monocrystalline growth layer on top of the buffer layer. *See* Appx2243 (Trial Tr. 2 at 81) (describing buffer layer as "a mixture of amorphous and a polycrystalline material"); Appx2245 (Trial Tr. 2 at 83) (referring to "polycrystalline" buffer layer). Thus, when Dr. Moustakas stated that the monocrystalline layer "will cover all of this amorphous material underneath," and "will cover underneath material which is still either amorphous or polycrystalline," he was not referring to an amorphous layer, as the district court believed, but instead a mixed amorphous and polycrystalline layer where these nuclei were first formed.

B. The Specification Of The ’738 Patent Also Fails To Enable A Monocrystalline Growth Layer Directly On An Amorphous Buffer Layer.

Even if the specification had enabled creation of an amorphous buffer layer, it did not enable the formation of a monocrystalline growth layer on top of such a buffer layer.

1. The Patent Was Required To Enable A Monocrystalline Growth Layer Directly On Top Of An Amorphous Buffer Layer.

The Patent requires a monocrystalline growth layer. *See* Appx213 col. 2 ll. 9-11. Claim 19 further requires that the growth layer be “grown on” a “non-single crystalline buffer layer,” Appx216 col. 8 ll. 5-9, which the court construed to include an amorphous buffer layer. The district court also accepted BU’s construction of “grown on” to include both “grown directly on” and “grown indirectly on.” *See* Epistar Br. 13-14. BU thus claims LED chips containing a monocrystalline growth layer directly on top of an amorphous layer.

The district court nonetheless held that the Patent was not required to enable such a device, concluding it would be “unreasonable” to “require the patent to enable multiple permutations, representing various combinations of a direct and indirect relationship between . . . the buffer and growth layer, for all three iterations of the buffer layer's crystallinity." Appx13-14. That conclusion runs directly contrary to this Court's settled precedent.

"[A]s part of the *quid pro quo* of the patent bargain, the applicant's specification must enable one of ordinary skill in the art to practice the *full scope* of the claimed invention." *AK Steel*, 344 F.3d at 1244 (emphasis added); *see also, e.g.*, *Nat'l Recovery Techs.*, 166 F.3d at 1195-96 ("The scope of the claims must be less than or equal to the scope of the enablement."); *In re Wright*, 999 F.2d 1557, 1561 (Fed. Cir. 1993) ("[T]he specification of a patent must teach those skilled in the art how to make and use the *full scope* of the claimed invention without undue experimentation.") (emphasis added) (internal quotation marks omitted)). A claim thus is invalid if "the written description fails to teach those in the art to make and use the invention as broadly as it is claimed without undue experimentation." *In re Cortright*, 165 F.3d 1353, 1356 (Fed. Cir. 1999); *see also Liquid Dynamics Corp. v. Vaughan Co.*, 449 F.3d 1209, 1224 (Fed. Cir. 2006) (same).

The district court may have believed that this precedent placed an unreasonable burden on inventors who claim multiple permutations of a device, but this Court's cases firmly hold otherwise, and wisely so. There could be no dispute that if the Patent claimed *only* an LED chip with a monocrystalline growth layer directly on top of an amorphous buffer layer, the Patent would have to enable a person skilled in the art to produce that device. There is no reason in logic or policy why an inventor should be allowed to avoid that responsibility by claiming multiple devices in a single claim. Certainly nothing in the language of the Patent Act or this Court's cases provides that special privilege.

The district court also overstated the difficulty of meeting the statute's enablement requirement in this and similar cases. To say that the Patent must enable the full scope of the claim is "not to say that the specification itself must necessarily describe how to make and use every possible variant of the claimed invention, for the artisan's knowledge of the prior art and routine experimentation can often fill gaps, . . . depending upon the predictability of the art." *AK Steel*, 344 F.3d at 1244. In this case, for example, Claim 19 includes semiconductors with several different substrates, while the specification uses the specific example of a sapphire substrate in the preferred embodiment. *See* Appx214 col. 4 ll. 40-50. The specification may well be sufficient to enable the creation of devices with every kind of listed substrate, so long as following the specification with the substitution still results in the claimed device, or if a person skilled in the art could, without undue experimentation, determine what changes to the process were necessary to produce the claimed semiconductor with each of the specified substrates.

Likewise, the fact that the claimed devices might (under the district court's construction) have any number of intervening layers between the substrate and the buffer layer, and the buffer layer and the growth layer, does not necessarily mean that the Patent was required to go on for hundreds of pages to enable the full scope of the claim. In epitaxy, the crystalline structure of the depositing layer will be determined by the structure of the layer on which it is *directly* being deposited; the composition of the lower layers is generally irrelevant. *See* Epistar Br. 6-8. Thus, the monocrystalline structure of the growth layer (which is the goal of the Patent), will be dictated by either the buffer layer (if the growth layer is directly on top of it) or the intervening layer immediately below the growth layer (for the "indirectly on" permutation), regardless of the number of other intervening layers. Requiring full enablement of the claims in this Patent thus would not be unreasonable. There are, at most, six distinct "permutations" that would have to be enabled.[5]

[5] There are six possible combinations for the growth layer/buffer layer structure due to BU's adopted constructions for "grown on" and "non-single crystalline": (1) monocrystalline growth layer directly on a polycrystalline buffer layer; (2) monocrystalline growth layer indirectly on a polycrystalline buffer layer; (3) monocrystalline growth layer directly on a mixed polycrystalline/amorphous buffer layer; (4) monocrystalline growth layer indirectly on a mixed polycrystalline/amorphous buffer layer; (5) monocrystalline growth layer directly on an amorphous buffer layer; or (6) monocrystalline growth layer indirectly on an amorphous buffer layer.

2. *The Parties Agreed That It Is Impossible To Grow A Monocrystalline Growth Layer Directly On Top Of An Amorphous Buffer Layer With Epitaxy.*

Although the Patent was required to enable a monocrystalline growth layer directly on top of an amorphous buffer layer, it plainly does not. Indeed, experts for both parties agreed that "one cannot *epitaxially* grow a monocrystalline layer on an amorphous structure." Appx17-18 (citing Dr. Piner's testimony); *see also* Appx2274 (Trial Tr. 4 at 137) (Dr. Piner), Appx2311-2313, Appx2325, Appx2332 (Trial Tr. 6 at 226-28, 7 at 23, 30) (Dr. Fitzgerald).[6] That is so for two reasons.

First, in order for a monocrystalline growth layer to grow on the buffer layer, there needs to be a fairly close lattice match. Appx2311-2313 (Trial Tr. 6 at 226-28). By definition, an amorphous substance has no lattice to which the GaN can match. *Id.* Thus, even Dr. Piner admitted that a monocrystalline growth layer will not be able to grow directly on an amorphous buffer layer using epitaxy. Appx17-18.

Second, as discussed, the disclosed process for creating the monocrystalline *growth* layer would necessarily crystallize the *buffer* layer, rendering it non-amorphous. *See supra* pp. 19-20; Appx2309-2311, Appx2316-2317 (Trial Tr. 6 at 224-26, 231-32) (Dr. Fitzgerald explaining that he has "no idea" how a person of

[6] As discussed below, BU's experts claimed that it *was* possible to "grow a monocrystalline film on an amorphous substance" through other means, Appx16, but that assertion does not save the Claim. *See infra* § I.B.3.

skill in the art could preserve the amorphous character of the buffer layer while heating the system to the temperature necessary to produce a monocrystalline growth layer).

3. *BU's Experts' Conclusory Testimony That It Is Possible To Create The Claimed Device Is Insufficient To Show That The Patent Enabled Its Creation.*

The district court nonetheless concluded that a reasonable jury could find Claim 19 enabled, pointing first to Dr. Piner's testimony that "a person of ordinary skill in the art could, using the teaching of the patent, make an amorphous buffer layer with a monocrystalline GaN layer on top" and that "the elements of the claim itself teaches how to do that accurately." Appx16-18 (quoting Appx 2265-2269 (Trial Tr. 4 at 46-50)). But this statement was completely conclusory. And "an expert's opinion on the ultimate legal issue must be supported by something more than a conclusory statement." *In re Buchner*, 929 F.2d 660, 661 (Fed. Cir. 1991).

Perhaps recognizing as much, the district court then cited testimony from Dr. Piner and Dr. Moustakas disputing "the impossibility of growing a monocrystalline layer on an amorphous substance" and claiming to have created such devices themselves. Appx17-19. Because "a reasonable jury could have concluded that it is *possible* to grow a monocrystalline GaN growth layer on an amorphous buffer layer," the court reasoned, the jury could reasonably find "that the patent teaches one skilled in the art how to do so." Appx19 (emphasis added).

Even if the court's premise were true (*i.e.*, that it is *possible* to create such a device), the conclusion is a non-sequitur. The enablement inquiry asks whether *the patent* teaches a person skilled in the art how to create the patented device at the time of filing, not whether creating the device is *possible*. BU's own expert testimony illustrates the difference. To substantiate his claim that it is possible to make a semiconductor with a monocrystalline growth layer on top of an amorphous buffer layer, Dr. Moustakas "testified that he has grown a single-crystalline semiconductor on an amorphous material" and that "other scientists recently 'reported single crystalline gallium nitride on glass,' which 'is an amorphous material,' in the scientific journal Nature." Appx17 (quoting Appx2253-2254 (Trial Tr. 2 at 118-19)). But the district court admitted that "this research occurred after the patent was issued." Appx17 n.3.[7] And this Court has made clear that the "sufficiency [of the specification] must be judged as of the filing date." *Application of Glass*, 492 F.2d 1228, 1232 (C.C.P.A. 1974) (Rich, J.). Dr. Piner's testimony that he grew "gallium nitride monocrystalline film that has grown on an amorphous material," Appx17 (quoting Appx2265 (Trial Tr. 4 at 46), suffered from the same defect. Although the district court did not acknowledge it,

[7] The district court noted that the evidence was admitted "solely to rebut the argument that such growth was scientifically impossible." *Id*. But the court ultimately used the evidence for the very different purpose of supporting BU's claim that the '738 Patent enabled such growth at the time of its filing.

this testimony referred to work conducted while Dr. Piner was working at Nitronics, *see* Appx2265-2266 (Trial Tr. 4 at 46-47), where he was employed from 2000-2009, Appx2219.

Noting that two experts were able to create the claimed invention years *after* the filing date does nothing to show that a person skilled in the art could have achieved Dr. Piner or Dr. Moustakas's results without undue experimentation at the time of the patent application. Indeed, that BU was forced to rely on evidence postdating the application by as much as seven years is a strong indication that at the time of filing of the parent application, a person of skill in the art could *not* have translated the disclosures of the specification to a different semiconductor fabrication platform without undue experimentation. *See Nat'l Recovery Techs.*, 166 F.3d at 1196.

4. *The Patent Does Not Enable Anything Through Non-Epitaxial Methods.*

Dr. Piner's and Dr. Moustakas's testimony was legally insufficient for an additional reason: the experts' claims to have created monocrystalline layers on top of an amorphous substance were premised on the use of *non*-epitaxial methods. *See* Appx17-18 (noting "Dr. Piner agreed . . . that one cannot *epitaxially* grow a monocrystalline layer on an amorphous structure); *see also* Appx2331-2334 (Trial Tr. 7 at 29-32) (Dr. Fitzgerald explaining that Dr. Moustakas and Dr. Piner did not use epitaxial methods in discussing placing a monocrystalline layer on an amorphous layer). The district court nonetheless concluded that the testimony was enough to support Claim 19's validity because the jury was entitled to credit Dr. Piner's testimony that "what the patent teaches is not epitaxy." Appx17-19 (quoting Appx2382-83 (Trial Tr. 9 at 143-44)). But that reasoning fails again.

First, the specification unambiguously teaches only epitaxy. *See* Appx2300-2301, Appx2311-2312 (Trial Tr. 6 at 215-16, 226-27) (Dr. Fitzgerald explaining that the "patent is about epitaxy"). The summary of the invention and the discussion of the preferred embodiment mention MBE as the only method of interest. The summary states that the two-step approach results in "[a] film [that] is epitaxially grown . . . ." Appx213 col. 2 ll. 14-15. The discussion of the preferred embodiment also relies on the use of an "ECR-MBE system," which is a molecular-beam *epitaxy* device. Appx214 col. 3 ll. 37-40. And that same section's discussion of how GaN is grown on the sapphire substrate is a textbook example of epitaxy. *Id.* col. 4 ll. 11-40; Appx2290-2292, Appx2295-2298 (Trial Tr. 6 at 187-89, 192-95).[8]

[8] Dr. Fitzgerald's statement that a monocrystalline growth layer *could* be formed on an amorphous buffer layer using non-epitaxial methods is therefore entirely irrelevant, Appx2330-2331 (Trial Tr. 7 at 28-29), because the '738 Patent is unconcerned with non-epitaxial methods.

Dr. Piner's assertion to the contrary is nothing more than clever wordplay. See Appx2382-2383 (Trial Tr. 9 at 143-44). He reasoned as follows: (1) Epitaxy is a process of depositing one crystalline layer on top of the next, intending that each layer's crystalline structure will affect the structure of the layer above it. *Id*. (2) An epitxial process could not, therefore, involve depositing a monocrystalline growth layer on an amorphous layer because the amorphous layer has no crystalline structure. *Id.* (3) Because BU had persuaded the district court to construe the claim to include semiconductors with amorphous buffer layers, Dr. Piner reasoned, "the patent does not teach epitaxy." Appx17-19.

There is no substance to this argument. Dr. Piner admitted that setting aside the amorphous buffer layer, the actual methods described are epitaxial, involving the depositing one layer of material on top of another through MBE. *Id*.; *see also* Appx2384-2385 (Trial Tr. 9 at 154-55). He therefore acknowledged that the process is properly called "epitaxy" when applied to other layers. *Id*. What label is applied when the exact same process is used to attempt to deposit the growth layer on an amorphous buffer layer is irrelevant to Defendants' enablement argument. Our point is that the Patent instructs the reader to deposit the GaN growth layer using the same machines and methods used in epitaxy, and promises that the result will be a monocrystalline growth layer, when everyone acknowledges it won't if the buffer layer is amorphous. Whether the doomed enterprise is called "non-epitaxy" or "*failed* epitaxy" makes no difference.[9]

Finally, to the extent Dr. Piner implied that the Patent *must* impliedly teach some other method for laying down the growth layer on an amorphous buffer layer, because epitaxy will not work, that argument is completely question-begging. The fact that Claim 19 *claims* a particular kind of device does not warrant the assumption that the Patent must *enable* it. Nor was the jury free to follow Dr. Piner's example and simply disregard the possibility that the Patent's teaching is limited to a method that would fail to enable the full scope of the claims.

Second, even if Dr. Piner were right that the Patent does not *exclusively* teach epitaxy, that would not show that the Patent was enabled; it would simply raise the next question – does the Patent enable production of the full scope of the claims through the hypothesized non-epitaxial method? *See ALZA Corp. v. Andrx. Pharms., LLC*, 603 F.3d 935, 941 (Fed. Cir. 2010) ("To satisfy the plain language of [§ 112(a)], ALZA was required to provide an adequate enabling disclosure in the specification; it cannot simply rely on the knowledge of a person of ordinary

[9] Dr. Piner's argument also assumes the Patent actually enables an amorphous buffer layer upon which one could attempt to deposit a monocrystalline growth layer. But, as discussed above, that assumption is false. *See supra* § I.A.

skill to serve as a substitute for the missing information in the specification.”). And the answer to that question is clear – it does not.

