

**IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION**

**AKOUSTIS TECHNOLOGIES, INC. AND
AKOUSTIS, INC.,**

Plaintiffs,

vs.

QORVO, INC.,

Defendant.

Civil Action No. 2:23-cv-180

JURY TRIAL

AKOUSTIS' ORIGINAL COMPLAINT

Plaintiffs Akoustis Technologies, Inc. and Akoustis, Inc. (collectively “Akoustis”) file this Complaint for Patent Infringement against Defendant Qorvo, Inc. (“Qorvo”), and allege as follows:

NATURE OF THE ACTION

1. This is an action for patent infringement arising under the patent laws of the United States, 35 U.S.C. § 1 *et seq.*
2. Qorvo has infringed and continues to infringe at least one claim of U.S. Patent No. 7,250,360 (“the ’360 Patent”).
3. With knowledge of the ’360 Patent, Qorvo infringes directly, literally and/or by the doctrine of equivalents, and/or induces infringement of the ’360 Patent by developing, making, using, selling, offering for sale, and/or importing into the United States products that incorporate the patented technology.
4. Akoustis seeks damages and other relief for Qorvo’s infringement.

THE PARTIES

5. Plaintiff Akoustis Technologies, Inc. is a Delaware corporation with its principal place of business at 9805 Northcross Center Court, Suite A, Huntersville, North Carolina, 28078.

6. Plaintiff Akoustis, Inc. is a Delaware corporation with its principal place of business located at 9805 Northcross Center Court, Suite A, Huntersville, North Carolina, 28078.

7. Defendant Qorvo, Inc. is a Delaware corporation with a regular and established place of business within this District at 500 W. Renner Road, Richardson, TX 75080.

8. Qorvo was formed on January 1, 2015, as a result of the merger between TriQuint Semiconductor (“TriQuint”) and RF Micro Devices (“RFMD”).

9. Qorvo may be served by serving its registered agent, Corporation Service Company, 251 Little Falls Drive, Wilmington, DE 19808.

10. On information and belief, Qorvo makes, uses, sells, offers for sale, and/or imports into the United States, including in this District, products and services, including the Accused Products (defined in “Qorvo’s Infringement” Section below).

11. The ’360 Patent is infringed by Qorvo, including through its work to design, manufacture, import, distribute, sell, and/or offer to sell the Accused Products.

JURISDICTION AND VENUE

12. This is an action for patent infringement arising under the Patent Laws of the United States, Title 35 of the United States Code, including 35 U.S.C. § 271.

13. The Court has subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

14. This Court has personal jurisdiction over Qorvo. Qorvo, has continuous and systematic business contacts with the State of Texas. Qorvo, directly or through subsidiaries or intermediaries, conducts its business extensively throughout Texas, by shipping, distributing,

offering for sale, selling, and advertising its products and/or services in the State of Texas and the Eastern District of Texas. Qorvo, directly and through subsidiaries or intermediaries, has purposefully and voluntarily placed one or more of its Accused Products into the stream of commerce with the intention and expectation that they will be purchased and used by consumers in the State of Texas and the Eastern District of Texas. These products and/or services have been and continue to be purchased and used by consumers in the State of Texas and the Eastern District of Texas. In addition, on information and belief, Qorvo conducts operations related to the Accused Products in its Eastern District of Texas facility located at 500 W. Renner Road, Richardson, TX 75080.

15. Venue is proper in this District under 28 U.S.C. §§ 1391 and 1400(b). Defendant is authorized to do business in the State of Texas, has offices in the State of Texas and the Eastern District of Texas, has transacted business in the Eastern District of Texas, and has committed acts of infringement in the Eastern District of Texas.

16. Qorvo has a “Design, Sales, Support & GaAs / GaN / BAW Manufacturing” facility in Richardson, Texas.¹

17. According to Qorvo’s Richardson job listings, Qorvo employs sales, engineering, and manufacturing personnel in Richardson.²

¹ *Locations*, QORVO (n.d.), <https://www.qorvo.com/about-us/locations>.

² *Careers*, QORVO (n.d.), https://careers.qorvo.com/search/?q=&sortColumn=referencedate&sortDirection=desc&optionsFacetsDD_location=TX+-+Richardson%2C+US.

Job Title	Location
Project Manager Intern	TX - Richardson, US
Marketing Engineering Intern	TX - Richardson, US
Product Engineering Intern	TX - Richardson, US
Engineering Technician	TX - Richardson, US
Manufacturing Equipment Maintenance Technician	TX - Richardson, US
Buyer - Spares/Repairs	TX - Richardson, US
Power Management Application Engineer	TX - Richardson, US
Yield Engineer	TX - Richardson, US
Process Development Engineer	TX - Richardson, US
Sr. MMIC Design Engineer	TX - Richardson, US
Process Development Engineering Manager	TX - Richardson, US
Cybersecurity Risk Analyst	TX - Richardson, US
Analog Products Marketing Manager	TX - Richardson, US
Product Engineering Intern	TX - Richardson, US
Procurement & Planning Business Analyst Intern	TX - Richardson, US
RF Design Engineer	TX - Richardson, US
Equipment Maintenance Technician	TX - Richardson, US
Manufacturing Equipment Engineering Intern	TX - Richardson, US
Equipment Maintenance Technician	TX - Richardson, US
Manager, Project Management	TX - Richardson, US
Production Control Technician	TX - Richardson, US
EDA Specialist	TX - Richardson, US
Electrical CAD Engineer Intern	TX - Richardson, US
EHS Engineer	TX - Richardson, US
Sr. MMIC Design Engineer	TX - Richardson, US

Job Title	Location
Sr Analog Design Engineer	TX - Richardson, US
Sr Project Manager	TX - Richardson, US
Sr. Module Design Engineer	TX - Richardson, US
Staff Design Engineer	TX - Richardson, US
Device Engineering Intern	TX - Richardson, US
Strategic Marketing/Communications Mgr	TX - Richardson, US
Production Control Technician	TX - Richardson, US
Process Development Engineer	TX - Richardson, US
Software Engineering Intern (Multiple Locations)	TX - Richardson, US
Data Science Engineering Intern	TX - Richardson, US
Mechanical Engineering Intern (Multiple Locations)	TX - Richardson, US
Process Integration Engineer	TX - Richardson, US
Research Scientist / Epitaxial Engineer	TX - Richardson, US
Staff Research Scientist / Epitaxial Engineer	TX - Richardson, US

18. Given Qorvo’s name for the facility and Qorvo’s job postings for the facility, Qorvo’s Richardson “Design, Sales, Support & GaAs / GaN / BAW Manufacturing” facility employs personnel—including sales, engineering, and manufacturing personnel—that perform work related to the Accused Products.

19. Additionally, Qorvo has consented to venue in the Eastern District of Texas at least twice, and, on information and belief, Qorvo has never contested venue in the District. *See Bandspeed, LLC, v. Qorvo, Inc.*, Case No. 5-21-cv-00086, Dkt. 26 (First Amended Answer), ¶ 20 (E.D. Tex. Dec. 28, 2021) (“For purposes of this action only, Qorvo does not contest that the Eastern District of Texas has personal jurisdiction over Qorvo.”); *Mimo Research, LLC., v. Qorvo, Inc.*, Case No. 5:22-cv-00075, Dkt. 17 (Answer), ¶ 7 (E.D. Tex. Aug. 29, 2021) (“For purposes of this action only, Qorvo does not contest that venue is proper in this District . . .”).

THE '360 PATENT

20. On July 31, 2007, the U.S. Patent and Trademark Office duly and legally issued U.S. Patent No. 7,250,360 (“the ’360 Patent”), entitled “Single step, high temperature nucleation process for a lattice mismatched substrate,” to inventors James Shealy and Joseph Smart. The ’360 Patent issued from an application filed on March 2, 2005. A true and correct copy of the ’360 Patent is attached hereto as Exhibit 1 and incorporated herein by reference.

21. Cornell Research Foundation, Inc. (“CRF”) owns the ’360 Patent, but Akoustis is the exclusive licensee to the ’360 Patent and owns all rights to the ’360 Patent necessary to bring this action.³

22. CRF and/or Cornell University are not necessary parties to this action.

23. On information and belief, RFMD (including through one or more subsidiaries) had an exclusive license to the ’360 Patent when the ’360 Patent issued in 2007, but RFMD terminated that license in 2008. Therefore, RFMD has known of the ’360 Patent since at least 2007.

24. The ’360 Patent concerns “a single step process for the nucleation and subsequent epitaxial growth on a lattice mismatched substrate.” ’360 Patent at 1:17-19. As the patent explains, the previous “practice for nucleation of these substrates with GaN-based material utilizes a two-temperature process involving either one or two flow paths. In addition, different growth pressures are used on certain steps in the nucleation process. In this fashion, high structural and electrical quality epitaxial films can be realized in severely mismatched material systems.” *Id.* at 1:29-35. The ’360 Patent notes, however, that prior processes presented issues

³ Akoustis™ Expands IP - Signs Exclusive License Agreement with Cornell University, AKOUSTIS (September 7, 2016), <https://ir.akoustis.com/news-events/press-releases/detail/33/akoustis-expands-ip---signs-exclusive-license-agreement>.

through at least their use of “large temperature ramps and complex flow requirements.” *Id.* at 2:3-7.