If Dr. Moustakas envisioned the use of other methods besides epitaxy, any “direction or examples of how such an idea might be implemented” is “glaringly missing from the specification[].” *Enzo Biochem, Inc. v. Calgene, Inc.*, 188 F.3d 1362, 1375 (Fed. Cir. 1999) (internal quotation marks omitted). The ’738 Patent includes no direct mention of non-epitaxial methods. At best, the Patent indirectly mentions other “[c]urrent methods of preparing GaN,” but only to establish that those methods are inadequate. Appx213 col. 1. 65 – col. 2 l. 6. And it certainly contains no *direction* on how to employ any non-epitaxial method to create a semiconductor with a monocrystalline GaN growth layer directly on top of an amorphous buffer layer. It is not enough that the patent contain the “mere germ of an idea,” *Genentech, Inc. v. Novo Nordisk*, 108 F.3d 1361, 1366 (Fed. Cir. 1997), that others must then discover how to bring to fruition.

* * *

Defendants have presented clear and convincing evidence that Claim 19 is not enabled by the specification of the Patent, and is therefore invalid. This Court should order judgment in favor of Defendants or, in the least, order a new trial on invalidity.

II. The ’738 Patent Fails The Written Description Requirement of Section 112(a).

Even if this Court concluded that there was sufficient evidence to support the jury’s enablement finding, it should order JMOL or a new trial for lack of an adequate written description.[10]

1. Section 112(a) requires that the “specification shall contain a written description of the invention.” *Ariad Pharms., Inc. v. Eli Lilly & Co.*, 598 F.3d 1336, 1343 (Fed. Cir. 2010) (en banc) (quoting 35 U.S.C. § 112). “[T]he test for sufficiency [of the written description] is whether the disclosure of the application relied upon reasonably conveys to those skilled in the art that the inventor *had possession* of the claimed subject matter as of the filing date.” *Id.* at 1351 (emphasis added). In other words, the written description requirement ensures that the inventor actually invented the full scope of what is later claimed to be encompassed by the patent. This Court has illustrated the principle through the example of an inventor who “created a particular fuel-efficient automobile engine and described the engine in such detail in the specification that a person of ordinary skill in the art would be able to build the engine.” *LizardTech, Inc. v. Earth Res. Mapping, Inc.*, 424 F.3d 1336, 1346 (Fed. Cir. 2005). Although the

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[10] The district court neglected to address Defendants’ written description argument, but this Court may do so in the first instance because the denial of JMOL is reviewed *de novo*. *See supra* pp. 9-10.

specification would support "a claim directed to that particular engine," a "broad claim to every possible type of fuel-efficient engine" would be invalid under Section 112(a) unless the written description would "reasonably convey to a person skilled in the art that [the inventor] had possession of the claimed subject matter at the time of filing." *Id.* (internal quotation marks and citations omitted).

The written description requirement thus "guards against the inventor's overreaching by insisting that he recount his invention in such detail that his future claims can be determined to be encompassed within his original creation." *Vas-Cath Inc. v. Mahurkar*, 935 F.2d 1555, 1561 (Fed. Cir. 1991) (quoting *Rengo Co. v. Molins Mach. Co.*, 657 F.2d 545, 551 (3d Cir. 1981)). And as is true of enablement, the written description requirement applies to the entirety of the invention claimed, "including *any variations and alternatives* contemplated by the inventor." *Space Systems/Loral, Inc. v. Lockheed Martin Corp.*, 405 F.3d 985, 987 (Fed. Cir. 2005) (emphasis added).

2. In this case, "an objective inquiry into the four corners of the specification from the perspective of a person of ordinary skill in the art," *Ariad Pharms.*, 598 F.3d at 1351, clearly demonstrates that Dr. Moustakas had not invented a semiconductor with a monocrystalline growth layer directly above an amorphous buffer layer, or indeed any kind of semiconductor with an amorphous buffer layer at all, as of the date of filing. As discussed, nothing in the written

description conveyed to a person skilled in the art at the time of filing that the invention described therein included an amorphous buffer layer, much less one with a monocrystalline GaN layer directly on top of it. Indeed, there are multiple indications in the written description that the inventor had possession only of devices with partially or fully crystallized buffer layers. *See, e.g.*, Appx214 at col. 4 ll. 23-40 (describing that the entire purpose of heating the buffer layer was to "ensure" that it "had crystallized" before attempting to form the growth layer).

Importantly, this would be true even if this Court concluded that the invention was fully enabled because a person skilled in the art could create a device with an amorphous buffer layer (and one with a monocrystalline growth layer on top of it) through reasonable experimentation. While enablement and written description analyses "usually rise and fall together," *LizardTech*, 424 F.3d at 1345, it is possible for a claim to meet the enablement requirement yet fail to provide an adequate written description, *see Amgen Inc. v. Hoechst Marion Roussel, Inc.*, 314 F.3d 1313, 1334 (Fed. Cir. 2003) (noting that the "enablement requirement is often more indulgent than the written description requirement"). This is because, for enablement, the "specification need not explicitly teach those in the art to make and use the invention; the requirement is satisfied if, given what they already know, the specification teaches those in the art enough that they can make and use the invention without undue experimentation." *Id.* (internal quotation marks omitted). The written description requirement, on the other hand, requires disclosure of exactly what the inventor actually invented – not what he (or someone else) could have invented with some additional experimentation. *Id.* at 1330-34.

In this case, even assuming, *arguendo*, that a person skilled in the art may have been able to eventually figure out how to create a semiconductor with a monocrystalline GaN growth layer directly on top of an amorphous buffer layer, there is no basis in the written description for concluding Dr. Moustakas had done so at the time of filing. Quite to the contrary, BU's principal evidence of enablement through reasonable experimentation is testimony that Dr. Moustakas did, in fact, create chips with amorphous buffer layers and monocrystalline growth layers, but only after an additional seven years of experimentation. *See supra* § I.B.3.

This case thus bears a striking resemblance to the engine patent hypothetical presented in *LizardTech*. Here, Dr. Moustakas invented a particular type of GaN semiconductor with a non-amorphous buffer layer, and the specification adequately describes *that* invention. BU, however, has claimed that the patent *also* covers semiconductors with an amorphous buffer layer. Like the hypothesized overbroad claim to all types of fuel-efficient engines, Dr. Moustakas's overbroad claim to all types of non-single crystalline buffer layers must fail for its lack of adequate description of what he actually invented.

3. BU presented no convincing response to Defendants' written description challenge below. Indeed, its response relied solely on a series of conclusory statements by Dr. Piner. Appx2489-2492. Beyond being entirely unsupported by the language of the written description, Dr. Piner's testimony is insufficient to rebut the Defendant's clear and convincing evidence of invalidity because such "conclusory testimony" that is "devoid of any factual content upon which the jury could have relied . . . cannot constitute substantial evidence." *Ariad*, 598 F.3d at 1357 n.8.

* * *

Through an overreaching claim construction, BU sought a patent monopoly for more than Dr. Moustakas actually invented, adequately described, or fully enabled. In advancing such "broad claim language" BU brought upon itself "the peril of losing any claim that cannot be enabled across the full scope of its coverage," *MagSil*, 687 F.3d at 1381, or was not shown to be in the possession of the inventor at the time of the patent application. The evidence at trial clearly and convincingly showed that the gamble did not pay off in this case.

III. The District Court Erred In Construing The Claim Term "Grown On."

Finally, Defendants Everlight and Lite-on incorporate by reference Epistar's argument that the district court erred in construing the claim term "grown on," necessitating a new trial on infringement if this Court does not reverse the denial of JMOL on invalidity. *See* Epistar Br. § I.

CONCLUSION

This Court should hold that the '738 Patent is invalid for lack of either enablement or written description and order JMOL or, at the very least, a new trial on invalidity. If the Court upholds the validity determination, it should adopt Defendants' proposed construction of "grown on" and order a new trial on infringement.

Respectfully submitted,

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December 27, 2016

ADDENDUM

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IN THE UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

TRUSTEES OF BOSTON UNIVERSITY, Plaintiff, v. LITE-ON, INC., ET AL., Defendants.	Civil Action No. 1:12-cv-12330-PBS

~~[PROPOSED]~~ FINAL JUDGMENT AGAINST
LITE-ON, INC. & LITE-ON TECHNOLOGY CORPORATION

In accordance with the Jury Verdict returned on November 19, 2015 (Dk. 1589) and the Court's Orders (Dkt. Nos. 1718 & 1768 from Case No. 1:12-cv-11935), the Court hereby renders the following **Final Judgment** against Lite-On Technology Corporation and Lite-On, Inc.:

1. U.S. Patent 5,686,738 ("the '738 patent") is not invalid.

2. Defendants Lite-On Technology Corporation and Lite-On, Inc. (collectively "Lite-On") have directly infringed claim 19 of the '738 patent.

3. The jury awarded Plaintiff Trustees of Boston University ("Boston University") a lump sum of $365,000 in reasonable royalty damages for Lite-On's infringement of the '738 patent.

4. Under 35 U.S.C. § 284, the Court awards Boston University prejudgment interest in the amount of $41,836, payable by Lite-On, calculated from December 14, 2012 to May 3, 2016, based upon the Prime Rate in effect on December 14th of each year in the interest period, compounded annually.

5. Under 28 U.S.C. § 1961(a), the Court awards Boston University postjudgment interest payable by Lite-On at the statutory rate of 0.54 %, compounded annually.

6. It is ORDERED that Boston University recover the sum of Four Hundred Six Thousand Eight Hundred and Thirty Six Dollars ($406,836.00) from Lite-On, plus postjudgment interest.

7. Lite-On Technology Corporation and Lite-On, Inc. are jointly and severally liable to Boston University for all damages and interest awarded herein.

Dated: 8/12, 2016

PATTI B. SARIS
UNITED STATES DISTRICT JUDGE

UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

IN RE TRUSTEES OF BOSTON UNIVERSITY PATENT CASES	)	Civil Action Nos. 12-cv-11935-PBS 12-cv-12326-PBS 12-cv-12330-PBS

~~UNCONTESTED PROPOSED FORM OF~~ JUDGMENT

In accordance with the Jury Verdict returned on November 19, 2015 (Dk. 1589) and pursuant to Federal Rule of Civil Procedure 58, the Court hereby renders the following Judgment:

A. Epistar Corporation

1. The jury having determined that Defendant Epistar Corporation ("Epistar") willfully infringed claim 19 of U.S. Patent 5,686,738 ("the '738 patent) both directly and indirectly; the jury having found that the asserted claim of the '738 patent is not invalid; and the jury having awarded Plaintiff Trustees of Boston University ("Boston University") the lump sum of $9,300,000 in reasonable royalty damages against Epistar: It is ORDERED that Boston University recover from Epistar the sum of $9,300,000 in reasonable royalty damages for Epistar's willful infringement of the '738 patent.

2. Under 35 U.S.C. § 284, the Court awards Boston University prejudgment interest in the amount of $4,476,490, payable by Epistar, calculated from December 14, 2006 to May 3, 2016, based upon the Prime Rate[1], compounded annually.

[1] For Epistar the Prime Rate in effect on December 14th of each year in the interest period will be used.

3. Under 28 U.S.C. § 1961(a), the Court awards Boston University post judgment interest payable by Epistar at the statutory rate of 0.54 %, compounded annually. The daily post judgment interest for Epistar will be $204.

B. Everlight Defendants

1. The jury having determined that Defendants Everlight Electronics Co., Ltd. and Everlight Americas, Inc. (collectively "Everlight") willfully infringed claim 19 of U.S. Patent 5,686,738 ("the '738 patent); the jury having found that the asserted claim of the '738 patent is not invalid; and the jury having awarded Plaintiff Trustees of Boston University ("Boston University") the lump sum of $4,000,000 in reasonable royalty damages against Everlight: It is ORDERED that Boston University recover from Everlight the sum of $4,000,000 in reasonable royalty damages for Everlight's willful infringement of the '738 patent.

2. Under 35 U.S.C. § 284, the Court awards Boston University prejudgment interest in the amount of $1,709,607, payable by Everlight, calculated from April 18, 2007 to May 3, 2016, based upon Prime Rate,[2] compounded annually.

3. Under 28 U.S.C. § 1961(a), the Court awards Boston University post judgment interest payable by Everlight at the statutory rate of 0.54 %, compounded annually. The daily post judgment interest for Everlight will be $85.

4. Everlight Electronics Co., Ltd. and Everlight Americas, Inc. are jointly and severally liable to Boston University for the damages and interest amounts herein.

C. Lite-On Defendants

1. The jury having determined that Defendants Lite-On Technology Corporation and Lite-On, Inc. (collectively "Lite-On") infringed claim 19 of U.S. Patent 5,686,738 ("the '738

[2] For Everlight the Prime Rate in effect on April 18th of each year in the interest period will be used.

patent); the jury having found that the asserted claim of the '738 patent is not invalid; and the jury having awarded Plaintiff Trustees of Boston University ("Boston University") the lump sum of $365,000 in reasonable royalty damages against Lite-On: It is ORDERED that Boston University recover from Lite-On the sum of $365,000 in reasonable royalty damages for Lite-On's infringement of the '738 patent.

2. Under 35 U.S.C. § 284, the Court awards Boston University prejudgment interest in the amount of $41,836, payable by Lite-On, calculated from December 14, 2012 to May 3, 2016, based upon the Prime Rate,[3] compounded annually.

3. Under 28 U.S.C. § 1961(a), the Court awards Boston University post judgment interest payable by Lite-On at the statutory rate of 0.54 %, compounded annually. The daily post judgment interest for Lite-On will be $6.

4. Lite-On Technology Corporation and Lite-On, Inc. are jointly and severally liable to Boston University for the damages and interest amounts herein

D. Additional Relief

1. Boston University is the prevailing party with respect to defendants Epistar and Everlight and, thus, entitled to costs under Federal Rule of Civil Procedure 54.

2. Rulings on the amount of costs, enhanced damages, and attorneys' fees are expressly reserved for later determination.

Dated: ~~May 3, 2016~~ 4/29/16

Patti B Saris
PATTI B. SARIS
UNITED STATES DISTRICT JUDGE

[3] For Lite-On the Prime Rate in effect on December 14th of each year in the interest period will be used.

UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

TRUSTEES OF BOSTON UNIVERSITY, Plaintiff, v. EVERLIGHT ELECTRONICS CO., LTD., et al., Defendants.	Consolidated Civil Action No. 12-11935-PBS
TRUSTEES OF BOSTON UNIVERSITY, Plaintiff, v. EPISTAR CORPORATION, et al., Defendants.	Civil Action No. 12-12326-PBS
TRUSTEES OF BOSTON UNIVERSITY, Plaintiff, v. LITE-ON INC., et al., Defendants.	Civil Action No. 12-12330-PBS

MEMORANDUM AND ORDER

July 22, 2016

Saris, C.J.

INTRODUCTION

Plaintiff Trustees of Boston University (BU) filed suit against Defendants Epistar Corporation, Everlight Electronics Co., Ltd., and Lite-On, Inc., alleging infringement of U.S. Patent No. 5,686,738. In November 2015, a jury found that the patent was valid and willfully infringed, and awarded BU damages in the amount of $13,665,000. The defendants have now renewed their motion for judgment as a matter of law pursuant to Federal Rule of Civil Procedure 50(b),[1] and moved for a new trial, or remittitur, under Rule 59 (Docket No. 1728). The plaintiff has moved for enhanced damages under 35 U.S.C. § 284 (Docket No. 1632), and for attorneys' fees under 35 U.S.C. § 285 (Docket No. 1732), which the Court resolves in separate orders.

In the renewed motion for judgment as a matter of law, the defendants allege that the '738 patent does not teach one of ordinary skill in the art how to enable the full scope of the claimed invention. The defendants also argue for a new trial, or remittitur, on the damages award because it is not supported by comparable lump-sum licenses or comparable running royalty licenses that could have been adjusted to calculate a lump sum. Finally, the defendants argue for a new trial on the grounds that BU made prejudicial and inflammatory remarks regarding the defendants' nationality throughout trial.[2] After hearing, I uphold the jury's verdict as to validity and **DENY** the

[1] The defendants had already so moved under Federal Rule of Civil Procedure 50(a) at the close of the plaintiff's case, and again at the close of evidence. The Court denied both motions.
[2] The defendants raise a number of other arguments in their renewed motion for judgment as a matter of law, or alternatively a new trial, which the Court has previously addressed in other orders in this case. The Court assumes familiarity with those orders, and does not repeat its discussion of those issues here.

defendants' Rule 50(b) motion. The Court **ALLOWS** the motion for a new trial on damages, or remittitur, with respect to Epistar and Everlight, and **DENIES** the motion with respect to Lite-On. I **DENY** the renewed motion for judgment as a matter of law, or alternatively a new trial, on all other issues.

DISCUSSION

I. Standards of Review

Federal Circuit law governs patent law issues, while regional circuit law applies to procedural issues. Shockley v. Arcan, Inc., 248 F.3d 1349, 1358 (Fed. Cir. 2001). "The grant or denial of a motion for judgment as a matter of law is a procedural issue not unique to patent law, reviewed under the law of the regional circuit in which the appeal from the district court would usually lie." Summit Tech., Inc. v. Nidek Co., 363 F.3d 1219, 1223 (Fed. Cir. 2004). Likewise, the grant or denial of a motion for a new trial, and a district court's duty to remit excessive damages, are procedural issues, governed by the law of the regional circuit. See Lucent Techs., Inc. v. Gateway, Inc., 580 F.3d 1301, 1309 (Fed. Cir. 2009); Shockley, 248 F.3d at 1358.

To prevail on a renewed motion for judgment as a matter of law following a jury trial, the moving party must show that "the evidence points so strongly and overwhelmingly in favor of the moving party that no reasonable jury could have returned a verdict adverse to that party." Marcano Rivera v. Turabo Med. Ctr. P'ship, 415 F.3d 162, 167 (1st Cir. 2005). The Court must view the evidence in the light most favorable to the non-moving party, and may not substitute its own view for that of the jury where evidence is in conflict. See Osorio v. One World Techs., Inc., 659 F.3d 81, 84 (1st Cir. 2011).

In contrast, the Court's "power to grant a motion for a new trial is much broader than its power to grant a JMOL." Jennings v. Jones, 587 F.3d 430, 436 (1st Cir. 2009). With respect to the damages award, the Court has discretion "to order a remittitur if such an action is warranted in light of the evidence adduced at trial." Trainor v. HEI Hosp., LLC, 699 F.3d 19, 29 (1st Cir. 2012). "In reviewing an award of damages, the district court is obliged to review the evidence in the light most favorable to the prevailing party and to grant remittitur or a new trial on damages only when the award exceeds any rational appraisal or estimate of the damages that could be based upon the evidence before it." Wortley v. Camplin, 333 F.3d 284, 297 (1st Cir. 2003) (internal quotation marks omitted); Lucent, 580 F.3d at 1310 ("A jury's decision with respect to an award of damages must be upheld unless the amount is grossly excessive or monstrous, clearly not supported by the evidence, or based only on speculation or guesswork."(internal quotation marks omitted)).

II. <u>Enablement</u>

A. Legal Standard

Pursuant to 35 U.S.C. § 112, ¶ 1, a patent must be enabled in order to be valid. The "enablement requirement is satisfied when one skilled in the art, after reading the specification, could practice the claimed invention without undue experimentation." <u>AK Steel Corp. v. Sollac & Ugine</u>, 344 F.3d 1234, 1244 (Fed. Cir. 2003). The full scope of the claim must be enabled, meaning that the "scope of the claims must be less than or equal to the scope of the enablement" in order to ensure "that the public knowledge is enriched by the patent specification to a degree at least commensurate with the scope of the claims." <u>Nat'l Recovery Techs., Inc. v. Magnetic Separation Sys., Inc.</u>, 166 F.3d 1190, 1196 (Fed. Cir. 1999). Enablement is a question of law based on underlying facts. <u>See In re Wands</u>, 858 F.2d 735, 735 (Fed. Cir. 1988). It was the defendants' burden at trial to show by clear and convincing evidence that the patent was invalid for lack of enablement. <u>See Microsoft Corp. v. i4i Ltd. P'ship</u>, 564 U.S. 91, 95 (2011).

The '738 patent at issue in this case, titled "Highly Insulating Monocrystalline Gallium Nitride Thin Films," claims "a semiconductor device comprising . . . a non-single crystalline buffer layer . . . [and] a growth layer grown on the buffer layer." These semiconductor devices are used in light-emitting diode (LED) packages. In its Markman order, this Court construed the term "non-single crystalline" to mean "polycrystalline, amorphous, or a mixture of polycrystalline and amorphous." Trs. of Boston Univ. v. Everlight Elecs. Co., Ltd., 23 F. Supp. 3d 50, 62-63 (D. Mass. 2014). The Court adopted the definition of "non-single crystalline" proposed by the inventor, Dr. Moustakas, at claim construction. See id. The Court also construed the term "grown on" to mean "formed indirectly or directly above." Id. at 59-62.

B. Analysis

Only enablement of the amorphous buffer layer was seriously in dispute at trial. In the first instance, the parties disputed whether the plaintiff was obliged to show enablement of the amorphous buffer layer, given the disjunctive nature of the claim construction definition. In BU's view, the specification need only enable at least one of the three possible iterations of the term "non-single crystalline," and the defendants could defeat the patent for invalidity only by showing that all three iterations of the buffer layer—polycrystalline, mixed, and amorphous—were not enabled. However, the defendants countered that they need only show that one iteration was not sufficiently enabled to demonstrate that the patent is invalid. The defendants' position ultimately won the day.

Although BU was entitled to request a changed claim construction up until the jury verdict, see Utah Med. Prods., Inc. v. Graphic Controls Corp., 350 F.3d 1376, 1381-82 (Fed. Cir. 2003), it pressed the tripartite definition throughout trial. Furthermore, BU pressed its position that it would deem an amorphous buffer layer infringing of the ‘738 patent. Having taken this stance, BU cannot also contend that it is not obliged to enable an amorphous buffer layer itself. This represents the fundamental “quid pro quo” of the patent endeavor. See AK Steel, 344 F.3d at 1244.

That said, the defendants raised a second, late-formed argument at trial that the patent must enable not only all three iterations of the buffer layer’s crystallinity—polycrystalline, mixed, and amorphous—but also semiconductor devices with a gallium nitride (GaN) growth layer formed both directly and indirectly above all three iterations of the buffer layer. Neither the parties nor the Court could find any cases requiring enablement of every possible permutation of every iteration. The defendants cite to AK Steel, 344 F.3d at 1244, however, to support their argument.

In AK Steel, the patent at issue “read on steel strips containing either a Type 1 or a Type 2 aluminum coating,” and “the claims require[d] that the coating wet well.” Id. The Federal Circuit explained that the specification does not necessarily have to "describe how to make and use every possible variant of the claimed invention, for the artisan's knowledge of the prior art and routine experimentation can often fill gaps, interpolate between embodiments, and perhaps even extrapolate beyond the disclosed embodiments, depending upon the predictability of the art." Id. Instead, "when a range is claimed, there must be reasonable enablement of the scope of the range." Id. The court concluded that the claims had not been enabled because the specification "clearly and strongly warn[ed]" that the Type 1 aluminum coating would not wet well, and the patent expressly taught against it. Id.

Here, the specification does not warn against any permutation. Claim 19 of the patent uses the term "grown on" to refer to both the relationship between the substrate and the buffer layer, and the relationship between the buffer layer and the growth layer. The Markman order specifically addressed "whether the term 'grown on' precludes the addition of layers between the layers expressly recited in the patent." Trs. of Boston Univ., 23 F. Supp. 3d at 59 (emphasis in original). The Court concluded that the term does not preclude additional layers, and construed "grown on" to mean "formed indirectly or directly above." Id. at 62 (emphasis added). Taken to its logical conclusion, the defendants' argument would require the patent to enable multiple permutations, representing various combinations of a direct and indirect relationship between the substrate and the buffer layer, and the buffer and growth layer, for all three iterations of the buffer layer's crystallinity. I find that such a requirement would be unreasonable. BU was not obliged to show that the patent enabled a device with a GaN growth layer formed directly on an amorphous buffer layer, as long as it could demonstrate that the patent enabled a device with a GaN growth layer formed indirectly on an amorphous buffer layer.

Given this, the defendants' primary contentions are now that (1) the specification fails to teach one of ordinary skill in the art how to produce a semiconductor device with an amorphous GaN buffer layer without undue experimentation, and (2) even if an amorphous buffer layer was possible, the specification does not teach how to epitaxially grow a monocrystalline GaN layer on an amorphous GaN buffer layer. The jury heard testimony about enablement from one of the defendants' experts, Dr. Eugene Fitzgerald, an MIT professor of material science and engineering, as well as from the plaintiff's experts, Dr. Theodore Moustakas, the inventor, and Dr. Edwin Piner, a professor of material science engineering and commercialization at Texas State University. Both parties presented strong arguments in support of their respective positions. Based on the conflicting expert opinions, a reasonable jury could have concluded that the defendants failed to show by clear and convincing evidence that the patent was invalid for lack of enablement.

As to the first theory of invalidity, Dr. Fitzgerald testified that "the patent does not teach how to make a device with an amorphous buffer layer," because "in the second step [of] . . . a two-step process, you crystallize the amorphous film, so there is no amorphous film." Trial Tr. vol. 6, Docket No. 1596, at 216, 223-24. Rather than teach how to grow an amorphous buffer layer, Dr. Fitzgerald opined, the patent "actually teaches you to crystallize the buffer," "[a]s the temperature increases to 600 degrees." Id. at 223.

However, the jury also heard testimony from Dr. Piner that one with ordinary skill in the art could "maintain[] the amorphous nature of the buffer layer, or even some sublayers" at the higher temperatures, based on "an understanding of what these temperature ranges mean." Trial Tr. vol. 4, Docket No. 1594, at 50. According to Dr. Piner, the patent "talks about forming an amorphous film to begin with," and that amorphous film "then can be, meaning can or cannot be as well, crystallized." Id. at 49. Dr. Piner further explained that "when the crystallization process happens, it doesn't necessarily have to occur throughout the entirety of the thickness of the buffer layer." Id. at 50.

Similarly, Dr. Moustakas testified that when he grew a "gallium nitride buffer, that material was amorphous. It didn't have any crystalline structure." Trial Tr. vol. 2, Docket No. 1592, at 76. Even though the GaN growth layer is monocrystalline, he clarified, "it will cover underneath material which is still either amorphous or polycrystalline." Id. at 88-89. The jury thus heard competing testimony from multiple qualified experts as to whether the patent enabled an amorphous buffer layer.

As to the defendants' second theory of invalidity, Dr. Fitzgerald testified that even if an amorphous buffer layer was enabled, the patent "does not teach how to make a device with a monocrystalline growth layer on an amorphous buffer layer." Trial Tr. vol. 6, Docket No. 1596, at 216. Furthermore, in Dr. Fitzgerald's opinion, "the patent is about epitaxy," and it is impossible to epitaxially grow a monocrystalline film on any amorphous substance without undue experimentation, whether or not that substance is GaN. See id. at 226-27, 232.

Once again, though, the jury heard conflicting testimony from the plaintiff's experts about what the patent teaches, whether it is possible to grow a monocrystalline film on an amorphous substance, and whether the patent requires an epitaxial process. First, Dr. Piner testified that a person of ordinary skill in the art could, using the teaching of the patent, make an amorphous buffer layer with a monocrystalline GaN layer on top: "if you were to follow those sorts of boundaries within the teachings of the '738 patent," Dr. Piner stated, "you could realize with not much experimentation . . . the amorphous buffer layer . . . and then a monocrystalline gallium nitride on top." Trial Tr. vol. 4, Docket No. 1594, at 50. He testified that "the elements of the claim itself teaches how to do that accurately." Id. at 46.

Furthermore, both Dr. Moustakas and Dr. Piner challenged Dr. Fitzgerald's view about the impossibility of growing a monocrystalline layer on an amorphous substance. Dr. Moustakas testified that he has grown a single-crystalline semiconductor on an amorphous material, Trial Tr. vol. 2, Docket No. 1592, at 118, and that other scientists recently "reported single crystalline gallium nitride on glass," which "is an amorphous material," in the scientific journal Nature. Id. at 119.[3] Likewise, Dr. Piner stated, "I published a gallium nitride monocrystalline film that has grown on an amorphous material." Trial Tr. vol. 4, Docket No. 1594, at 46.

Although Dr. Piner agreed with Dr. Fitzgerald's view that one cannot epitaxially grow a monocrystalline layer on an

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[3] Although this research occurred after the patent was issued, it was admitted solely to rebut the argument that such growth was scientifically impossible.

amorphous structure, he cautioned that "what the patent teaches is not epitaxy." Trial Tr. vol. 9, Docket No. 1599, at 143. Epitaxy is a process used to make semiconductors, involving the "controlled and oriented growth of a thin single-crystal layer upon the surface of another single crystal, with the deposited layer having the same crystalline orientation as its substrate." Trs. of Boston Univ., 23 F. Supp. 3d at 55 (quoting Wiley Electrical and Electronics Engineering Dictionary 260–61 (Steven M. Kaplan ed., 2004)). Dr. Piner agreed with this technical definition at trial, explaining that "in order to have epitaxy, you have one crystal structure, and on top of that you have another crystal structure, one single crystal, on top of that, another single crystal." Trial Tr. vol. 9, Docket No. 1599, at 143. He pointed out, however, that "the patent teaches the deposition of a film that is amorphous." Id.; see also U.S. Patent No. 5,686,738 col. 2 l. 40-41 ("A film . . . is deposited, which is amorphous at the low temperatures of the nucleation step."). By definition, amorphous means "having a noncrystalline structure." William D. Callister, Jr. & David G. Rethwisch, Materials Science and Engineering: An Introduction G1 (2010). Thus, Dr. Piner concluded that, "strictly speaking," the patent does not teach epitaxy. Trial Tr. vol. 4, Docket No. 1594, at 138.

Dr. Piner clarified that, although Dr. Moustakas "was using a growth process that happens to have in the term 'molecular beam epitaxy,'" it would be "misleading" to say that the patent uses an epitaxial process to form each layer. Trial Tr. vol. 4, Docket No. 1594, at 138. "You're still forming the material, you're still growing it," Dr. Piner explained, but "if you do not have an epitaxial relationship" between two materials, "[y]ou would say I'm growing a layer." Id. "Now, once you get to the GaN growth layer on top, you could perhaps use the term 'epitaxy' to describe the relationship of the crystal structure of the monocrystalline of the gallium nitride to that of the sapphire [substrate]." Id. Dr. Fitzgerald acknowledged that the word "epitaxy" does not appear anywhere in Claim 19 of the '738 patent. Trial Tr. vol. 7, Docket No. 1597, at 24. Thus, a reasonable jury could have concluded that it is possible to grow a monocrystalline GaN growth layer on an amorphous buffer layer, even if not epitaxially, and that the patent teaches one skilled in the art how to do so.