25. The '360 Patent addresses these shortcomings of the prior art. The '360 Patent discloses novel techniques wherein a “single step process is a single flow, single pressure, high temperature process. The single step process involves a surface treatment prior to epitaxial growth that allows complete coalescence of the epitaxial film within the first 200 Å of growth.” *Id.* at 2:3-7. The benefits of this are that “[t]he single step process eliminates the large temperature ramps and complex flow requirements of the commonly used two-step nucleation technologies.” *Id.* at 2:7-10.

26. Pursuant to 35 U.S.C. § 282, the '360 Patent is presumed valid.

27. The benefits discussed in the '360 Patent specification are also reflected in the '360 Patent's claims. *See, e.g., id.* at Claim 1. Claim 1 of the '360 Patent reads as follows:

1. A process for growing an epitaxial layer on a lattice mismatched substrate comprising the steps of:

- a) providing a substrate;
- b) pre-treating a surface of the substrate with at least one group III reactant or at least one group II reactant at an elevated growth temperature prior to introducing a group V reactant or a group VI reactant;
- c) introducing a group V reactant or a group VI reactant to grow a nucleation layer on the surface of the substrate; and
- d) growing a buffer layer on said nucleation layer, said buffer layer providing a surface upon which said epitaxial layer is grown.

28. A person of ordinary skill in the art reading the '360 Patent and its claims would understand that the patent's disclosure and claims are drawn to solving specific, technical problems arising in the area of epitaxial growth on mismatched substrates, and that the invention provides for advancements in the field that were not routine, well-understood or conventional.

Accordingly, each claim of the '360 Patent recites a combination of elements sufficient to ensure that the claim in practice amounts to significantly more than a patent claiming an abstract concept. A person of ordinary skill in the art would understand that the ordered combination of claim elements is inventive. Further, the claimed improvements over prior art epitaxial growth on mismatched substrates processes are concrete and improve the capabilities of existing methods.

29. A person of ordinary skill in the art reviewing the specification of the '360 Patent would understand that the inventors had possession of the claimed subject matter and would know how to practice the claimed invention without undue experimentation.

QORVO'S INFRINGEMENT

30. The allegations provided below are exemplary and without prejudice to Akoustis' infringement contentions provided pursuant to the Court's scheduling order and local rules. Akoustis' claim construction contentions regarding the meaning and scope of the claim terms will be provided under the Court's scheduling order and local rules. As detailed below, each element of at least one claim of the '360 Patent is literally present in the Accused Products. To the extent that any element is not literally present, each such element is present under the doctrine of equivalents. Akoustis' analysis below should not be taken as an admission that the preamble for any claim is limiting. While Akoustis cites publicly available information and information obtained through reverse engineering, Akoustis may rely on other forms of evidence to show infringement.

31. Generally, the Accused Products for the '360 Patent include semiconductors with epitaxial layers of AlN, AlGaIn, or GaN on lattice mismatched substrates and made by a process that includes pre-treating a surface of the substrate with at least one group III reactant or at least

one group II reactant at an elevated growth temperature prior to introducing a group V reactant or a group VI reactant (the “Accused Products”). One exemplary, non-limiting Accused Product is Qorvo’s QPD1000.⁴



QPD1000
15W, 28V, 0.03 – 1.215 GHz, GaN RF Input-Matched Transistor

Product Overview

The Qorvo QPD1000 is a 15W (P_{3dB}), 50 Ω -input matched discrete GaN on SiC HEMT which operates from 30MHz to 1.215 GHz. The integrated input matching network enables wideband gain and power performance, while the output can be matched on board to optimize power and efficiency for any region within the band.

The device is housed in a 5 x 6 mm leadless SMT package that saves real estate of already space-constrained handheld radios.

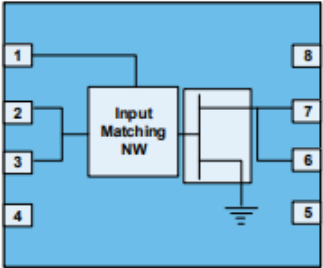
Lead-free and ROHS compliant

Evaluation boards are available upon request.



5 x 6 x 1.09 mm QFN

Functional Block Diagram



Key Features

- Frequency: 30 MHz to 1.215 GHz
- Output Power (P_{3dB})¹: 24 W
- Linear Gain¹: 19 dB
- Typical PAE_{3dB}¹: 78 %
- Operating Voltage: 28 V
- Low thermal resistance package
- CW and Pulse capable
- 5 x 6 mm package

Note 1: @ 1 GHz

Applications

- Military radar
- Civilian radar
- Land mobile and military radio communications
- Test instrumentation
- Wideband or narrowband amplifiers
- Jammers

32. Identification of the Accused Products will be provided in Akoustis’ infringement contentions pursuant to the Court’s scheduling order and local rules.

⁴ QPD1000 Datasheet Rev. F, QORVO (June 2021), <https://www.qorvo.com/products/d/da003625>.

COUNT I: INFRINGEMENT OF THE '360 PATENT

33. Akoustis incorporates by reference the preceding paragraphs as if fully stated herein.

34. Qorvo has been and is now directly infringing and/or indirectly infringing the '360 Patent by way of inducement, literally and/or under the doctrine of equivalents, in violation of 35 U.S.C. § 271, including by making, using, selling, and/or offering for sale in the United States or importing into the United States infringing products, including at least the Accused Products. Qorvo derives revenue from the activities relating to the Accused Products. As explained below, these products are covered by one or more claims of the '360 Patent, including but not limited to claims 1-4, 6-7, and 9-14. Claim 1 reads as follows:

1. A process for growing an epitaxial layer on a lattice mismatched substrate comprising the steps of:

- a) providing a substrate;
- b) pre-treating a surface of the substrate with at least one group III reactant or at least one group II reactant at an elevated growth temperature prior to introducing a group V reactant or a group VI reactant;
- c) introducing a group V reactant or a group VI reactant to grow a nucleation layer on the surface of the substrate; and
- d) growing a buffer layer on said nucleation layer, said buffer layer providing a surface upon which said epitaxial layer is grown.

35. As a non-limiting example, the Qorvo Accused Products are made using a process for growing an epitaxial layer on a lattice mismatched substrate comprising the claimed limitations. This is supported by the exemplary evidence below.

36. For example, Qorvo's QPD1000 Accused Product is made using a process that grows a gallium nitride (GaN) epitaxial material on a silicon carbide (SiC) substrate. As Qorvo explains in the QPD1000 Datasheet, "The Qorvo QPD1000 is a 15W (P3dB), 50Ω-input

matched discrete GaN on SiC HEMT which operates from 30MHz to 1.215 GHz.”⁵ GaN and SiC have different lattice constants.⁶



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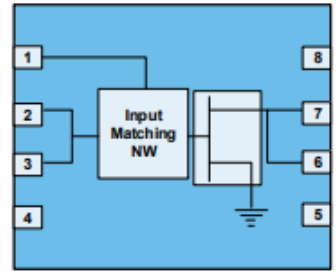
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Note 1: @ 1 GHz

Applications

- Military radar
- Civilian radar
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- Test instrumentation
- Wideband or narrowband amplifiers
- Jammers

37. The Qorvo Accused Products comprise providing a substrate.

38. For example, as Qorvo explains in the QPD1000 Datasheet, “The Qorvo QPD1000 is a 15W (P_{3dB}), 50 Ω -input matched discrete GaN on SiC HEMT which operates

⁵ *QPD1000 Datasheet Rev. F*, QORVO (June 2021), <https://www.qorvo.com/products/d/da003625>.

⁶ See, e.g., *Lattice Constants and Crystal Structures of some Semiconductors and Other Materials*, SECTOR 7 (n.d.), https://7id.xray.aps.anl.gov/calculators/crystal_lattice_parameters.html.

from 30MHz to 1.215 GHz.”⁷ On information and belief, Qorvo uses “HEMT” to refer to high-electron-mobility transistor.



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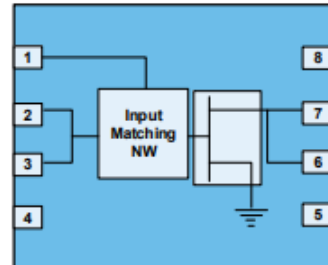
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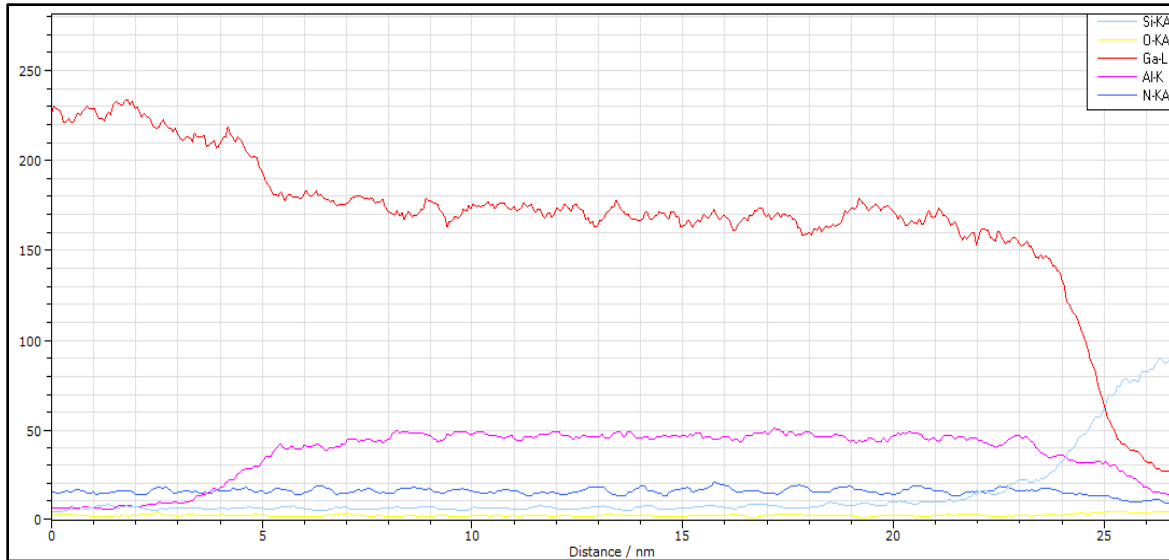
Note 1: @ 1 GHz