While the defendants presented credible evidence from Dr. Fitzgerald that the '738 patent did not enable an amorphous buffer layer, or teach how to grow a monocrystalline GaN layer on such an amorphous buffer, the plaintiff presented contrary evidence from Dr. Moustakas and Dr. Piner. Their testimony plainly supports that the patent teaches how to form a monocrystalline GaN growth layer indirectly above an amorphous buffer layer, perhaps with an intervening polycrystalline layer. It is less clear whether the patent teaches how to grow a monocrystalline GaN layer directly on an amorphous buffer layer, with no intervening layers. Even if BU were required to show enablement of every possible permutation of every iteration, it was a close call at trial whether the patent enables a monocrystalline GaN growth layer formed directly on an amorphous buffer. The jury was ultimately tasked with weighing the conflicting views of qualified experts. Given the defendants' high burden in proving invalidity, a reasonable jury could have concluded that the defendants failed to show that the patent was not enabled by clear and convincing evidence. Accordingly, I **DENY** the motion for judgment as a matter of law.

III. Lump-Sum Damages Awards

A. Legal Standard for a Reasonable Royalty

Upon a finding for the claimant in a patent infringement case, "the court shall award the claimant damages adequate to compensate for the infringement, but in no event less than a reasonable royalty for the use made of the invention by the infringer, together with interest and costs as fixed by the court." 35 U.S.C. § 284. "The burden of proving damages falls on the patentee." Lucent, 580 F.3d at 1324. "To properly carry this burden, the patentee must sufficiently tie the expert testimony on damages to the facts of the case." Uniloc, USA, Inc. v. Microsoft Corp., 632 F.3d 1292, 1315 (Fed. Cir. 2011) (internal quotation marks and citations omitted).

There are several approaches for calculating a reasonable royalty. Lucent, 580 F.3d at 1324. Here, the parties agreed on the hypothetical negotiation approach, which "attempts to ascertain the royalty upon which the parties would have agreed had they successfully negotiated an agreement just before infringement began." Virnetx, Inc. v. Cisco Sys., Inc., 767 F.3d 1308, 1326 (Fed. Cir. 2014). "The hypothetical negotiation tries, as best as possible, to recreate the ex ante licensing negotiation scenario and to describe the resulting agreement." Lucent, 580 F.3d at 1325. "In other words, if infringement had not occurred, willing parties would have executed a license agreement specifying a certain royalty payment scheme. The hypothetical negotiation also assumes that the asserted patent claims are valid and infringed." Id. This analysis "necessarily involves an element of approximation and uncertainty." Id. The parties here agreed that the hypothetical negotiation would have occurred in 2000.

"A reasonable royalty may be a lump-sum payment not calculated on a per unit basis, but it may also be, and often is, a running payment that varies with the number of infringing units." Virnetx, 767 F.3d at 1326. Here, the jury awarded a one-time, lump-sum payment for the life of the patent with respect to each defendant in the following amounts: $9,300,000 against Epistar, $4,000,000 against Everlight, and $365,000 against Lite-On. Verdict Form, Docket No. 1589, at 3. The jury, which was given the option on the verdict form of awarding a lump sum or a running royalty, left the space next to the running royalty option blank. Id.

B. Trial Testimony

At trial, BU's damages expert, Mr. Ratliff, testified that BU would have negotiated a hypothetical license with a running royalty of four to six percent on sales of the accused products. He ultimately applied a four-percent rate to each defendant's accused sales base to determine that the total damages against Epistar should be at least $8,660,914, the total damages against Everlight should be at least $5,686,693, and the total damages against Lite-On should be at least $538,700.[4] Mr. Ratliff structured his testimony around the Georgia-Pacific framework, which outlines fifteen factors for juries to consider in awarding a reasonable royalty. See Georgia-Pacific Corp. v. U.S. Plywood Corp., 318 F. Supp. 1116, 1120 (S.D.N.Y. 1970). Subsumed

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[4] Mr. Ratliff also presented an alternative, lower set of damages figures, calculated using a four-percent rate and a smaller revenue base, in case the jury accepted the defendants' arguments under the entire market value rule. The lower damages figures were: $7,814,260 against Epistar, $4,407,990 against Everlight, and $221,552 against Lite-On.

within the second factor "is the question of whether the licensor and licensee would have agreed to a lump-sum payment or instead to a running royalty based on ongoing sales or usage." Lucent, 580 F.3d at 1326.

Mr. Ratliff only testified in support of a running royalty, and did not explain how the jury could convert his figures into lump-sum payments should the jury choose to adopt a lump-sum format. He highlighted one of the critical differences between a running royalty and a lump-sum payment. He explained that when parties enter "a running royalty, a percentage of sales is an unknown. You don't know how much someone's actually going to use your patents and what you're going to sell. So on day one when you enter a running royalty license, you may never see any royalties." Trial Tr. vol. 5, Docket No. 1595, at 107-08. In contrast, in a lump-sum license, "you never know how much the licensee is going to use the technology, but they're paying you money up-front. It's a guaranteed return." Id. at 108. Despite the fact that the plaintiff's expert never testified in support of lump-sum awards, BU's counsel pivoted from his expert's testimony and argued for lump-sum awards in closing argument.[5]

[5] The issue of damages became complicated at trial because, at the last minute, Everlight claimed there was a mistake in the sales data it provided to the plaintiff in that it included non-GaN LEDs. Everlight argued that the data Mr. Ratliff used to generate the sales base included revenue from "red and yellow LED chips which [were] not accused and could not conceivably

In contrast, the defendants' damages expert, Dr. Mangum, testified that the parties would have negotiated a hypothetical license under which BU would have accepted the lesser of a $500,000 lump-sum payment, a $250,000 lump-sum payment plus a 0.5% running royalty on sales of accused products, or a 1% running royalty on sales of accused products, with respect to each defendant. Dr. Mangum derived this royalty structure from a 2002 license agreement for the '738 patent between BU and Cree Lighting Company (Cree). Mr. Ratliff also relied heavily on this agreement in his analysis, even though he only testified in support of a running royalty.

BU first licensed the '738 patent to Cree in March 2001. In exchange for an exclusive license to the '738 patent, Cree agreed to (1) an upfront fee of $250,000, (2) a 2% running royalty on net sales of Cree products that practice the '738 patent, (3) a minimum annual royalty payment of $25,000, and (4) certain sublicense royalty lump-sum payments. In June 2002, BU and Cree amended the license agreement. Under the amended agreement, Cree paid an additional $250,000 upfront fee, and the

infringe the patent." Docket No. 1456, at 6-7. At trial, the parties presented conflicting evidence about whether a red or yellow LED could be made from a GaN LED chip, which typically produces blue or green light. Regardless, correcting this alleged error in the sales data could have reduced a running royalty damages award. Using a lump sum, made the math easy by comparison, and BU's counsel argued the jury should award a lump sum in part to avoid wading through the confusion on this issue.

parties lowered the running royalty rate to 1%, increased the minimum royalty obligation to $50,000 per year, and changed the sublicense royalty arrangement so that Cree now had three options for sharing any sublicense royalty with BU. Cree could (1) pay BU a $500,000 lump-sum royalty for a new sublicense, (2) pay BU a $250,000 lump-sum royalty plus a 0.5% running royalty on sublicensee sales, or (3) pay BU a 1% running royalty on sublicensee sales.

At trial, Dr. Mangum calculated a range of damages figures for each of the defendants based on how the jury decided different issues, such as whether certain sales constituted foreign sales or were licensed, and should therefore be excluded from the sales base for a running royalty payment. He explained that a royalty base, however, would only be relevant to the royalty analysis if the jury believed that a running royalty was the appropriate structure. Dr. Mangum further testified that a "lump-sum royalty is perfectly applicable in this case," because the licensing history of the '738 patent is mostly comprised of lump-sum agreements. Trial Tr. vol. 9, Docket No. 1599, at 67-68. Under his approach, the damages awards for each defendant were essentially capped at a $500,000 lump-sum payment.

C. Analysis

The defendants now argue that they are entitled to a new trial on damages, or remittitur, because the lump-sum damages awards are not supported by the evidence under Lucent, 580 F.3d at 1323-36. In Lucent, the plaintiff "asked for a damages award based only on a running royalty" of approximately $562 million. Id. at 1323-25. The defendant, "on the other hand, told the jury that the damages should be a lump-sum royalty payment of $6.5 million." Id. at 1325. The jury ultimately awarded a one-time, lump-sum payment of $358 million, and the district court denied the defendant's motions for judgment as a matter of law and for a new trial, with respect to the damages award. Id. at 1309.

In deciding whether substantial evidence supported the jury's verdict of a $358 million lump-sum payment, the Federal Circuit emphasized that "certain fundamental differences exist between lump-sum agreements and running-royalty agreements." Id. at 1330. The Federal Circuit further clarified:

> This is not to say that a running-royalty license agreement cannot be relevant to a lump-sum damages award and vice versa. For a jury to use a running-royalty license agreement as a basis to award lump-sum damages, however, some basis for comparison must exist in the evidence presented to the jury.

Id. The Lucent court determined that "the jury had almost no testimony with which to recalculate in a meaningful way the value of any of the running royalty agreements to arrive at the lump-sum damages award." Id. Furthermore, the court found that the lump-sum license agreements in evidence did not support the damages award because they were not sufficiently comparable to the hypothetical agreement for the patent at issue. Id. at 1328-30. Thus, the court concluded that “no reasonable jury could have found that Lucent carried its burden of proving the evidence, under the relevant Georgia-Pacific factors, supported a lump-sum damages award of $357,693,056.18.” Id. at 1335.

According to the defendants in this case, BU repeated the same errors as the Lucent plaintiff, and the lump-sum awards are “not supported with comparable lump-sum licenses, or comparable running royalty licenses that could have been adjusted for purposes of calculating a lump-sum royalty.” Docket No. 1728, Ex. 1, at 53. BU responds that “the jury had a great deal of evidence to both support its lump sum findings and to support converting the royalty rates that Alan Ratliff testified about into the lump sum form that the Defendants argued was the correct form of royalty.” Docket No. 1739, at 53. More specifically, BU points to several license agreements as offering sufficient support for the lump-sum verdict.

First, BU points to a lump-sum license agreement between RPX and BU, in which RPX paid $13.5 million for a license to the ‘738 patent. Mr. Ratliff testified that this was the largest lump-sum payment that any entity ever made to BU for a license to the ‘738 patent. RPX and BU entered into this agreement in January 2014, when the patent only had ten months left on its term, and fourteen years after the agreed-upon date for the hypothetical negotiation. Mr. Ratliff explained at trial that RPX "aggregates IP and then sells memberships to companies who can sort of buy into the IP that is aggregated . . . ." Trial Tr. vol. 5, Docket No. 1595, at 201. The RPX-BU license involved twenty-five companies, which obtained rights to the '738 patent through their RPX memberships. The defendants highlight that the payment attributable to each company receiving rights under the RPX license was $540,000.

Furthermore, BU's damages expert testified that he chose not to rely on the RPX license in his damages calculations because "it was so late in time, so long after the hypothetical," and because he lacked crucial information about the twenty-five companies that gained rights to the patent. Trial Tr. vol. 5, Docket No. 1595, at 234-36. For example, he did not know whether the companies were previously on notice of the patent or whether their LED chip suppliers already had a license to the patent. He also did not know the specific amounts these companies paid for their RPX memberships. Like BU's damages expert, without more information, the jury could only speculate about how the RPX agreement could be compared to any licensing agreement resulting from the hypothetical negotiation between BU and the defendants.

Next, BU points to the fact that "Cree used the patent to offset an infringement claim against it brought by Nichia

Corporation" in 2001. Docket No. 1739, at 53. To settle the litigation, Nichia and Cree entered a cross-licensing agreement, in which Cree gave Nichia a sublicense to the '738 patent. In return, Nichia gave Cree a license to some of its patents, but did not pay BU or Cree any money. BU argues that this cross-license was worth more than $10 million because the Nichia lawsuit was a "bet-the-company dispute," which "would have been very detrimental to [Cree's] ability to continue to operate successfully had they ended up having to pay large license fees to Nichia." Trial Tr. vol. 5, Docket No. 1595, at 107. BU highlights testimony from Mr. Ratliff that if Nichia and Cree had entered the standard sublicensing agreement provided for in the BU-Cree license—with a $250,000 lump-sum payment and 1% or 0.5% running royalty—instead of the cross-licensing agreement, Nichia would have ultimately paid "[t]ens of millions of dollars." Trial Tr. vol. 5, Docket No. 1595, at 38.

The defendants respond that this testimony is based on "utter speculation" on what Nichia would have paid Cree if it had taken a running royalty license, assumes that Nichia would have actually practiced the patent, and is contrary to what actually happened. Docket No. 1748, at 14. Under the original BU-Cree license agreement, the parties specified that if Cree settled with Nichia, Cree would pay BU a lump-sum payment of $350,000. BU and Cree amended their agreement in 2002, as discussed above, “to provide Cree with greater flexibility in how it would sublicense to others,” and to address the Nichia litigation. Trial Tr. vol. 5, Docket No. 1595, at 106-07. Under the amended agreement, they increased the amount Cree would pay BU upon reaching a settlement with Nichia to $1 million. Thus, when Cree settled with Nichia and entered the cross-license, Cree paid BU $1 million.

The Court agrees with the defendants that Mr. Ratliff’s testimony about what Nichia would have paid under a running royalty agreement with Cree, if the parties had not entered a cross-license, does not support the jury’s lump-sum awards. BU’s argument ignores the differences between a running royalty and a lump-sum payment that BU’s damages expert discussed at trial, and the Federal Circuit emphasized in Lucent, 580 F.3d at 1326. The jury had no basis on which to compare a hypothetical running royalty agreement between Cree and Nichia to a lump-sum award between BU and the defendants because BU’s damages expert did not provide a framework for how the jury could have done so. Furthermore, BU did not put on any evidence of Nichia’s sales of patented technology to support the $10 million running royalty estimate.

Third, BU argues that testimony related to a 2009 license agreement between Philips and Epistar for red LED patents supports the jury’s lump-sum awards. The defendants correctly point out that the Court excluded the Philips license agreement because the plaintiff's expert, Dr. Piner, could not recall whether the agreement involved GaN LEDs—and therefore was comparable to the '738 patent—when he testified at trial.[6] Despite the fact that the license agreement is not in evidence, BU cites to clips of a videotaped deposition played at trial of Epistar's corporate representative, Meng Kuo, who discussed the Philips license.

Meng Kuo testified that Epistar paid Philips between $10 million and $20 million for a license to three patents for red LED chips. The $10-to-$20-million estimate included an up-front fee of $6.4 million, and subsequent minimum payments that totaled $4.6 million. BU did not offer any evidence of the time period over which the $4.6 million was paid, or how these payments are comparable to a one-time, lump-sum payment. When asked whether the Philips license was the best evidence of Epistar's attitude toward licensing LED patents in 2009, Meng Kuo responded that the products in the Philips patents are "different." Trial Tr. vol. 9, Docket No. 1599, at 139.

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[6] As discussed above, GaN LED chips typically produce blue or green light, as opposed to red, and there was conflicting evidence about whether a red LED could be made from a GaN chip. BU did not produce any evidence at trial about whether the Philips license agreement applied to GaN LEDs.

BU also cites to its cross-examination of the defendants' damages expert, when counsel for BU asked whether defense expert Dr. Mangum presented the $20-million estimate from the Philips license to the jury. Dr. Mangum simply answered that he did not.[7] Given that the license agreement itself is not in evidence, and that the agreement covered three patents for a different type of LED chip, this testimony is not enough to establish that the Philips license is comparable to the hypothetical negotiation in this case.