Applications

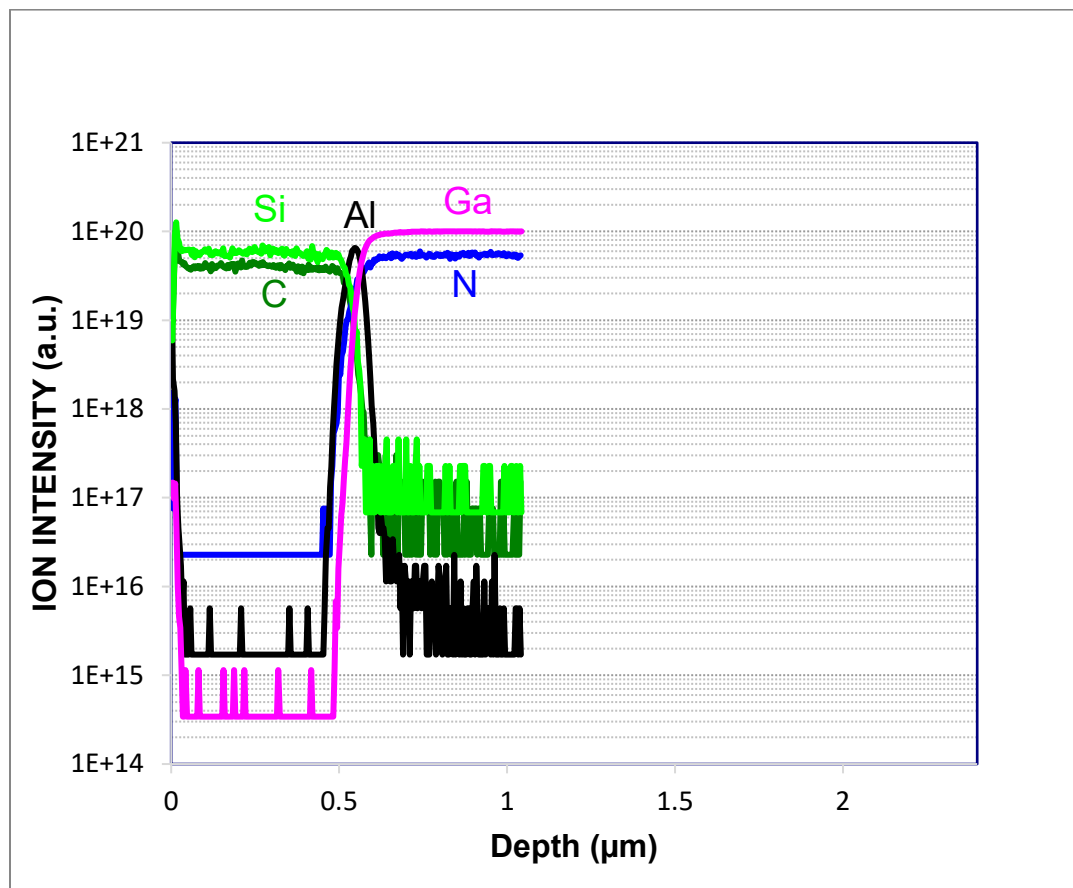
- Military radar
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- Test instrumentation
- Wideband or narrowband amplifiers
- Jammers

39. The QPD1000 Accused Product’s SiC substrate is further indicated by the light blue line (“Si”) in the below EDS line scan.

⁷ QPD1000 Datasheet Rev. F, QORVO (June 2021), <https://www.qorvo.com/products/d/da003625>.

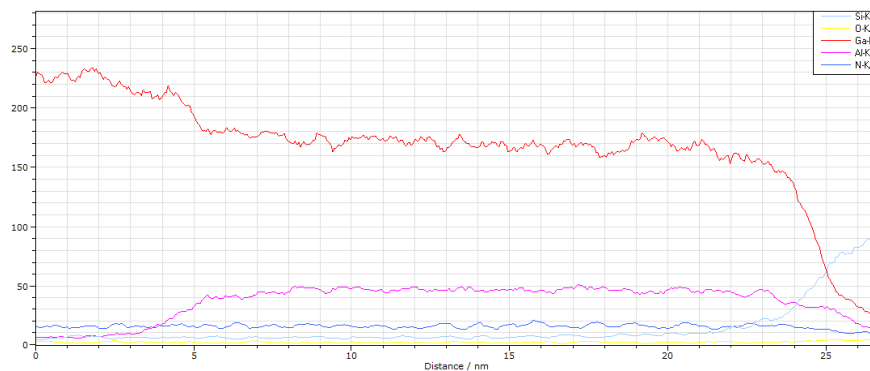


40. The QPD1000 Accused Product's SiC substrate is also indicated by the below SIMS element trace analysis (done from the device's backside), which shows the SiC substrate on the left-hand side (light-green and dark-green traces).



41. The Qorvo Accused Products comprise pre-treating a surface of the substrate with at least one group III reactant or at least one group II reactant at an elevated growth temperature prior to introducing a group V reactant or a group VI reactant.

42. For example, as to Qorvo's QPD1000 Accused Product, the below line scan demonstrates that an aluminum gallium nitride (AlGa_N) material is overlying a SiC substrate. Specifically, the purple (Al), red (Ga), and blue (N) curves rise from lower values (right-to-left) while the light blue curve (Si) drops (right-to-left). The Ga concentration is larger than the Al concentration resulting in a Ga-rich AlGa_N material overlying the SiC substrate.

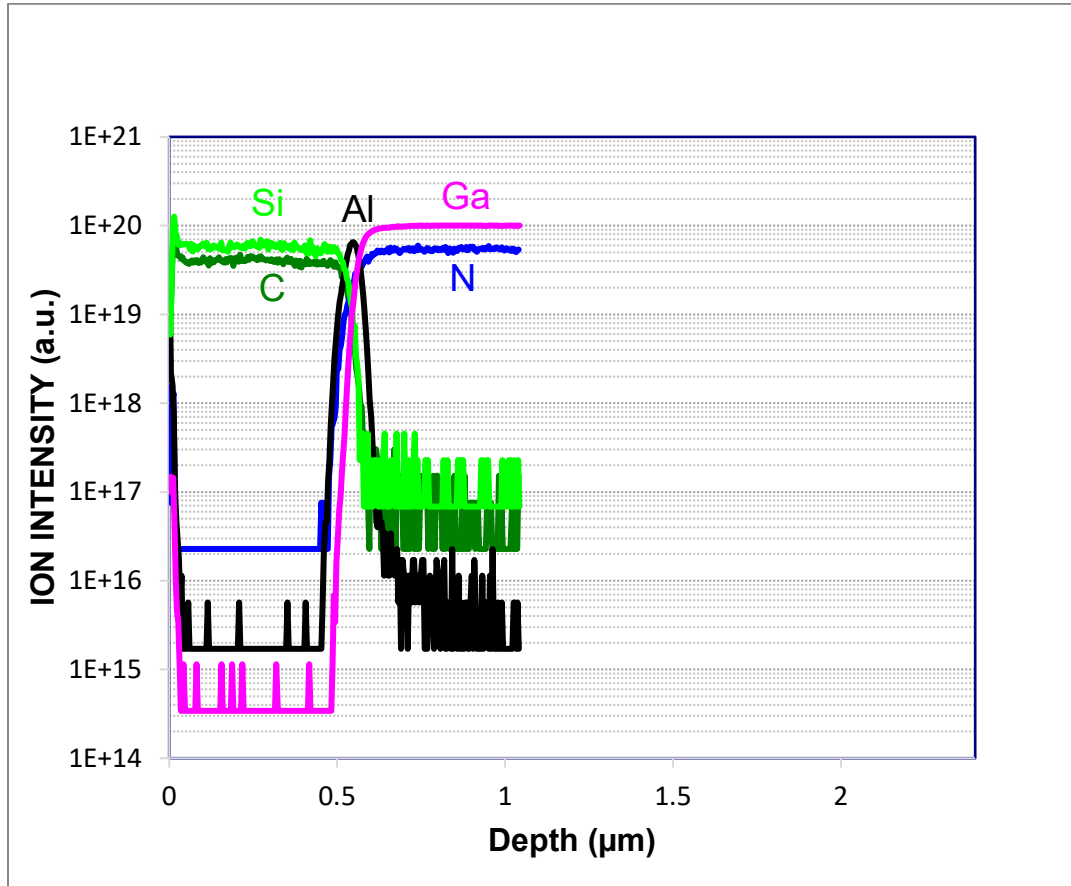


43. On information and belief, the AlGa_N material of Qorvo's QPD1000 Accused Product is grown by using Group III reactants (an Al-bearing reactant and a Ga-bearing reactant) and a Group V reactant (a N-bearing reactant) at an elevated temperature.