Finally, BU cites to the evidence it presented in support of a running royalty for each defendant as support for the lump-sum verdict. The lump-sum payments awarded by the jury are close to the amounts Mr. Ratliff testified to as appropriate running royalties. However, as discussed above, BU produced no evidence of how the jury could "recalculate in a meaningful way" the value of the running royalties to arrive at the lump-sum damages awards. Lucent, 580 F.3d at 1330. The lump-sum awards for Epistar and Everlight—of $9.3 million and $4 million

[7] BU similarly cites to its cross examination of the defendants' damages expert to argue that Epistar licensed a "limited number of patents" from Osram for 14 million Euros. Docket No. 1739, at 54. In the cross-examination, BU's counsel asked whether Dr. Mangum had told the jury about a 14 million Euro lump-sum royalty payment from Everlight, not Epistar, to Osram. Dr. Mangum replied that it was not in his slides. The defendants correctly point out that the Osram license was never introduced into evidence nor discussed by any other witness.

respectively—are well above the $1 million Cree paid BU when it entered a cross-license with Nichia involving a sublicense to the '738 patent, and the $500,000 figure that the defendants' damages expert argued would be the highest appropriate lump-sum for each defendant. Therefore, as in Lucent, the Epistar and Everlight damages awards are based on speculation and not supported by the evidence. The Court **ALLOWS** the defendants' motion for a new trial on damages, or remittitur, with respect to these two defendants.

In contrast, the lump-sum award against Lite-On of $365,000 is within the range of options that Dr. Mangum testified about at trial. Dr. Mangum stated that BU would have accepted the lesser of a $500,000 lump-sum payment, a $250,000 lump-sum payment plus a 0.5% running royalty on sales of accused products, or a 1% running royalty on sales of accused products. For Lite-On, he explained that a 1% running royalty on sales of accused products would have been the lesser of these options, and calculated this royalty to be $103,479. However, the jury could have reasonably disagreed with his analysis that BU would have accepted the lesser of these options, and instead concluded that the parties would have negotiated a lump-sum award closer to $500,000. I find that the damages award against Lite-On is supported by the evidence, and **DENY** the motion for a new trial on damages, or remittitur, with respect to Lite-On.

D. Remittitur

Both the First Circuit and the Federal Circuit follow the "maximum recovery rule," which permits the Court to grant a remittitur "geared to the maximum recovery for which there is evidentiary support (subject, of course, to the plaintiff's right to reject the remittitur and instead elect a new trial on the disputed damages claim)." Trainor, 699 F.3d at 33; see also Shockley, 248 F.3d at 1362 (noting that the Federal Circuit follows the "'maximum recovery rule,' which remits an excessive jury award to the highest amount the jury could 'properly have awarded based on the relevant evidence'" (quoting Unisplay, S.A. v. Am. Elec. Sign Co., 69 F.3d 512, 519 (Fed. Cir. 1995))). After a careful review of the record, the Court concludes that, in this case, based on the jury's choice of a lump-sum format, "the upper limit of the universe of reasonable outcomes," Trainor, 699 F.3d at 33, is a $1 million one-time, lump-sum payment against each defendant. The defendants concede that a $1 million lump-sum award against Epistar, and a $1 million lump-sum award against Everlight, are supported by the evidence, including the BU-Cree license and the $1 million payment from Cree to BU surrounding the Nichia settlement and cross-license. The Court, therefore, allows the plaintiff the option of a new trial on damages or the remitted damages award of a $1 million lump sum against Epistar and a $1 million lump-sum against

Everlight. If BU refuses to accept this reduction in the damages awards, it will be entitled to a new trial on damages.

IV. Remarks Regarding Defendants' Nationality

Defendants argue that BU's "prejudicial and inflammatory remarks regarding [the] defendants' nationality" throughout trial and in closing argument merit a new trial. Docket No. 1728, Ex. 1, at 50. More specifically, they contend that BU "repeatedly argued that the jury should award higher royalties against Defendants because they are Taiwanese companies that would not help American industry and would cost American jobs." Id. BU responds that "merely noting that Defendants are Taiwanese companies is not inflammatory." Docket No. 1739, at 67. Furthermore, BU argues that its higher royalty rate theory was not prejudicial because the Bayh-Dole Act, 35 U.S.C. § 204, requires BU to "give a preference to companies that make products in the United States," when licensing its patents. Docket No. 1739, at 67 (emphasis omitted).

"In assessing the effect of improper conduct by counsel, the Court must examine the totality of the circumstances, including the nature of the comments, their frequency, their possible relevancy to the real issues before the jury, the manner in which the parties and the court treated the comments, the strength of the case, and the verdict itself." Osorio, 659 F.3d at 90 (quoting P.R. Aqueduct & Sewer Auth. v. Constructora

Lluch, Inc., 169 F.3d 68, 82 (1st Cir. 1999)). However, when no timely objection is made, claims that counsel made improper arguments are forfeited, and thus subject to review for plain error. P.R. Aqueduct, 169 F.3d at 82; Smith v. Kmart Corp., 177 F.3d 19, 25-26 (1st Cir. 1999). Under plain error review, the Court "will consider a forfeited objection only if: (1) an error was committed; (2) the error was 'plain' (i.e. obvious and clear under current law); (3) the error was prejudicial (i.e. affected substantial rights); and (4) review is needed to prevent a miscarriage of justice." Smith, 177 F.3d at 26. The movant's burden under the plain error standard is considerable. Id. "Plain error is a 'rare species in civil litigation,' encompassing only those errors that reach the 'pinnacle of fault' envisioned by the standard set forth above." Id. (quoting Cambridge Plating Co., Inc. v. Napco, Inc., 85 F.3d 752, 767 (1st Cir. 1996)).

Here, the allegedly improper remarks include (1) questions BU's counsel asked a Cree employee, (2) testimony from the plaintiff's damages expert, and (3) statements BU's counsel made during closing arguments. The defendants only objected to the first set of statements. The defendants now argue that they did not object to BU counsel's comments during closing argument because the Court "specifically stated that the parties were not to object during closing argument." Docket No. 1728, Ex. 1, at

51. However, the defendants mischaracterize what the Court said. When instructing the jury that closing arguments are not evidence, before closing arguments began, I noted:

> Also, there is a certain etiquette, for the most part, people don't pop up and object every time they disagree with the other side's versions of the facts, or we'd never finish this. So, in general, you will not be hearing objections, but I can guarantee you that doesn't mean they agree with it, they probably disagree with most of it. That's the working order here.

Trial Tr. vol. 9, Docket No. 1599, at 162. The parties were free to object to anything opposing counsel said at sidebar after closing arguments, or to object to anything particularly egregious, during the arguments. The defendants chose not to do so. Thus, I review the first set of statements based on a totality of the circumstances and the other remarks for plain error.

First, BU's counsel asked Mr. Garceran, the chief intellectual property counsel at Cree, the following question: "In your view is it fair, is it reasonable to try to compare how BU treated a U.S.-based company, a company that had a long relationship with BU, and pretend like that's what would have happened if BU had been dealing with Epistar, a Taiwanese company?" Trial Tr. vol. 5, Docket No. 1595, at 43. The defendants objected to this question, and the Court overruled the objection. However, the witness became confused on the stand, and asked BU's counsel to repeat the question. In doing so, BU's counsel rephrased the question as follows:

> In your experience in dealing with BU for ten years, in your experience in this industry for many years and in licensing for many years, is it reasonable in any way to assume that BU would have treated Epistar, Everlight and Lite-On in licensing the same way they would have treated a U.S. partner entity that they're trying to support U.S. industry?

Id. at 44. The defendants' counsel again objected, and this time, I sustained the objection.

Next, BU's damages expert, Mr. Ratliff, testified that, as part of the hypothetical negotiation analysis, the jury "may consider a higher royalty rate" than that contained in the BU-Cree license because the defendants "are all non-U.S. entities and don't have any part in building the domestic industry." Trial Tr. vol. 5, Docket No. 1595, at 127. Cree is an American company, located in North Carolina. These statements must be considered in light of testimony from Mr. Pratt, the managing director of BU's Office of Technology Development. Mr. Pratt noted that one factor BU considers when licensing its patents is whether the potential licensee is an American company. He explained that when BU grants an exclusive license to a patent for an invention created through the use of federal funds, BU has a "responsibility" under the Bayh-Dole Act to "give a preference to companies that make products in the United States." Trial Tr. vol. 6, Docket No. 1596, at 76-77; 35 U.S.C.

§ 204. He further testified that there are business reasons why it is more convenient for BU to license its patents to “local” companies that operate under the same laws, have similar business practices, speak the same language, and are located in the same time zone. Trial Tr. vol. 6, Docket No. 1596, at 76.

Finally, in closing argument, BU’s counsel emphasized that the jury should award a higher royalty than that in the BU-Cree license because the defendants are “three Taiwanese companies, who literally were going to be taking away American jobs and American industry and competing directly with American industry,” as compared to “Cree, who . . . [BU] supported precisely to build the American industry.” Trial Tr. vol. 9, Docket No. 1599, at 245-46.

While BU’s counsel went further than “merely noting that Defendants are Taiwanese companies,” the comments in question do not warrant a new trial. In light of BU’s stated preference to license its patents to local companies for business reasons, and the policies underlying the Bayh-Dole Act, all of the statements were relevant to the issue of whether BU would have sought a higher royalty from foreign defendants, as compared to Cree, in the hypothetical negotiation. It is not “obvious and clear under current law” that the statements were inflammatory and prejudicial. Smith, 177 F.3d at 26. Thus, the Court **DENIES** the motion for a new trial on the basis on these statements.

ORDER

For the foregoing reasons, the defendants' renewed motion for judgment as a matter of law pursuant to Federal Rule of Civil Procedure 50(b), and motion for a new trial, or remittitur, under Rule 59 (Docket No. 1728), is **DENIED** in part and **ALLOWED** in part. The Court **DENIES** the motion for judgment as a matter of law in its entirety, and **DENIES** the motion for a new trial on all issues, except damages. The Court **ALLOWS** the motion for a new trial on damages, or remittitur, with respect to Epistar and Everlight, and **DENIES** the motion with respect to Lite-On.

BU shall inform the Court within two weeks whether it accepts the remittitur or seeks a new trial on damages. It shall also submit a separate form of judgment as to each defendant. If BU requests a new trial on damages, the Court anticipates the defendants will appeal all other issues to the Federal Circuit, before a new trial on damages, under 28 U.S.C. § 1292(c)(2). Cf. Bosch v. Pylon Mfg. Corp., 719 F.3d 1305, 1313 (Fed. Cir. 2013).

/s/ PATTI B. SARIS
Patti B. Saris
Chief United States District Judge

US005686738A

United States Patent [19]

Moustakas

[11] **Patent Number: 5,686,738**

[45] **Date of Patent: Nov. 11, 1997**

[54] **HIGHLY INSULATING MONOCRYSTALLINE GALLIUM NITRIDE THIN FILMS**

[75] Inventor: **Theodore D. Moustakas**, Dover, Mass.

[73] Assignee: **Trustees of Boston University**, Boston, Mass.

[21] Appl. No.: **372,113**

[22] Filed: **Jan. 13, 1995**

Related U.S. Application Data

[63] Continuation of Ser. No. 113,964, Aug. 30, 1993, Pat. No. 5,385,862, which is a continuation of Ser. No. 670,692, Mar. 18, 1991, abandoned.

[51] **Int. Cl.**[6] **H01L 33/00**; H01L 29/20

[52] **U.S. Cl.** **257/103**; 257/94; 257/79; 257/615

[58] **Field of Search** 257/103, 94, 79, 257/615

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,683,240	8/1972	Pankove .
3,819,974	6/1974	Stevenson et al. .
3,829,556	8/1974	Logan et al. .

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

3802732	8/1988	Germany .
4006449	9/1990	Germany .
64-30110	8/1989	Japan .
208143	3/1990	Japan .
2081483	3/1990	Japan .
0143420	6/1990	Japan .
2-143420	6/1990	Japan .
2257678	10/1990	Japan .

OTHER PUBLICATIONS

Maruska et al. *Solid State Elec* 1974 vol. 17 pp. 1171–1179 "Mechanism . . . Diodes".

Boulon et al, *Philips Tech Rev.* 37, pp. 237–240 1977 No. 9/10 "Light–emitting diodes based on GaN".

T. Sasaki et al., "Substrate–polarity dependence of metal–organic vapor phase epitaxy–grown GaN on SiC," J. Appl. Phys., Nov., 1988, pp. 4531–4535.

R.F. Davis et al., "Critical Evaluation of the Status of the Areas for Future Research Regarding the Wide Band Gap Semiconductors Diamond, Gallium Nitride and Silicon Carbide," Materials Science and Engineering, 1988, pp. 77–104.

S. Yoshida et al., "Epitaxial growth of GaN/AlN heterostructures," J. Vac. Sci. Technol., Apr.–Jun. 1983, pp. 250–253.

Z. Sitar et al., "Growth of AlN/GaN layered structures by gas source molecular–beam epitaxy," J. Vac. Sci. Technol., Mar./Apr. 1990, pp. 316–322.

H. Amano et al., "UV and blue electroluminescence from Al/GaN:Mg/GaN LED Treated with low–energy electron beam irradiation (LEEBI)," Proceedings of the SPIE–The International Society for Optical Engineering, vol. 1361, Part 1, 1991, pp. 138–149.

S. Zembutsu et al., "Growth of GaN single crystal films using electron cyclotron resonance plasma excited metalorganic vapor phase epitaxy," Appl. Phys. Lett., Mar. 1986, pp. 870–872.

(List continued on next page.)

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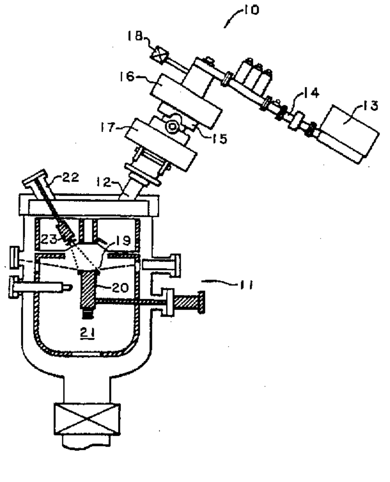
[57] **ABSTRACT**

This invention relates to a method of preparing highly insulating GaN single crystal films in a molecular beam epitaxial growth chamber. A single crystal substrate is provided with the appropriate lattice match for the desired crystal structure of GaN. A molecular beam source of Ga and source of activated atomic and ionic nitrogen are provided within the growth chamber. The desired film is deposited by exposing the substrate to Ga and nitrogen sources in a two step growth process using a low temperature nucleation step and a high temperature growth step. The low temperature process is carried out at 100–400° C. and the high temperature process is carried out at 600–900° C. The preferred source of activated nitrogen is an electron cyclotron resonance microwave plasma.