44. On information and belief, the AlGa_N material of Qorvo's QPD1000 Accused Product is grown on a nucleation layer formed at the interface with the SiC substrate. This is evidenced by the change in the concentrations of Ga and Al near the AlGa_N/SiC interface.

45. The below SIMS element trace analysis of Qorvo's QPD1000 Accused Product (done from the device's backside) demonstrates that the Al-concentration increases before the N and Ga traces increase. The sequence of element traces as a function of the distance from the substrate interface reflects the growth process: The Al-bearing reactant is introduced first, prior

to the N-bearing reactant. This indicates that the substrate surface is pre-treated with one group III reactant (Al), which is incorporated into the surface prior to the introduction of the group V reactant (N) to form the nitride.



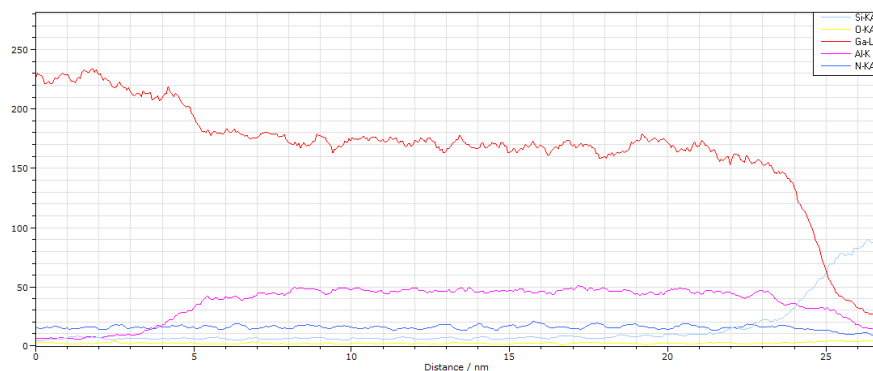
46. The below excerpt (highlighting added) of the underlying raw SIMS data used for the above SIMS element trace analysis shows that the Al signal (black in trace analysis and green in raw SIMS data) appears approximately 20nm before N (blue), while the Ga signal (magenta) appears approximately 10nm after N (blue).

0.420962065	3.72E+19	0.421610697	2.28E+16	0.422091939	1.71E+15	0.423723981	5.72E+19	0.424205224	3.42E+14
0.424853856	3.75E+19	0.425502488	2.28E+16	0.425983731	1.71E+15	0.427615772	5.13E+19	0.428097015	3.42E+14
0.428745647	3.88E+19	0.429394279	2.28E+16	0.429875522	1.71E+15	0.431507563	5.58E+19	0.431988806	3.42E+14
0.432637438	3.72E+19	0.43328607	2.28E+16	0.433767313	1.71E+15	0.435399354	4.51E+19	0.435880597	3.42E+14
0.436529229	3.98E+19	0.437177861	2.28E+16	0.437659104	1.71E+15	0.439291145	5.58E+19	0.439772388	3.42E+14
0.44042102	3.65E+19	0.441069652	2.28E+16	0.441550895	1.71E+15	0.443182936	5.15E+19	0.443664179	3.42E+14
0.444312811	3.86E+19	0.444961443	2.28E+16	0.445442686	1.71E+15	0.447074727	5.04E+19	0.44755597	3.42E+14
0.448204602	3.69E+19	0.448853234	2.28E+16	0.449334477	1.71E+15	0.450966518	4.88E+19	0.451447761	3.42E+14
0.452096393	3.87E+19	0.452745025	7.6E+16	0.453226268	1.71E+15	0.454858309	5.49E+19	0.455339552	3.42E+14
0.455988184	3.66E+19	0.456636816	2.28E+16	0.457118059	5.7E+15	0.4587501	5.65E+19	0.459231343	3.42E+14
0.459879975	4.01E+19	0.460528607	7.6E+16	0.46100985	2.28E+16	0.462641891	6.22E+19	0.463123134	3.42E+14
0.463771766	3.77E+19	0.464420398	2.28E+16	0.464901641	4.56E+16	0.466533682	5.93E+19	0.467014925	3.42E+14
0.467663557	3.63E+19	0.468312189	2.28E+16	0.468793432	4.56E+16	0.470425473	5.08E+19	0.470906716	3.42E+14
0.471555348	3.52E+19	0.47220398	2.28E+16	0.472685223	1.31E+17	0.474317264	5.11E+19	0.474798507	3.42E+14
0.475447139	3.71E+19	0.476095771	1.52E+17	0.476577014	2.22E+17	0.478209056	5.81E+19	0.478690299	3.42E+14
0.47933893	4.08E+19	0.479987562	2.28E+17	0.480468805	5.3E+17	0.482100847	5.06E+19	0.48258209	3.42E+14
0.483230721	3.94E+19	0.483879353	5.32E+17	0.484360596	9.74E+17	0.485992638	5.27E+19	0.486473881	1.14E+15
0.487122512	3.62E+19	0.487771144	6.08E+17	0.488252387	1.73E+18	0.489884429	5.74E+19	0.490365672	6.84E+15
0.491014303	3.44E+19	0.491662935	6.84E+17	0.492144178	3.21E+18	0.49377622	5.11E+19	0.494257463	3.42E+15
0.494906095	3.87E+19	0.495554726	9.12E+17	0.496035969	4.8E+18	0.497668011	5.54E+19	0.498149254	1.6E+16
0.498797886	3.52E+19	0.499446517	2.81E+18	0.49992776	7.13E+18	0.501559802	5.01E+19	0.502041045	3.31E+16
0.502689677	3.38E+19	0.503338308	2.43E+18	0.503819551	1.02E+19	0.505451593	4.81E+19	0.505932836	6.38E+16
0.506581468	3.39E+19	0.5072301	4.03E+18	0.507711342	1.38E+19	0.509343384	4.42E+19	0.509824627	8.78E+16
0.510473259	3.31E+19	0.511121891	4.41E+18	0.511603134	1.74E+19	0.513235175	4.03E+19	0.513716418	1.6E+17
0.51436505	2.64E+19	0.515013682	5.7E+18	0.515494925	2.17E+19	0.517126966	3.9E+19	0.517608209	2.68E+17
0.518256841	2.64E+19	0.518905473	8.28E+18	0.519386716	2.65E+19	0.521018757	3.26E+19	0.5215	4.08E+17

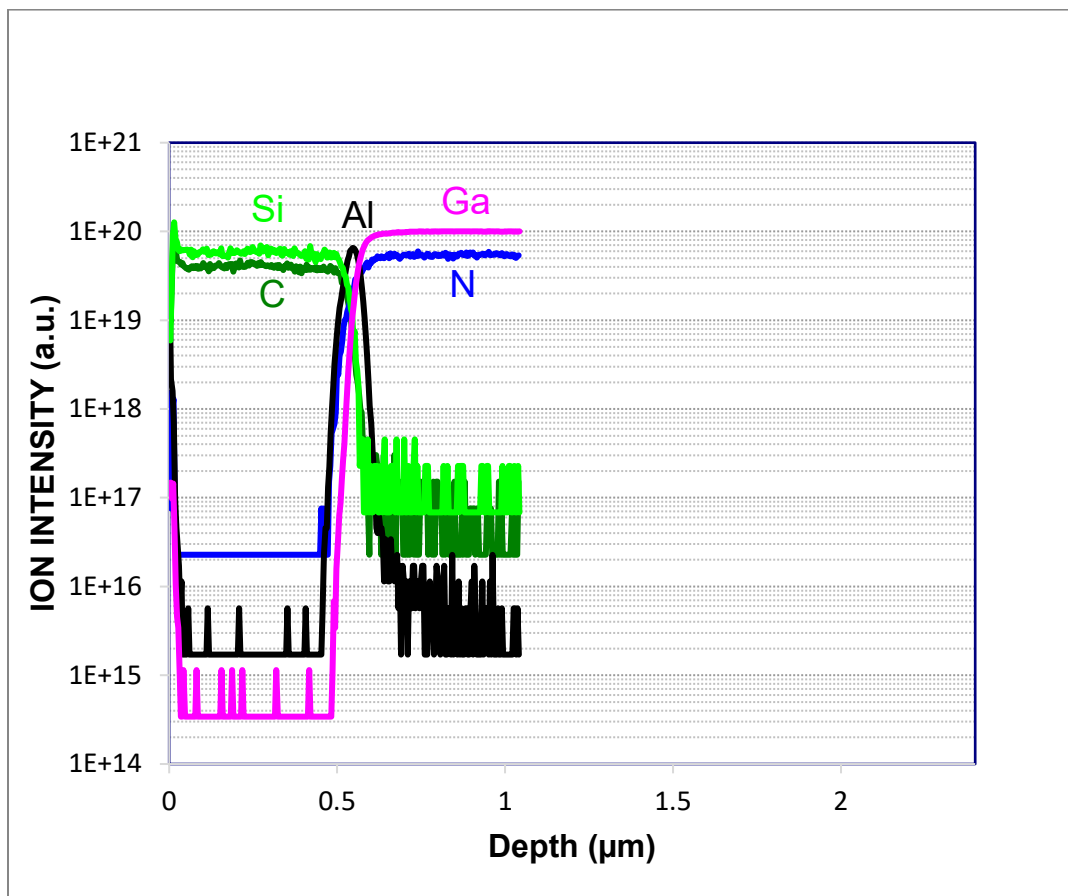
47. On information and belief, Qorvo's QPD1000 Accused Product nucleation layer is formed after pre-treating the surface of the substrate with Al group III reactants prior to introducing the N group V reactant.

48. The Qorvo Accused Products comprise introducing a group V reactant or a group VI reactant to grow a nucleation layer on the surface of the substrate.

49. For example, as to Qorvo's QPD1000 Accused Product, after pretreating the SiC surface with Group III reactants (Al), an N-bearing Group V reactant is introduced to grow a nucleation layer on the surface of the SiC substrate. The N-bearing reactant is reacting with Al-bearing reactants adsorbed on the SiC surface during the pre-treatment step and Ga- and/or Al-bearing reactants, which may be also introduced simultaneously with the N-bearing reactant to grow a nucleation layer on the SiC surface. As shown in the EDS line scan below, although the N-bearing reactant was subsequently added, the stable line in dark blue (N) shows that such N-bearing material reacted throughout the thickness of the interfacial region to form the constant concentration throughout this region.



50. The below SIMS element trace analysis of Qorvo's QPD1000 Accused Product (done from the device's backside), along with the corresponding excerpt (highlighting added) of the underlying raw SIMS data used for the SIMS element trace analysis, shows that the Al signal (black in trace analysis and green in raw SIMS data) appears approximately 20nm before N (blue), while the Ga signal (magenta) appears approximately 10nm after N (blue).



0.420962065	3.72E+19	0.421610697	2.28E+16	0.422091939	1.71E+15	0.423723981	5.72E+19	0.424205224	3.42E+14
0.424853856	3.75E+19	0.425502488	2.28E+16	0.425983731	1.71E+15	0.427615772	5.13E+19	0.428097015	3.42E+14
0.428745647	3.88E+19	0.429394279	2.28E+16	0.429875522	1.71E+15	0.431507563	5.58E+19	0.431988806	3.42E+14
0.432637438	3.72E+19	0.43328607	2.28E+16	0.433767313	1.71E+15	0.435399354	4.51E+19	0.435880597	3.42E+14
0.436529229	3.98E+19	0.437177861	2.28E+16	0.437659104	1.71E+15	0.439291145	5.58E+19	0.439772388	3.42E+14
0.44042102	3.65E+19	0.441069652	2.28E+16	0.441550895	1.71E+15	0.443182936	5.15E+19	0.443664179	3.42E+14
0.444312811	3.86E+19	0.444961443	2.28E+16	0.445442686	1.71E+15	0.447074727	5.04E+19	0.44755597	3.42E+14
0.448204602	3.69E+19	0.448853234	2.28E+16	0.449334477	1.71E+15	0.450966518	4.88E+19	0.451447761	3.42E+14
0.452096393	3.87E+19	0.452745025	7.6E+16	0.453226268	1.71E+15	0.454858309	5.49E+19	0.455339552	3.42E+14
0.455988184	3.66E+19	0.456636816	2.28E+16	0.457118059	5.7E+15	0.4587501	5.65E+19	0.459231343	3.42E+14
0.459879975	4.01E+19	0.460528607	7.6E+16	0.46100985	2.28E+16	0.462641891	6.22E+19	0.463123134	3.42E+14
0.463771766	3.77E+19	0.464420398	2.28E+16	0.464901641	4.56E+16	0.466533682	5.93E+19	0.467014925	3.42E+14
0.467663557	3.63E+19	0.468312189	2.28E+16	0.468793432	4.56E+16	0.470425473	5.08E+19	0.470906716	3.42E+14
0.471555348	3.52E+19	0.47220398	2.28E+16	0.472685223	1.31E+17	0.474317264	5.11E+19	0.474798507	3.42E+14
0.475447139	3.71E+19	0.476095771	1.52E+17	0.476577014	2.22E+17	0.478209056	5.81E+19	0.478690299	3.42E+14
0.47933893	4.08E+19	0.479987562	2.28E+17	0.480468805	5.3E+17	0.482100847	5.06E+19	0.48258209	3.42E+14
0.483230721	3.94E+19	0.483879353	5.32E+17	0.484360596	9.74E+17	0.485992638	5.27E+19	0.486473881	1.14E+15
0.487122512	3.62E+19	0.487771144	6.08E+17	0.488252387	1.73E+18	0.489884429	5.74E+19	0.490365672	6.84E+15
0.491014303	3.44E+19	0.491662935	6.84E+17	0.492144178	3.21E+18	0.49377622	5.11E+19	0.494257463	3.42E+15
0.494906095	3.87E+19	0.495554726	9.12E+17	0.496035969	4.8E+18	0.497668011	5.54E+19	0.498149254	1.6E+16
0.498797886	3.52E+19	0.499446517	2.81E+18	0.49992776	7.13E+18	0.501559802	5.01E+19	0.502041045	3.31E+16
0.502689677	3.38E+19	0.503338308	2.43E+18	0.503819551	1.02E+19	0.505451593	4.81E+19	0.505932836	6.38E+16
0.506581468	3.39E+19	0.5072301	4.03E+18	0.507711342	1.38E+19	0.509343384	4.42E+19	0.509824627	8.78E+16
0.510473259	3.31E+19	0.511121891	4.41E+18	0.511603134	1.74E+19	0.513235175	4.03E+19	0.513716418	1.6E+17
0.51436505	2.64E+19	0.515013682	5.7E+18	0.515494925	2.17E+19	0.517126966	3.9E+19	0.517608209	2.68E+17
0.518256841	2.64E+19	0.518905473	8.28E+18	0.519386716	2.65E+19	0.521018757	3.26E+19	0.5215	4.08E+17

51. The Qorvo Accused Products comprise growing a buffer layer on said nucleation layer, said buffer layer providing a surface upon which said epitaxial layer is grown.

52. For example, as to Qorvo's QPD1000 Accused Product (and as already evidenced above), an AlGaN material is formed overlying the AlN nucleation layer by turning on the Ga-reactant. The AlGaN material is a buffer layer providing a surface upon which to grow an overlying GaN material, which is epitaxial in form.

53. On information and belief, Qorvo also indirectly infringes claims of the '360 Patent, as provided in 35 U.S.C. § 271(b), by inducing infringement by others. For example, to the extent Qorvo's partners and suppliers are involved in the manufacturing and development of the Accused Products, those partners and suppliers directly infringe through their use of the inventions claimed in the '360 Patent. Qorvo induces this direct infringement through its affirmative acts of seeking, buying, distributing, and/or otherwise having the Accused Products made, and providing instructions, documentation, technical support, marketing, product manuals, advertisements, and other information to partners and suppliers suggesting they make the

Accused Products in an infringing manner. As a result of Qorvo's inducement, Qorvo's suppliers are involved in making the Accused Products in the way Qorvo intends and directly infringe the '360 Patent. Qorvo has known of the '360 Patent since at least its issuance through RFMD's prior exclusive licensee agreement with Cornell.

54. Qorvo's infringement is willful, deliberate, and intentional, and Qorvo is acting in reckless disregard of Akoustis' patent rights. For example, Qorvo has known of the '360 Patent since at least its issuance through RFMD's prior exclusive licensee agreement with Cornell.

55. To the extent applicable, the requirements of 35 U.S.C. § 287(a) have been met with respect to the '360 Patent.

DEMAND FOR JURY TRIAL

Akoustis demands a trial by jury of any and all issues triable of right before a jury, except for future patent infringement, which is an issue in equity to be determined by the Court.

PRAYER FOR RELIEF

WHEREFORE, Akoustis pray for the following relief:

- A. A judgment in favor of Akoustis that Qorvo has infringed, directly and indirectly, by way of inducement, literally and/or under the doctrine of equivalents, the '360 Patent;
- B. An order awarding damages sufficient to compensate Akoustis for Qorvo's infringement of the '360 Patent, but in no event less than a reasonable royalty, including supplemental damages post-verdict, together with pre-judgment and post-judgment interest and costs;
- C. A judgment that Qorvo's infringement has been willful;
- D. Enhanced damages pursuant to 35 U.S.C. § 284;

- E. Entry of judgment declaring that this case is exceptional and awarding Akoustis its costs and reasonable attorney fees under 35 U.S.C. § 285;
- F. An accounting for acts of infringement;
- G. A judgment and order requiring Qorvo to pay Akoustis compulsory ongoing licensing fees, as determined by the Court in equity; and
- H. Such other equitable relief which may be requested and to which Akoustis is entitled; and
- I. Such other and further relief as the Court deems just and proper.

Dated: April 20, 2023.

McKool Smith, P.C.

/s/ John B. Campbell

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**ATTORNEYS FOR PLAINTIFFS
AKOUSTIS TECHNOLOGIES, INC.
AND AKOUSTIS, INC.**

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON NEXT PAGE OF THIS FORM.)

I. (a) PLAINTIFFS

AKOUSTIS TECHNOLOGIES, INC. AND AKOUSTIS, INC.

(b) County of Residence of First Listed Plaintiff
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorneys (Firm Name, Address, and Telephone Number)
John B. Campbell, McKool Smith PC, 303 Colorado Street Suite 2100, Austin, TX 78701, Tel. (512) 692-8700

DEFENDANTS

QORVO, INC.