21 Claims, 4 Drawing Sheets



U.S. PATENT DOCUMENTS

4,144,116	3/1979	Jacob et al. .	
4,153,905	5/1979	Chamakadze et al. .	
4,396,929	8/1983	Ohki et al.	257/103
4,473,938	10/1984	Kobayashi et al. .	
4,476,620	10/1984	Ohki et al. .	
4,589,015	5/1986	Nakata et al. .	
4,608,581	8/1986	Bagratishvilli et al.	257/103
4,615,766	10/1986	Jackson et al. .	
4,792,467	12/1988	Melas et al. .	
4,819,057	4/1989	Naito et al. .	
4,819,058	4/1989	Nishizawa .	
4,855,249	8/1989	Akasaki et al. .	
4,866,007	9/1989	Taguchi et al. .	
4,897,149	1/1990	Suzuki et al. .	
4,911,102	3/1990	Manabe et al. .	
4,918,497	4/1990	Edmond .	
4,946,547	8/1990	Palmour et al. .	
4,946,548	8/1990	Kotaki et al. .	
4,960,728	10/1990	Shaake et al. .	
4,966,862	10/1990	Edmond .	
4,966,867	10/1990	Crotti et al. .	
4,983,249	1/1991	Taguchi et al. .	
5,005,057	4/1991	Izumiya et al. .	
5,006,908	4/1991	Matsuoka et al. .	
5,010,033	4/1991	Tokunaga et al. .	
5,015,327	5/1991	Taguchi et al. .	
5,027,168	6/1991	Edmond .	
5,042,043	8/1991	Hatano et al. .	
5,063,421	11/1991	Suzuki et al. .	
5,068,204	11/1991	Kukimoto et al. .	
5,076,860	12/1991	Ohba et al. .	
5,093,576	3/1992	Edmond et al. .	
5,097,298	3/1992	Ehara .	
5,117,267	5/1992	Kimoto et al. .	
5,119,540	6/1992	Kong et al. .	
5,122,845	6/1992	Manabe et al. .	
5,140,385	8/1992	Kukimoto et al. .	
5,173,751	12/1992	Ota et al. .	
5,178,911	1/1993	Gordon et al. .	
5,182,670	1/1993	Khan et al. .	
5,192,419	3/1993	Matsuura et al. .	
5,200,022	4/1993	Kong et al. .	
5,205,905	4/1993	Kotaki et al. .	
5,210,051	5/1993	Carter, Jr. .	
5,218,216	6/1993	Manabe et al. .	
5,237,182	8/1993	Kitagawa et al. .	
5,243,204	9/1993	Suzuki et al. .	
5,248,631	9/1993	Park et al. .	
5,272,108	12/1993	Kozawa .	
5,290,393	3/1994	Nakamura .	
5,298,767	3/1994	Shor et al. .	
5,304,820	4/1994	Tokunaga et al. .	
5,306,662	4/1994	Nakamura et al. .	
5,307,363	4/1994	Hosokawa et al. .	
5,313,078	5/1994	Fujii et al. .	
5,323,022	6/1994	Glass et al. .	
5,329,141	7/1994	Suzuki et al. .	
5,334,277	8/1994	Nakamura .	
5,338,944	8/1994	Edmond et al. .	
5,359,345	10/1994	Hunter .	
5,385,862	1/1995	Moustakas .	

OTHER PUBLICATIONS

M.J. Paisley, "Growth of cubic phase gallium nitride by modified molecular–beam epitaxy" J. Vac. Sci. Technol., May/Jun. 1989, pp. 701–705.

T.L. Chu, "Gallium Nitride Films," J. Electrochemical Society, Jul. 1971, pp. 1200–1203.

"P–Type Conduction in MG–Doped GaN Treated with Low–Energy Electron Beam Irradiation (LEEBI)", Hiroshi Amano et al., Japanese Journal of Applied Physics, 28 No. 12, pp. L2112–L2214 (Dec., 1989).

"Growth of High–Resistivity Wurtzite and Zincblende Structure Single Crystal Gan By Reactive–Ion Molecular Beam Epitaxy", R.C. Powell et al., Materials Research Society Symposium Proceedings, 162, pp. 525–530 (Nov./Dec., 1989)

"Growth of Cubic GaN Films on (100) Si by ECR Assisted MBE", T. Lei et al,. Bulletin of the American Physical Society, 36 N. 3 (Mar., 1991).

"Growth of GaN Films on the a–plane of Sapphire by ECR Assisted MBE", G. Merion et al., Bulletin of the American Physical Society, 36 No. 3 (Mar., 1991).

"Growth of Single Crystalline GaN Films on the R–plane of Sapphire by ECR Assited", C.R. Eddy et al., Bulletin of the American Physical Society, 36 No. 3 (Mar., 1991).

"Electron Beam Effects on Blue Luminescence of Zinc–Doped GaN", Hiroshi Amano et al., 40 and 41, pp. 121–122 (Feb., 1988) *Jour. of Luminescence.*

"Commercialization of GaN Blue LED with The Highest Reported Light Intensity in The World", unknown author, Japanese R&D Trend Analysis, 33 (Jan. 1991).

Sitar, Z., Design and Performance of an Electron Cyclotron Resonance Plasma Source for Standard Molecular Beam Epitaxy Equipment, Rev. Sci. Instrum., 61(9), Sep. 1990, pp. 2407–2411.

Kiode, et al., *Effect of an AlN Buffer Layer on AlGaN/* α–Al_2O_3 Heteroepitaxial Growth by MOVPE (in Japanese), vol. 13, No. 4, 1986, pp. 218–225.

S. Yoshida, et al., *Improvements on the electrical and luminescent properties of reactive molecular beam epitaxially grown GaN films by using AlN–coated sapphire substrates,* Appl. Phys. Lett, 42(5), Mar. 1983, pp. 427–429.

H. Amano, et al., *Effect Of The Buffer Layer in Metalorganic Vapour Phase Epitaxy of GaN on Sapphire Substrate,* Thin Solid Films, 163, 1988, pp. 415–420.

H. Amano, et al., *Metalorganic vapor phase epitaxial growth of a high quality GaN film using an AlN buffer layer,* Appl. Phys. Lett. 48 (5), Feb. 1986, pp. 353–355.

M.R.H. Khan, et al., Edge Emission of $Al_xGa_{1-x}N$, Solid State Communications, vol. 60, No. 6, 1986, pp. 509–512.

H. Amano, et al., *P–Type Conduction in Mg–Doped GaN Tread with Low–Energy Electron Beam Irradiation* (LEEBI), Japanese Journal of Applied Physics, vol. 28, No. 12, Dec. 1989, pp. L2112–L2114.

T. Nagatomo, et al., *Epitaxial Growth of GaN films by Low Pressure Metalorganic Chemical Vapor Diposition,* Abstract #1156, 104b Extended Abstracts Fall Meeting, Honolulu, Hawaii, Oct. 1987, pp. 1602–1603.

H. Kawakami, et al., Epitaxial Growth of AlN Film with an Initial–Nitriding Layer on α–$Al_2O_{3\ Substrate}$, Japanese Journal of Applied Physics, vol. 27, No. 2, Feb. 1988, pp. L161–L163.

I. Akasaki, et al., *Effects of AlN Buffer Layer on Crystallographic Structure and On Electrical and Optical Properties of GaN and* $Ga_{1-x}Al_xN$ ($0<x\leqq0.4$) *Films Grown on Sapphire Substrate by MOVPE,* Journal of Crystal Growth 98, 1989, pp. 209–219.

B. Goldenberg, et al., *Ultraviolet and Violet Light–Emitting GaN Diodes Grown By Law–Pressure Metalorganic Chemical Vapor Deposition,* Appl. Phys. Lett. 62 (4), Jan. 1993, pp. 381–383.

T. Mariizumi, et al., *Epitaxial Vapor Growth of ZnTe on InAs,* Japan. J. Appl. Phys. 9 (1970), pp. 849–850.

I. Akasaki, et al., *Photoluminescence of Mg–doped p–type GaN and electroluminescence of GaN p–n junction LED,* Journal of Luminescence 48 & 49, 1991, pp. 666–670.

A. Yoshikawa, et al., *Effects of Ar ion laser irradiation on MOVPE of ZnSe using DMZn and DMSe as reactants,* Journal of Crystal Growth 107, 1991, pp. 653–658.

Sitar, et al., *Design and performance of an electron cyclotron resonance plasma source for standard molecular beam epitaxy equipment,* Rev. Sci. Instrum., vol. 61, No. 9, Sep. 1990, pp. 2407–2411.

Program of the 1991 March Meeting, Bulletin of the American Physical Society, vol. 36, Number 3, Mar. 1991, pp. 543–544.

T. Lei, et al., *Epitaxial Growth of zinc–blende and wurtzitic gallium nitride thin films on (001) silicon,* Appl. Phys. Lett. 59 (8), Aug. 1991, pp. 944–946.

T. Lei, et al., *Epitaxial Growth and Characterization of zinc–blende gallium nitride on (001) silicon,* J. Appl. Phys. 71 (10), May 1992, pp. 4933–4943.

T.D. Moustakas, et al., *A Comparative Stude of GaN Films Grown on Different Faces of Sapphire by ECR–Assisted MBE,* Mat. Res. Soc. Symp. Proc., vol. 242, 1992, pp. 427–432.

T. Lei, et al., *A Comparative Study of GaN Epitaxy on Si(001 and SI(111) Substrates,* Mat. Res. Soc. Symp. Proc., vol. 242, 1992, pp. 433–439.

C.R. Eddy, Jr., et al., *Growth of Gallium Nitride Thin Films By Electron Cyclotron Resonance Microwave Plasma–Assisted Molecular Beam Epitaxy,* J. Appl. Phys. 73, Jan. 1993, pp. 448–455.

R.J. Molnar, et al., *Electron Transport Mechanism in Gallium Nitride, Appl. Phys. Lett.* 62 (1), Jan. 1993, pp. 72–74.

J.S. Foresi, et al., *Metal Contacts to Gallium Nitride,* Appl. Phys. Lett. 62 (22), May 31, 1993, pp. 2859–2861.

T. Lei, et al., *Heteroepitaxy, Polymorphism, and Faulting In GaN Thin Films on Silicon and Sapphire Substrates,* J. Appl. Phys. 74 (7), Oct. 1993, pp. 4430–4437.

M. Fanciulli et al., *Conduction–electron spin resonance in zinc–blende GaN Thin Films,* Physical Review B, vol. 48, No. 20, Nov. 1993, pp. 15144–15147.

T.D. Moustakas, et al., *Growth and Doping of GaN Films by ECR–Assisted MBE,* Mat. Res. Soc. Symp. Proc., vol. 281, 1993, pp. 753–763.

R.J. Molnar, et al., *High Mobility GaN Films Produced by ECR–Assisted MBE,* Mat. Res. Soc. Symp. Proc., Vol. 281, 1993, pp. 765–768.

T.D. Moustakas, et al., *Growth of GaN by ECR–Assisted MBE, Physics B* 185 (1993) pp. 36–49.

M.S. Brandt, et al., *Hydrogenation of Gallium Nitride,* MRS Meeting, 1993, six pages.

R. Singh, et al., *Intensity Dependence of Photoluminescence in GaN Thin Films,* Appl. Phys. Lett. 64 (3), Jan. 1994, pp. 336–338.

M.S. Brandt, et al., *Hydrogenation of p–type gallium nitride,* Applied Physics Letters, vol. 64, No. 17, Apr. 1994, pp. 2264–2266.

M.S. Brandt, et al., *Local Vibrational Modes In Mg–Doped Gallium Nitride,* Physical Review B. Condensed Matter, vol. 49, No. 20, May 1994, pp. 14,758–14,761.

H. Teisseyre, et al., *Temperature dependence of the energy gap in GaN bulk single crystals and epitaxial layer,* J. Appl. Phys. 76 (4), Aug. 1994, pp. 2429–2434.

S.N. Basu, et al., *Microstructures of GaN Films Deposited On (001) and (111) Si Substrates Using Electron Cyclotron Resonance Assisted–Molecular Beam Epitaxy,* J. Mater, Res., vol. 9, No. 9, Sep. 1994, pp. 2370–2378.

R.J. Molnar, et al., *Growth of Gallium Nitride by Electron–Cyclotron Resonance Plasma–Assisted Molecular–Beam Epitaxy: The Role of Charged Species,* J. Appl. Phys. 76(8), Oct. 1994, pp. 4587–4595.

M. Leszcynski, et al., *Thermal Expansion of Gallium Nitride,* J. Appl. Phys. 76 (8), Oct. 1994, pp. 4909–4911.

M. Manfra, et al., *Reactive Ion Etching of GaN Thin Films,* Mat. Res. Soc. Symp. Proc., vol. 324, 1994, pp. 477–480.

R.J. Molnar, *Blue–Violet Light Emitting Gallium Nitride p–n Junctions Grown by Electron Cyclotron Resonance–assisted Molecular Beam Epitaxy,* Applied Physics Letters, Jan. 1995, three pages.

J.T. Glass, et al., *Diamond, Silicon Carbide and Related Wide Bandgap Semiconductors,* Materials Research Society Symposium Proceedings, vol. 162, 1989, pp. 525–530.

H. Amano, et al., *Electron Beam Effects on Blue Luminescence of Zinc–Doped GaN,* Journal of Luminescence 40 & 41, 1988, pp. 121–122.

H. Amano, et al., *Stimulated Emission Near Ultraviolet at Room Temperature from a GaN Film Grown on Sapphire by MOVPE Using an AlN Buffer Layer,* Japanese Journal of Applied Physics, vol. 29, No. 2, Feb. 1990, pp. L205–L206.

KRI Fax News #53, *Commercialization of GaN Blue LED With the Highest Reported Light Intensity in The World,* Japanese R&D Trend Analysis, Jan. 1991.

G. Menon, *Growth of Intrinsic Monocrystalline Gallium Nitride Thin Films by Electron Cyclotron Resonance Microwave Plasma Assisted Molecular Beam Epitaxy,* Boston University College of Engineering Thesis. 1990.

T. Lei, *Heteroepitaxial Growth of Gallium Nitride And Native Defect Formation In III–V Nitrides,* Boston University Graduate School Dissertation, 1993.

R. Molnar, *The Growth and Doping of Gallium Nitride (GaN) Thin Films By Electron Cyclotron Resonance Plasma Assisted Molecular,* Boston University, College of Engineering, Disseration. Jun. 1994.