County of Residence of First Listed Defendant
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

☐ 1 U.S. Government Plaintiff

☒ 3 Federal Question
(U.S. Government Not a Party)

☐ 2 U.S. Government Defendant

☐ 4 Diversity
(Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated or Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated and Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

Click here for: [Nature of Suit Code Descriptions.](#)

CONTRACT	TORTS	FORFEITURE/PENALTY	BANKRUPTCY	OTHER STATUTES
☐ 110 Insurance ☐ 120 Marine ☐ 130 Miller Act ☐ 140 Negotiable Instrument ☐ 150 Recovery of Overpayment & Enforcement of Judgment ☐ 151 Medicare Act ☐ 152 Recovery of Defaulted Student Loans (Excludes Veterans) ☐ 153 Recovery of Overpayment of Veteran's Benefits ☐ 160 Stockholders' Suits ☐ 190 Other Contract ☐ 195 Contract Product Liability ☐ 196 Franchise	PERSONAL INJURY ☐ 310 Airplane ☐ 315 Airplane Product Liability ☐ 320 Assault, Libel & Slander ☐ 330 Federal Employers' Liability ☐ 340 Marine ☐ 345 Marine Product Liability ☐ 350 Motor Vehicle ☐ 355 Motor Vehicle Product Liability ☐ 360 Other Personal Injury ☐ 362 Personal Injury - Medical Malpractice PERSONAL INJURY ☐ 365 Personal Injury - Product Liability ☐ 367 Health Care/Pharmaceutical Personal Injury Product Liability ☐ 368 Asbestos Personal Injury Product Liability PERSONAL PROPERTY ☐ 370 Other Fraud ☐ 371 Truth in Lending ☐ 380 Other Personal Property Damage ☐ 385 Property Damage Product Liability	☐ 625 Drug Related Seizure of Property 21 USC 881 ☐ 690 Other LABOR ☐ 710 Fair Labor Standards Act ☐ 720 Labor/Management Relations ☐ 740 Railway Labor Act ☐ 751 Family and Medical Leave Act ☐ 790 Other Labor Litigation ☐ 791 Employee Retirement Income Security Act IMMIGRATION ☐ 462 Naturalization Application ☐ 465 Other Immigration Actions	☐ 422 Appeal 28 USC 158 ☐ 423 Withdrawal 28 USC 157 INTELLECTUAL PROPERTY RIGHTS ☐ 820 Copyrights ☒ 830 Patent ☐ 835 Patent - Abbreviated New Drug Application ☐ 840 Trademark ☐ 880 Defend Trade Secrets Act of 2016 SOCIAL SECURITY ☐ 861 HIA (1395ff) ☐ 862 Black Lung (923) ☐ 863 DIWC/DIWW (405(g)) ☐ 864 SSID Title XVI ☐ 865 RSI (405(g)) FEDERAL TAX SUITS ☐ 870 Taxes (U.S. Plaintiff or Defendant) ☐ 871 IRS—Third Party 26 USC 7609	☐ 375 False Claims Act ☐ 376 Qui Tam (31 USC 3729(a)) ☐ 400 State Reapportionment ☐ 410 Antitrust ☐ 430 Banks and Banking ☐ 450 Commerce ☐ 460 Deportation ☐ 470 Racketeer Influenced and Corrupt Organizations ☐ 480 Consumer Credit (15 USC 1681 or 1692) ☐ 485 Telephone Consumer Protection Act ☐ 490 Cable/Sat TV ☐ 850 Securities/Commodities/Exchange ☐ 890 Other Statutory Actions ☐ 891 Agricultural Acts ☐ 893 Environmental Matters ☐ 895 Freedom of Information Act ☐ 896 Arbitration ☐ 899 Administrative Procedure Act/Review or Appeal of Agency Decision ☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an "X" in One Box Only)

☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from Another District (specify) ☐ 6 Multidistrict Litigation - Transfer ☐ 8 Multidistrict Litigation - Direct File

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing (Do not cite jurisdictional statutes unless diversity):
35 U.S.C. § 1 et seq.
Brief description of cause:
Patent Infringement

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER RULE 23, F.R.Cv.P.

DEMAND \$

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions):

JUDGE

DOCKET NUMBER

DATE
Apr 20, 2023

SIGNATURE OF ATTORNEY OF RECORD
/s/ John B. Campbell

FOR OFFICE USE ONLY

RECEIPT # AMOUNT APPLYING IFP JUDGE MAG. JUDGE

Qorvo - Exhibit 1029, Page 21

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS 44

Authority For Civil Cover Sheet

The JS 44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently, a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

- I.(a) Plaintiffs-Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.
 - (b) County of Residence.** For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)
 - (c) Attorneys.** Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".
- II. Jurisdiction.** The basis of jurisdiction is set forth under Rule 8(a), F.R.Cv.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.
- United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here. United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an "X" in this box.
- Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.
- Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; **NOTE: federal question actions take precedence over diversity cases.**)
- III. Residence (citizenship) of Principal Parties.** This section of the JS 44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.
- IV. Nature of Suit.** Place an "X" in the appropriate box. If there are multiple nature of suit codes associated with the case, pick the nature of suit code that is most applicable. Click here for: [Nature of Suit Code Descriptions](#).
- V. Origin.** Place an "X" in one of the seven boxes.
- Original Proceedings. (1) Cases which originate in the United States district courts.
- Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441.
- Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.
- Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.
- Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.
- Multidistrict Litigation – Transfer. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407.
- Multidistrict Litigation – Direct File. (8) Check this box when a multidistrict case is filed in the same district as the Master MDL docket.
- PLEASE NOTE THAT THERE IS NOT AN ORIGIN CODE 7.** Origin Code 7 was used for historical records and is no longer relevant due to changes in statute.
- VI. Cause of Action.** Report the civil statute directly related to the cause of action and give a brief description of the cause. **Do not cite jurisdictional statutes unless diversity.** Example: U.S. Civil Statute: 47 USC 553 Brief Description: Unauthorized reception of cable service.
- VII. Requested in Complaint.** Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.Cv.P.
- Demand. In this space enter the actual dollar amount being demanded or indicate other demand, such as a preliminary injunction.
- Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.
- VIII. Related Cases.** This section of the JS 44 is used to reference related pending cases, if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.

EXHIBIT 1



US007250360B2

(12) **United States Patent**
Shealy et al.

(10) **Patent No.:** **US 7,250,360 B2**

(45) **Date of Patent:** **Jul. 31, 2007**

(54) **SINGLE STEP, HIGH TEMPERATURE
NUCLEATION PROCESS FOR A LATTICE
MISMATCHED SUBSTRATE**

(75) Inventors: **James R. Shealy**, Ithaca, NY (US);
Joseph A. Smart, Mooresville, NC
(US)

(73) Assignee: **Cornell Research Foundation, Inc.**,
Ithaca, NY (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 124 days.

* cited by examiner

Primary Examiner—David Nhu

(74) *Attorney, Agent, or Firm*—Jones, Tullar & Cooper PC

(21) Appl. No.: **11/069,040**

(57) **ABSTRACT**

(22) Filed: **Mar. 2, 2005**

(65) **Prior Publication Data**

US 2006/0199364 A1 Sep. 7, 2006

(51) **Int. Cl.**

H01L 21/28 (2006.01)

H01L 21/3205 (2006.01)

(52) **U.S. Cl.** **438/603**; 438/604; 438/607;
257/E21.097; 257/E21.108; 257/E21.112;
257/E21.118; 257/E21.126

(58) **Field of Classification Search** 438/603,
438/604, 606, 608, 688, 660, 663, 341, 363,
438/416, 502, 913, 931, 933

See application file for complete search history.

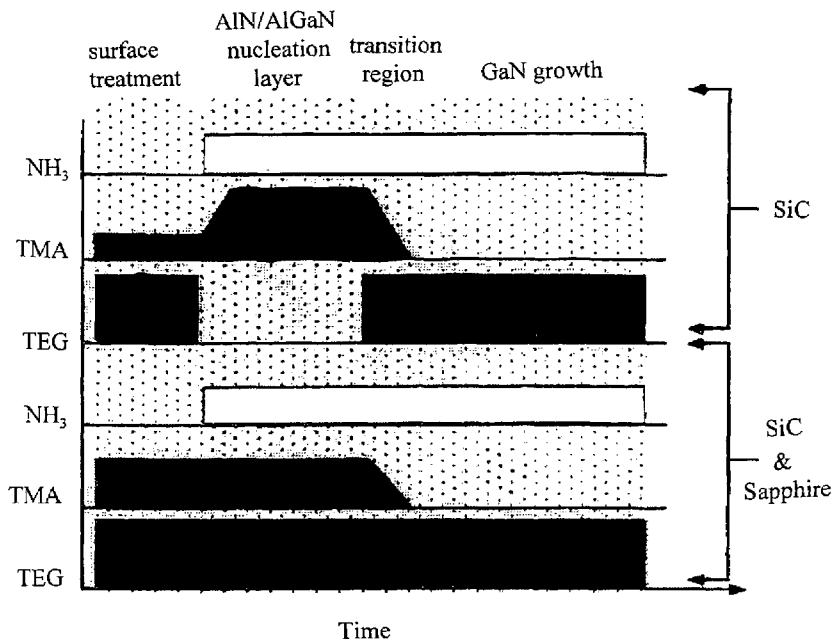
(56) **References Cited**

U.S. PATENT DOCUMENTS

5,625,202 A * 4/1997 Chai 257/94

A single step process for nucleation and subsequent epitaxial growth on a lattice mismatched substrate is achieved by pre-treating the substrate surface with at least one group III reactant or at least one group II reactant prior to the introduction of a group V reactant or a group VI reactant. The group III reactant or the group II reactant is introduced into a growth chamber at an elevated growth temperature to wet a substrate surface prior to any actual crystal growth. Once the pre-treatment of the surface is complete, a group V reactant or a group VI reactant is introduced to the growth chamber to commence the deposition of a nucleation layer. A buffer layer is then grown on the nucleation layer providing a surface upon which the epitaxial layer is grown preferably without changing the temperature within the chamber.

24 Claims, 1 Drawing Sheet



U.S. Patent

Jul. 31, 2007

US 7,250,360 B2

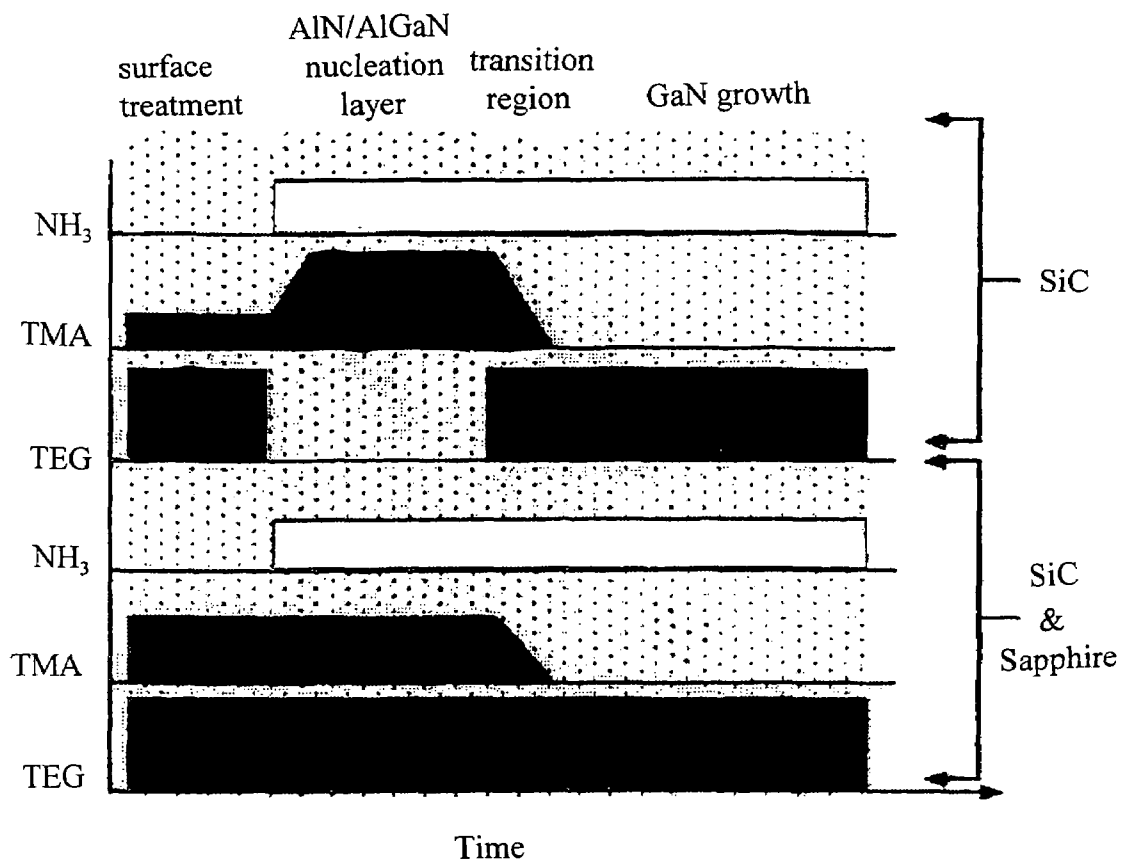


FIG. 1

US 7,250,360 B2

1

SINGLE STEP, HIGH TEMPERATURE NUCLEATION PROCESS FOR A LATTICE MISMATCHED SUBSTRATE

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Governmental support from the Office of Naval Research under Contract No. N00014-96-1-1223 and DARPA under Contract No. DABT63-C95-0121. The Government has certain rights in the invention.

BACKGROUND ON THE INVENTION

1. Field of the Invention

The present invention relates to a single step process for the nucleation and subsequent epitaxial growth on a lattice mismatched substrate.

2. Description of Related Art

Heteroepitaxial growth of GaN and related alloys on severely mismatched substrates such as sapphire, SiC and silicon requires thin nucleation layers to provide nucleation sites to initiate crystal growth. When optimized, these nucleation layers accommodate the strain between the substrate and epitaxial layers caused by lattice and thermal mismatches, while still maintaining crystallographic registration of the epitaxial films to the substrate lattice structure. The most commonly accepted practice for nucleation of these substrates with GaN-based material utilizes a two-temperature process involving either one or two flow paths. In addition, different growth pressures are used on certain steps in the nucleation process. In this fashion, high structural and electrical quality epitaxial films can be realized in severely mismatched material systems.

BRIEF SUMMARY OF THE INVENTION

The present invention is a single step process for the nucleation and subsequent epitaxial growth on a lattice mismatched substrate. A nucleation layer and a buffer layer are formed on the lattice mismatched substrate prior to the formation of an epitaxial layer. The epitaxial layer preferably includes a III-V compound or a II-VI compound. Crystal growth can be carried out by any conventional means such as organometallic vapor phase epitaxy (OM-VPE), molecular beam epitaxy (MBE), or atomic layer epitaxy. The techniques for crystal growth preferably involve flow (beam) modulation, growth at atmospheric or reduced pressures, as well as various precursor chemistries that are widely accepted in the industrial and research communities.

In a preferred embodiment, a lattice mismatched substrate is pre-treated with a group III reactant or a group II reactant at an elevated growth temperature prior to the addition of a group V reactant or a group VI reactant and the growth of a nucleation layer. The group III reactant or the group II reactant is introduced into a growth chamber to pre-treat a surface of the substrate. Then, a nucleation layer is formed by introducing the group V reactant or the group VI reactant into the growth chamber. In a preferred embodiment, the nucleation layer is $Al_xGa_{1-x}N$ where x varies from 0 to 1. A buffer layer, preferably GaN, is formed on the nucleation layer to provide a surface upon which the epitaxial layer is grown. In a preferred embodiment, aluminum reacts with the surface of the substrate providing the needed nucleation sites while gallium prepares the aluminum saturated surface for

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subsequent growth of the epitaxial layer, preferably an epitaxial layer including AlN, AlGa_{0.5}N, or GaN.

The present single step process is a single flow, single pressure, high temperature process. The single step process involves a surface treatment prior to epitaxial growth that allows complete coalescence of the epitaxial film within the first 200 Å of growth. This single step process eliminates the large temperature ramps and complex flow requirements of the commonly used two-step nucleation technologies.

BRIEF DESCRIPTION OF THE DRAWING(S)

The features and advantages of the present invention will become apparent from the following detailed description of a preferred embodiment thereof, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic representation of one embodiment of the single step nucleation process.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a single step process, preferably a single flow, single pressure, high temperature nucleation process. This single step process for nucleation and subsequent growth of an epitaxial layer on a lattice mismatched substrate is achieved by pre-treating a surface of the substrate with at least one group III reactant or at least one group II reactant prior to the introduction of a group V or a group VI reactant. The substrate is a mismatched substrate comprising a material that is lattice mismatched to an epitaxial layer to be grown thereon. Preferably, the mismatched substrate is silicon, sapphire or SiC. The reactants are generally selected from a group of compounds which are volatile near room temperature and can be vapor transported in a carrier gas. The group III reactant is preferably selected from the group consisting of a gallium reactant, an aluminum reactant, a boron reactant, and an indium reactant. Most preferably, the gallium reactant is triethylgallium (TEG) or trimethylgallium (TMG). Most preferably, the aluminum reactant is triethylaluminum (TEA) or trimethylaluminum (TMA). Most preferably, the boron reactant is triethylboron (TEB) or trimethylboron (TMB). Most preferably, the indium reactant is triethylindium (TEIn) or trimethylindium (TMIn). The group II reactant is preferably selected from the group consisting of a cadmium reactant and a zinc reactant. At least one group III reactant or at least one group II reactant is introduced into a growth chamber at an elevated growth temperature to pre-treat the surface of the substrate prior to any actual crystal growth. In a preferred embodiment, the elevated growth temperature is 900 to 1100° C. In a preferred embodiment, more than one group III reactant or more than one group II reactant is introduced into the growth chamber. For example, two group III reactants, preferably a gallium reactant and an aluminum reactant, may be introduced into the growth chamber. Once the pre-treatment is complete, the group V reactant or the group VI reactant is introduced to begin the growth of the nucleation layer. Preferably, the group V reactant contains a nitrogen reactant, an arsenic reactant or a phosphorus reactant. In one preferred embodiment, the group V reactant is a group V hydride, most preferably ammonia, arsine or phosphine. In a second preferred embodiment, the group V reactant is a group V organic precursor, most preferably tertiarybutylarsine (TBAs) or tertiarybutylphosphine (TBP). Preferably, the group VI reactant contains a tellurium reactant or a sulfur reactant. After the nucleation layer is formed, a buffer layer

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is formed on the nucleation layer. The buffer layer provides a surface upon which the epitaxial layer is grown. The epitaxial layer includes a III-V compound or a II-VI compound. Preferably, the III-V compound or the II-VI compound includes, but is not limited to, AlN, GaN, AlGaIn, 5 BGaN, BInN, BAlN, CdTe, and ZnS.