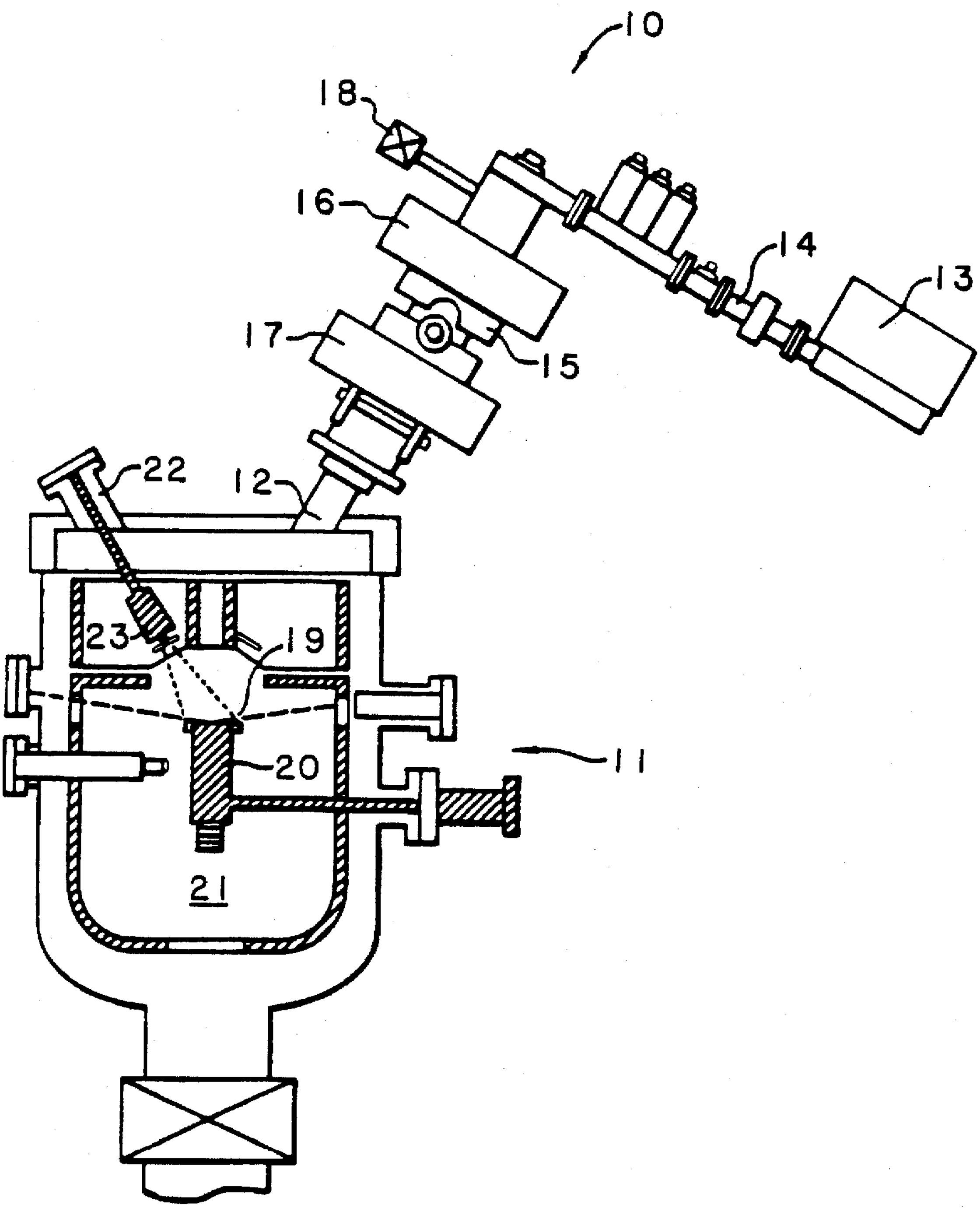
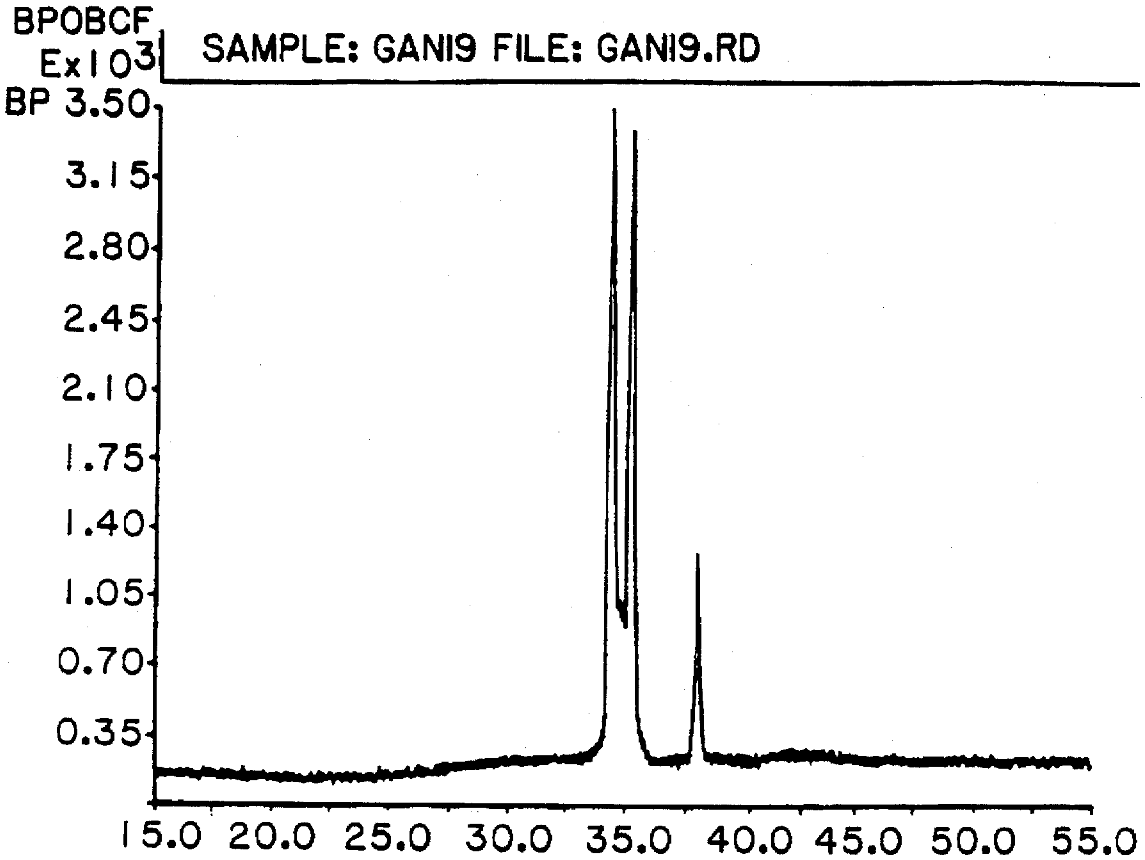


FIG. 1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Ex103
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2.80
2.45
2.10
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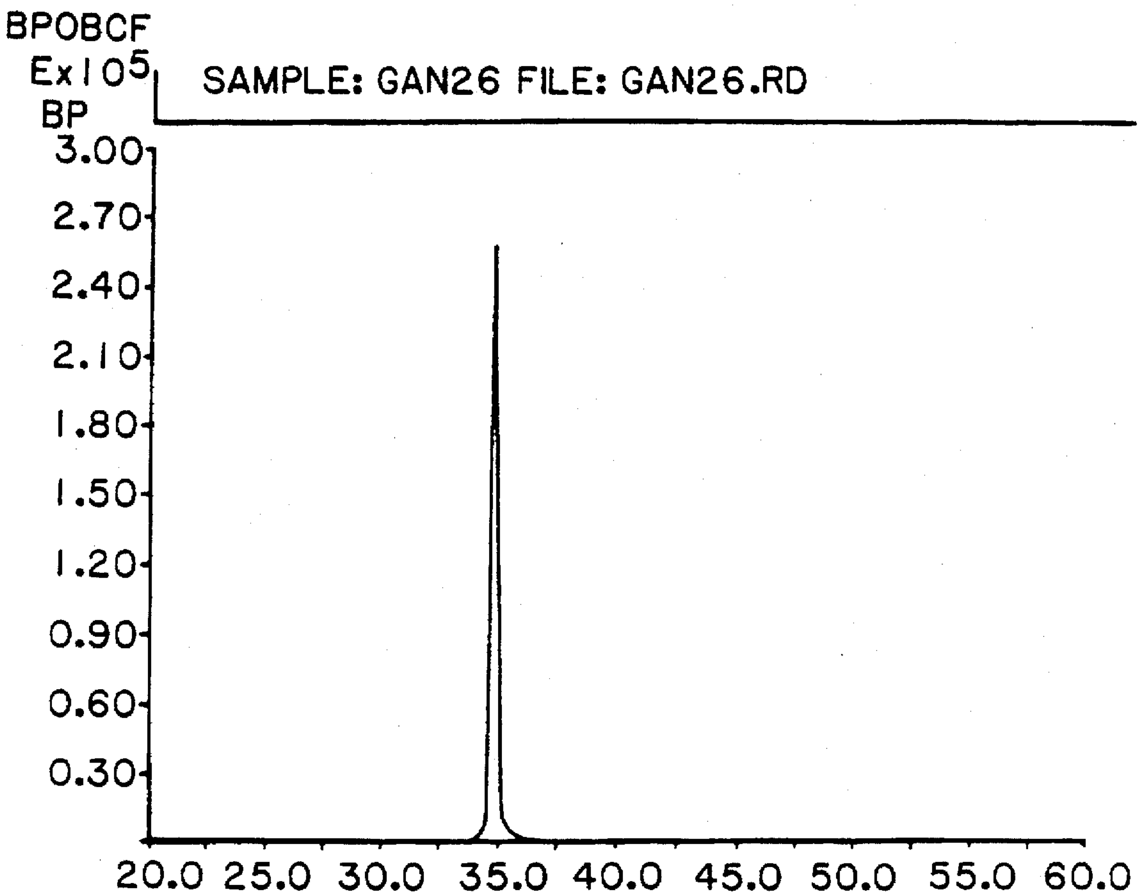
FIG.2A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2.10
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FIG.2B

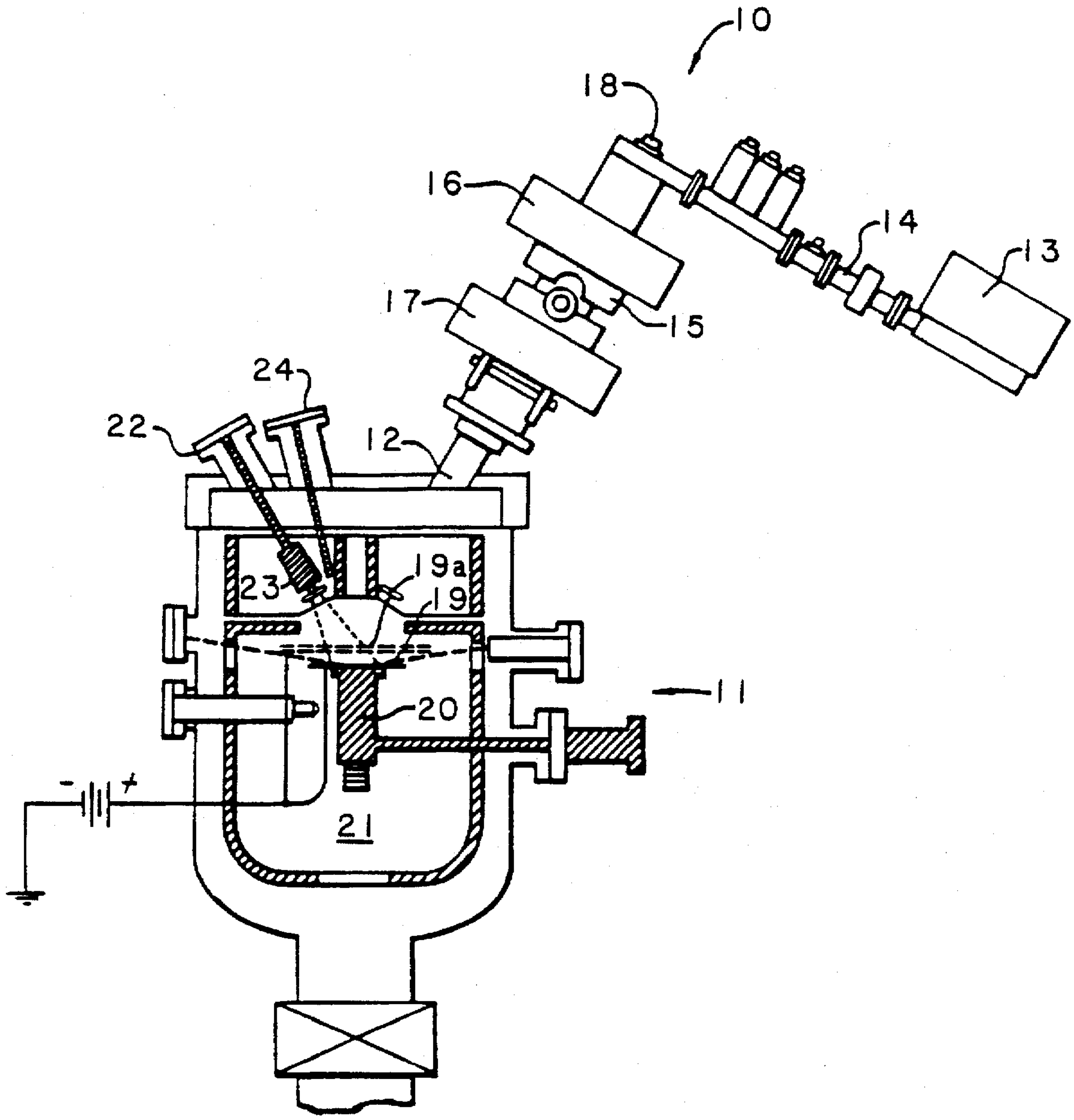

FIG.3

HIGHLY INSULATING MONOCRYSTALLINE GALLIUM NITRIDE THIN FILMS

This application is a continuation of application Ser. No. 08/113,964, filed Aug. 30, 1993, now U.S. Pat. No. 5,538, 862, entitled "A METHOD FOR THE PREPARATION AND DOPING OF HIGHLY INSULATING MONOCRYSTALLINE GALLIUM NITRIDE THIN FILMS", which is a continuation of application Ser. No. 07/670,692, filed Mar. 18, 1991, which is abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a method of preparing monocrystalline gallium nitride thin films by electron cyclotron resonance microwave plasma assisted molecular beam epitaxy (ECR-assisted MBE). The invention further relates to a method for the preparation of n-type or p-type gallium nitride (GaN) films.

Efforts have been made to prepare monocrystalline GaN because of its potentially useful electrical and optical properties. GaN is a potential source of inexpensive and compact solid-state blue lasers. The band gap for GaN is approximately 3.4 eV, which means that it can emit light on the edge of the UV-visible region. For intrinsic GaN, the carrier concentration, n_i, is 5.2×10^3 cm^{-3}, the mobility is 330 $cm^2V^{-1}s^{-1}$ and the resistivity is 3.6×10^{12} Ω-cm.

Despite the desirability of a monocrystalline GaN film, its development has been hampered by the many problems encountered during the growth process. Previous attempts to prepare monocrystalline GaN firms have resulted in n-type films with high carrier concentration. The n-type characteristic is attributed to nitrogen vacancies in the crystal structure which are incorporated into the lattice during growth of the film. Hence, the film is unintentionally doped with nitrogen vacancies during growth. Nitrogen vacancies affect the electrical and optical properties of the film.

ECR-assisted metalorganic vapor phase epitaxy gave GaN films that were highly conductive and unintentionally doped n-type (S. Zembutsu and T. Sasaki *J. Cryst. Growth* 77, 25–26 (1986)). Carrier concentrations and mobilities were in the range of 1×10^{19} cm^{-3} and 50–100 $cm^2V^{-1}s^{-1}$, respectively. Efforts to dope the film p-type were not successful. The carrier concentration was reduced by compensation, that is, the effect of a donor impurity is "neutralized" by the addition of an acceptor impurity.

Highly resistive films were prepared by sputtering using an ultra-pure gallium target in a nitrogen atmosphere. The films were characterized n-type and the high resistivity was attributed to the polycrystalline nature of the films (E. Lakshmi, et al. *Thin Solid Films* 74, 77 (1977)).

In reactive ion molecular beam epitaxy, gallium was supplied from a standard effusion cell and nitrogen was supplied by way of an ionized beam. Monocrystalline films were characterized n-type, but higher resistivities of 10^6 Ω-cm and relatively low carrier concentrations and mobilities (10^{14} cm^{-3} and 1–10 $cm^2V^{-1}s^{-1}$, respectively) were obtained (R. C. Powell, et al. in "*Diamond, Silicon Carbide and Related Wide Bandgap Semiconductors*" Vol. 162, edited by J. T. Glass, R. Messier and N. Fujimori (Material Research Society, Pittsburgh, 1990) pp.525–530).

The only reported p-type GaN was a Mg-doped GaN treated after growth with low energy electron beam irradiation. P-type conduction was accomplished by compensation of n-type GaN (H. Areario et al. *Jap. J Appl. Phys.* 28(12), L2112–L2114 (1989)).

Current methods of preparing GaN do not permit control of nitrogen vacancies within the lattice. Thus it has not been possible to prepare intrinsic GaN. Additionally, it is desirable to control the doping process in GaN films, thereby enabling the production of p-n junctions. The present invention presents a method to prepare near-intrinsic monocrystalline GaN films and to selectively dope these films n- or p-type.