In a preferred embodiment, an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ nucleation layer where x varies from 0 to 1 is grown on a substrate. Generally, the aluminum content requirements increase from SiC, to sapphire, then to silicon for obtaining atomically flat two-dimensional epitaxial growth. In order to obtain the desired nucleation layer, the surface of the substrate is first cleaned with hydrogen near a growth temperature. The substrate is then subjected to the desired elevated growth temperature, preferably 900 to 1100° C. After the growth temperature has stabilized, an aluminum reactant and a gallium reactant are introduced into the growth chamber to pre-treat the surface of the substrate prior to the introduction of a nitrogen source and nucleation layer growth. The exposure time and flux of the aluminum reactant and the gallium reactant depend again on the substrate material and the crystal qualities desired. Once the pre-treatment of the surface is complete, a nitrogen source, preferably ammonia, is introduced into the growth chamber to commence the deposition of a nucleation layer. Preferably, the nucleation layer is grown at the same elevated growth temperature used to pre-treat the surface of the substrate. This provides a nucleation layer of crystalline $\text{Al}_x\text{Ga}_{1-x}\text{N}$ of a specific thickness and aluminum content. In the case of an AlN nucleation layer, the gallium reactant is stopped prior to the formation of the nucleation layer and then re-introduced after the AlN nucleation layer is formed. After the nucleation layer is formed, a buffer layer is grown on the nucleation layer. Preferably, the buffer layer is grown at the same elevated growth temperature used to pre-treat the surface of the substrate. In the preferred embodiment, the aluminum reactant is ramped down and switched out resulting in a preferred GaN buffer layer. The buffer layer provides a surface upon which the epitaxial layer is grown. In a preferred embodiment, a GaN buffer layer provides a surface on which GaN-based materials can subsequently be deposited without changing the temperature within the chamber. 40

Numerous applications exist for a lattice mismatched substrate having an epitaxial nitride based material, such as (Al)GaN, in the areas of high power, high frequency electronics, short wavelength optoelectronics, biology, and micromachining technologies. 45

EXAMPLE 1

A schematic representation of a single step process for nucleation and subsequent growth of a preferred GaN-based material is shown in FIG. 1. Relative reactant fluxes and exposure cycles are depicted for the surface pre-treatment, the AlN/AlGaIn nucleation layer, and the transition to GaN epitaxial growth on both sapphire and SiC substrates. For this example, flow modulation OMVPE is used for the growth. 50

A detailed description of the single step process depicted in FIG. 1 follows. 55

1. The substrates are heated up to 1100° C. in hydrogen for 10 minutes to clean the surface of the substrate.
2. After 10 minutes, the temperature is decreased to the growth temperature of 1040° C.
3. After the temperature has stabilized, the aluminum reactant and the gallium reactant, preferably TEG and TMA, are introduced into the growth chamber. For 60

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sapphire substrates the TMA/TEG ratio is set at 0.15, while for SiC is fixed at 0.06. The substrates are exposed for 100 seconds.

4. Ammonia is then switched into the growth chamber, forming $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ($x=0.06$ for SiC, and $x=0.15$ for sapphire) on the metal rich substrate surface. Around 20 nm of AlGaIn is grown.
5. The gallium reactant is switched into the growth chamber if not already present (in the case of an AlN nucleation layer).
6. The aluminum reactant is then ramped down to 0.0 in 30 seconds, then switched out of the growth chamber.
7. This results in GaN deposition, providing a buffer layer on which other GaN-based epitaxial layers can subsequently be deposited without any change in growth chamber temperature.

EXAMPLE 2

The following is an example of a high electron mobility transistor (HEMT) nucleation sequence in accordance with the present invention. TEG and TMA flows are total flows, not actual organometallic flux. Temperature calibrations with a clean cell indicated 1016° C. was actually more like 1040° C. The nucleation sequence is as follows:

1. The substrate is heated in hydrogen to a temperature of approximately 1060° C. It generally takes about 14 minutes to ramp up from room temperature to approximately 1060° C. The RF is on at a lower power for the first 4 minutes.
2. RF power is decreased to stabilize the substrate at the growth temperature of about 1016° C. It takes about 10 minutes from turning RF down to the start of growth, typically arriving at the growth temperature about 5 minutes before growth.
3. An organometallic pre-treatment then begins, whereby TEG and TMA are switched into the cell to zone 1 for 100 sec for sapphire, 80 sec. for SiC in the absence of the nitrogen source. TEG flow is at 90 sccm and TMA flow is adjusted based on previous runs, typically 15-25 sccm for sapphire, 5-15 sccm for SiC. All procedures other than this step are the same for SiC and sapphire.
4. TEG is switched out of the cell and ammonia is switched into zone 1 at approximately 4500 sccm, and the balance of hydrogen flow to zone 1 is switched out, all simultaneously. Immediately after (1-2 sec.), ammonia is switched into the block at 1200 sccm for distribution to the rest of the cell. This causes some pressure fluctuations due to the sudden change in ammonia flow, affecting all flows in to the cell, but primarily the ammonia flow. It typically takes 20-30s to stabilize.
5. 60 sec. after ammonia is first switched in, TMA flow is increased from nucleation value to full AlN flow of about 90 sccm. This increase occurs somewhat slowly, over about 30 sec.
6. Continue growing AlN for 20 min.
7. Switch in TEG at full flow of approximately 90 sccm and simultaneously begin reducing TMA flow. Steadily decrease flow for 2 min. to zero and switch out.
8. 30 sec. after TMA switched out, raise ammonia flow to GaN buffer value of about 9000 sccm to zone 1, and 2600 sccm to block. GaN buffer is now grown.

Although the present invention has been disclosed in terms of a preferred embodiment, it will be understood that numerous additional modifications and variations could be made thereto without departing from the scope of the invention as defined by the following claims.

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What is claimed is:

1. A process for growing an epitaxial layer on a lattice mismatched substrate comprising the steps of:

- a) providing a substrate;
- b) pre-treating a surface of the substrate with at least one group III reactant or at least one group II reactant at an elevated growth temperature prior to introducing a group V reactant or a group VI reactant;
- c) introducing a group V reactant or a group VI reactant to grow a nucleation layer on the surface of the substrate; and
- d) growing a buffer layer on said nucleation layer, said buffer layer providing a surface upon which said epitaxial layer is grown.

2. The process of claim 1, wherein said substrate is selected from the group consisting of silicon, sapphire and SiC.

3. The process of claim 1, wherein said group III reactant is selected from the group consisting of a gallium reactant, an aluminum reactant, a boron reactant, and an indium reactant.

4. The process of claim 3, wherein said group III reactant is selected from the group consisting of triethyl gallium, trimethyl gallium, triethylaluminum, trimethyl aluminum, triethylboron, trimethylboron, triethylindium and trimethylindium.

5. The process of claim 1, wherein said group II reactant is a cadmium reactant or a zinc reactant.

6. The process of claim 1, wherein said step of pre-treating includes pre-treating the surface of the substrate with an aluminum reactant and a gallium reactant.

7. The process of claim 6, wherein said nucleation layer is AlN or AlGaN.

8. The process of claim 1, wherein said buffer layer is GaN.

9. The process of claim 1, wherein said epitaxial layer includes a compound selected from the group comprising AlN, GaN, AlGaN, BGaN, BInN, BAlN, CdTe, and ZnS.

10. The process of claim 1, further comprising the step of preheating said substrate in hydrogen prior to pre-treating the surface of the substrate with at least one group III reactant or at least one group II reactant.

11. The process of claim 1, wherein said elevated growth temperature is 900 to 1100° C.

12. The process of claim 11, wherein the step of introducing a group V reactant or a group VI reactant includes growing a nucleation layer at a growth temperature of 900 to 1100° C. and the step of growing a buffer layer includes growing a buffer layer at a growth temperature of 900 to 1100° C.

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13. The process of claim 1, wherein said group V reactant is a group V hydride.

14. The process of claim 13, wherein said group V hydride is selected from the group consisting of ammonia, arsine, and phosphine.

15. The process of claim 1, wherein said group V reactant is a group V organic precursor.

16. The process of claim 15, wherein said group V organic precursor is tertiarybutylarsine or tertiarybutylphosphine.

17. The process of claim 1, wherein said group VI reactant is a tellurium reactant or a sulfur reactant.

18. A process for growing an epitaxial layer on a lattice mismatched substrate comprising the steps of:

- a) providing a substrate;
- b) pre-treating a surface of the substrate with at least a first group III reactant and a second group III reactant at a growth temperature of 900 to 1100° C. prior to introducing a nitrogen source;
- c) stopping a flow of the first group III reactant;
- d) introducing a nitrogen source to grow a nucleation layer on the surface of the substrate;
- e) resuming the flow of the first group III reactant and reducing a flow of the second group III reactant;
- f) stopping the flow of the second group III reactant; and
- g) growing a buffer layer on said nucleation layer, said buffer layer providing a surface upon which said epitaxial layer is grown.

19. The process of claim 18, wherein said first group III reactant is a gallium reactant and said second group III reactant is an aluminum reactant.

20. The process of claim 19, wherein said gallium reactant is triethylgallium and said aluminum reactant is trimethylaluminum.

21. The process of claim 18, wherein said nucleation layer is AlN or AlGaN.

22. The process of claim 18, wherein said buffer layer is GaN.

23. The process of claim 18, wherein said epitaxial layer includes a compound selected from the group comprising AlN, GaN, AlGaN, BGaN, BInN, and BAlN.

24. The process of claim 18, further comprising the step of preheating said substrate in hydrogen prior to pre-treating the surface of the substrate with the first group III reactant and the second group III reactant.

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