SUMMARY OF THE INVENTION

The method according to this invention for preparing highly insulating near-intrinsic monocrystalline GaN films uses ECR-assisted MBE. In a preferred embodiment, a molecular beam source of Ga and an activated nitrogen source is provided within an MBE growth chamber. The desired substrate is exposed to Ga and activated nitrogen. A film is epitaxially grown in a two step process comprising a low temperature nucleation step and a high temperature growth step. The nucleation step preferably occurs by exposure of the substrate to gallium and a nitrogen plasma at a temperature in the range of 100°–400° C. and the high temperature growth step is preferably carried out in the temperature range of 600°–900° C. Preferred substrates include, but are not limited to, (100) and (111) silicon and (0001), (11–20) and (1–102) sapphire, (111) and (100) gallium arsenide, magnesium oxide, zinc oxide and silicon carbide. The preferred source of activated nitrogen species is a nitrogen plasma which can be generated by electron cyclotron resonance microwave plasma or a hot tungsten filament or other conventional methods.

In a preferred embodiment, the nitrogen plasma pressure and Ga flux pressure are controlled, thus preventing the bearing of metallic gallium on the film surface and the forming of nitrogen vacancies within the lattice. The Ga flux is preferably in the range of 2.0–5.0×10^{-7} torr. There is preferably an overpressure of nitrogen in the growth chamber, more preferably in the range of 10^{-3}–10^{-5} torr.

In yet another preferred embodiment, the low temperature nucleation step includes exposure of the substrate to Ga and nitrogen for a period of time in the range of 3–15 minutes. A film with a thickness of 200–500 Å is deposited, which is amorphous at the low temperatures of the nucleation step. The amorphous film can be crystallized by heating at 600°–900° C. in the presence of activated nitrogen. Subsequent treatment at higher temperatures, preferably 600°–900° C., results in the epitaxial growth of monocrystalline near-intrinsic GaN film. Preferred thickness of the growth layer is in the range of 0.5–10 μm.

In another aspect of this invention, the monocrystalline GaN film is preferentially doped n- or p-type. To generate a p-type semiconductor, the MBE growth chamber is equipped with Ga, activated nitrogen and acceptor sources. Acceptor sources include Group II elements such as Be, Zn, Cd, and Ca. The substrate is bombarded with electrons either by applying a positive bias to the substrate surface or a metal grid placed directly in front of the substrate. Conditions for low and high temperature deposition are as described above. Exposing the substrate to Ga, nitrogen and acceptor sources results in a doped GaN film, whereby the acceptor takes on an electron and is incorporated into the lattice as a negatively charged species. A charged acceptor species requires less energy to incorporate into the GaN lattice than a neutral acceptor. To dope the material n-type the substrate is bombarded with positive ions by biasing either the substrate or the grid negatively. Thus, the donor impurities incorporate into the GaN in their charged state. This requires less energy than to incorporate a neutral donor species. Suitable donors include Groups IV and VI elements.

Practice of this invention affords near-intrinsic GaN films with resistivities of up to 10^{10} ohms-cm and mobilities of 100 $cm^2V^{-1}s^{-1}$ at 200° C. P-type and n-type semiconductors can be selectively prepared simply by choice of surface or grid bias and impurity source. It is possible to efficiently manufacture p-n junctions using the methods of this invention,

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a cross-sectional view of an ECR-assisted MBE growth chamber.

FIG. **2***a* is a an X-ray diffraction pattern from a GaN film on (11–20) sapphire grown from a one-step process.

FIG. **2***b* is a an X-ray diffraction pattern from a GaN film on (11–20) sapphire grown from a two-step process.

FIG. **3** is a schematic illustration of the method for doping GaN films.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The unintentional doping of GaN has been attributed to the formation of nitrogen vacancies in the GaN lattice. GaN decomposes (and loses nitrogen) at about 650° C., well below the processing temperatures of the above processes (>10000° C.). Therefore, the growth process itself provides sufficient thermal energy for vacancy formation. Growth processes at lower temperatures should reduce the number of nitrogen vacancies in the lattice, prevent the unintentional n-type doping of the GaN lattice and result in intrinsic GaN.

The practice of the present invention forms GaN at significantly lower processing temperatures using an activated nitrogen source. An ECR microwave nitrogen plasma is the preferred activated nitrogen source. A two step heating process permits the formation of monocrystalline GaN at lower processing temperatures.

The ECR-MBE system used in this invention is shown in FIG. **1**. An ECR-system **10** was integrated with an MBE system **11** by attaching the ECR system **10** to an effusion pert **12**. The ECR system includes a microwave generator **13**, a waveguide **14**, a high vacuum plasma chamber **15**, and two electromagnets **16** and **17**. The microwaves at 2.43 GHz are created in the microwave generator **13** and travel down the rectangular waveguide **14**. The microwave power (100–500 W) passes from the waveguide **14** into the plasma chamber **15**. Nitrogen flows into the plasma chamber **15** through a mass flow controller **18**. The mass flow controller **18** maintains an adjustable constant flow rate. The plasma chamber **15** is surrounded by the two electromagnets **16** and **17**. The upper magnet **16** is powered by a 2 kW power supply (not shown) and the lower magnet **17** is powered by a 5 kW power supply (not shown). Positioning of the electromagnets in this way results in a more intense and stable plasma.

The upper electromagnet **16** sets the free electrons in the chamber **15** into cyclotron orbits. The cyclotron frequency is dependent upon the strength of the magnetic field and the electron charge-to-mass ratio. Since all the electrons assume cyclotron orbits, the energy lost in random motion and collisions is reduced. Additionally, the plasma will be confined to the center of the chamber **15**. The magnetic field is adjusted such that the frequency of oscillation of the microwaves is exactly equal to the cyclotron frequency of the electrons. N_2 is then introduced into the chamber through the mass flow controller **18** and is decomposed to high energy atomic and ionic nitrogen species by impact with the high energy electrons. The lower electromagnet **17** then guides the ions through the effusion pert **12** towards a substrate **19** which is positioned on a continuous azimuthal rotation (C.A.R.) unit **20** in a growth chamber **21** of the MBE system **11**. The C.A.R. **20** can be rotated between 0 and 120 rpm. On certain substrates, GaN films grow in the wurtzitic structure and on others in the zincblende structure. Such substrates include for example sapphire (GaN in wurtzitic structure) and Si(100) (GaN in the zincblende structure). Gallium flux is generated in a Knudsen effusion cell **22**.

In a typical process, the substrate **19** was sputter-etched by the nitrogen plasma at 600° C. The substrate was cooled down to 270° C. in the presence of the nitrogen plasma. A Ga shutter **23** was then opened to deposit the initial buffer layer of GaN. The use of an activated nitrogen source permitted the deposition of GaN at this low temperature. The buffer layer was allowed to nucleate over ten minutes and then the Ga shutter **23** was closed to stop the nucleation of the film. The substrate was then brought slowly to 600° C. at the rate of 4° C. every **15** seconds in the presence of the nitrogen plasma. The nitrogen overpressure also helped reduced the formation of nitrogen vacancies.

Once at 600° C., the substrate **19** was kept at this temperature for 30 minutes in the presence of nitrogen plasma to ensure that the GaN buffer layer had crystallized. The Ga shutter **23** was opened once again to grow the GaN monocrystalline film, The thickness of the film was about 1 μm, although in theory there is no limitation to film thickness. Nitrogen pressure and gallium flux are kept constant during the entire process.

The two step growth process allows for the nucleation of a buffer layer. The buffer layer is grown at a temperature in the range of 100°–400° C. Because the temperature is low, the probability of nitrogen vacancy formation is reduced. As the temperature increases to 600° C., the amorphous film crystallizes. Any further growth takes place on the crystallized GaN buffer layer. The films grown by this two step process are superior to those grown by a one step growth process.

FIG. **2** shows the X-ray diffraction (XRD) pattern of a GaN film grown on the α-plane of sapphire (11–20) in a one-step process (FIG. **2***a*) and a two-step process (FIG. **2***b*). The two peaks at ca. 2θ=35° of FIG. **2***a* are attributed to a defective GaN crystal. FIG. **2***b* has a single peak indicating a film of better quality. This is because the majority of the film grows on the top of the GaN buffer and does not see the underlying substrate. The growth layer of GaN "recognizes" the GaN buffer layer and on which it can grow without defects. The buffer is the only part of the film which is highly defective.

Films grown by the method described above were highly resistive at room temperature (10^{10} Ω-cm). The mobility of this material is 10 $cm^2V^{-1}s^{-1}$, a reasonable value compared to the theoretic mobility of intrinsic GaN 330 which is $\Omega\text{-cm}^{-3}$.

GaN films are doped n-type or p-type by incorporating the proper impurities in their charged state. This is because the energy to incorporate a charged impurity into the lattice is lower than the energy needed to incorporate a neutral impurity. FIG. **3** is a schematic illustration of the doping of a charged acceptor into the GaN lattice. The substrate **19** or a grid **19***a* directly in front of it is positively biased. FIG. **3** shows both substrate **19** and grid **19***a* connected to a voltage source. In practice of this invention, either substrate **19** or grid **19***a* would be positively biased. Electrons are therefore attracted to the substrate surface, while positive ions such as

N^+ are repelled. The growth process is carried out as described above with addition of an acceptor source **24** so that Ga, nitrogen and acceptor are deposited on the electron-rich surface of the substrate. As the acceptor atom approaches the surface, it takes on an electron and is incorporated into the lattice as a negative species, the energy of incorporation being lower than that of the neutral acceptor species. The same procedure is used to dope the GaN lattice with donor impurities, except that a negative bias is used on the substrate or the grid. Alternately, a charged surface can be generated by bombarding the substrate with electrons or positive ions. Electron guns and ion guns, respectively, are conventional sources of these species.

Suitable acceptor species include, but are not limited to, zinc, magnesium, beryllium, and calcium. Suitable donor species include, but are not limited to, silicon, germanium, oxygen, selenium and sulfur.

What is claimed is:

1. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of(100) Silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer having a thickness of about 30 Å to about 500 Å, comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride; and

a first growth layer grown on the buffer layer, the first growth layer comprising gallium nitride and a first dopant material.

2. The semiconductor device of claim **1** further comprising:

a second growth layer grown on the first growth layer, the second growth layer comprising gallium nitride and a second dopant material.

3. The semiconductor device of claim **1** wherein the buffer layer is grown at a first temperature and wherein the first growth layer is grown at a second temperature higher than the first temperature.

4. The semiconductor device of claim **3** wherein the first temperature is in the range of about 100° C. to about 400° C.

5. The semiconductor device of claim **3** wherein the second temperature is in the range of about 600° C. to about 900° C.

6. The semiconductor device of claim **1** wherein the buffer layer is grown by exposing the substrate to gallium and nitrogen at the first temperature for about 3 to about 15 minutes.

7. The semiconductor device of claim **1** wherein the first dopant material is a donor.

8. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of(100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide. (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride;

a first growth layer grown on the buffer layer, the first growth layer comprising gallium nitride and an acceptor dopant material;

a second growth layer grown on the first growth layer, the second growth layer comprising gallium nitride and a donor dopant material.

9. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a fast material grown on said substrate, the first material consisting essentially of gallium nitride;

a first growth layer grown on the buffer layer, the first growth layer comprising gallium nitride and a first dopant material;

a second growth layer grown on the first growth layer, the second growth layer comprising gallium nitride and a second dopant material; and

wherein the first growth layer comprises a first conductivity type and the second growth layer comprises the opposite conductivity type.

10. The semiconductor device of claim **9** wherein the first conductivity type is n-type.

11. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of(100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride;

a first growth layer grown on the buffer layer, the first growth layer comprising gallium nitride and a first dopant material;

wherein the buffer layer is a recrystallized , partially amorphous layer.

12. The semiconductor device of claim **3** wherein the buffer layer is a recrystallized, partially amorphous layer.

13. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a first material grown on said substrate, the first material comprising gallium nitride; and

a near intrinsic gallium nitride layer grown on the buffer layer and having a resistivity of greater than $\mathbf{10^8}$ Ω·cm. at room temperature.

14. The semiconductor device of claim **13**, wherein the near intrinsic gallium nitride layer has a resistivity in the range of about 10^8 Ω·cm to about 10^{12} Ω·cm at room temperature.

15. A semiconductor device having an activated p-type layer comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer having a thickness of about 30 Å to about 500 Å comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride; and an activated p-type growth layer comprising gallium nitride and an acceptor dopant material formed without the use of a post-growth activation step.

16. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (0001) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer having a thickness of about 30 Å to about 500 Å grown on the substrate and comprising a first material consisting essentially of a Group III nitride grown at a temperature of about 100° C. to about 400° C. from a molecular Group III source and an activated nitrogen source in a molecular beam epitaxial growth chamber; and

a first growth layer grown on the buffer layer and comprising gallium nitride and a first dopant material, the first growth layer being grown at a temperature of at least about 600° C. from a molecular gallium source and an activated nitrogen source in a molecular beam epitaxial growth chamber.

17. The semiconductor device of claim **16** wherein the Group III nitride is gallium nitride.

18. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer having a first thickness, comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride; and

a growth layer grown on the buffer layer having a second thickness which is at least ten times greater than the first thickness, the growth layer comprising gallium nitride and a first dopant material.

19. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a first material grown on said substrate, the first material consisting essentially of gallium nitride; and

a growth layer grown on the buffer layer, the growth layer comprising gallium nitride and a first dopant material.

20. A semiconductor device having an activated p-type layer comprising:

a substrate, said substrate consisting of a material selected from the group consisting of(100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer, comprising a material grown on said substrate, the material consisting essentially of gallium nitride; and

an activated p-type growth layer comprising gallium nitride and a dopant material formed without the use of a post-growth activation step.

21. A semiconductor device comprising:

a substrate, said substrate consisting of a material selected from the group consisting of (100) silicon, (111) silicon, (0001) sapphire, (11–20) sapphire, (1–102) sapphire, (111) gallium aresenide, (100) gallium aresenide, magnesium oxide, zinc oxide and silicon carbide;

a non-single crystalline buffer layer grown on the substrate and comprising a material consisting essentially of a Group III nitride grown at a temperature of about 100° C. to about 400° C. from a molecular Group III source and an activated nitrogen source in a molecular beam epitaxial growth chamber; and

a growth layer grown on the buffer layer and comprising gallium nitride and a first dopant material, the growth layer being grown at a temperature of at least about 600° C. from a molecular gallium source and an activated nitrogen source in a molecular beam epitaxial growth chamber.

* * * * *

CERTIFICATE OF SERVICE

I, Kevin K. Russell, a member of the Bar of this Court, hereby certify that on this 27th day of December, 2016, I electronically filed the foregoing brief with the Court using the CM/ECF system. The following counsel are registered CM/ECF users and will be served by the appellate CM/ECF system:

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CERTIFICATE OF COMPLIANCE

Pursuant to Federal Rules of Appellate Procedure 28.1(e)(3) and 32(a)(7)(C), the undersigned hereby certifies that this brief complies with the type volume limitation of Federal Rule of Appellate Procedure 28.1(e)(2)(B)(i).

1. This brief complies with the type-volume limitation of Federal Rule of Appellate Procedure 32(a)(7)(B) and Federal Circuit Rule 32(b) because this brief contains 9,254 words, excluding the parts of the brief exempted by Federal Rule of Appellate Procedure 32(a)(7)(B)(iii) and Federal Circuit Rule 32(b)(1)-(3).
2. This brief complies with the typeface requirements of Federal Rule of Appellate Procedure 32(a)(5) and the type style requirements of Federal Rule of Appellate Procedure 32(a)(6) because this brief has been prepared in a proportionally spaced typeface using Microsoft Word 2013 in 14-point Times New Roman Font.

Dated: December 27, 2016

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