US008969181B2

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

(10) **Patent No.: US 8,969,181 B2**
(45) **Date of Patent: Mar. 3, 2015**

(54) **METHOD FOR EPITAXIAL LAYER OVERGROWTH**

(75) Inventors: **Ludovic Godet**, Boston, MA (US); **Morgan D. Evans**, Manchester, MA (US); **Christopher R. Hatem**, Hampton, NH (US)

(73) Assignee: **Varian Semiconductor Equipment Associates, Inc.**, Gloucester, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 194 days.

(21) Appl. No.: **13/440,616**

(22) Filed: **Apr. 5, 2012**

(65) **Prior Publication Data**

US 2012/0258583 A1 Oct. 11, 2012

Related U.S. Application Data

(60) Provisional application No. 61/473,984, filed on Apr. 11, 2011.

(51) **Int. Cl.**
H01L 21/205 (2006.01)
H01L 21/02 (2006.01)
H01L 21/265 (2006.01)
H01L 21/266 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/02658*** (2013.01); ***H01L 21/02381*** (2013.01); ***H01L 21/0254*** (2013.01); ***H01L 21/02639*** (2013.01); ***H01L 21/02647*** (2013.01); ***H01L 21/26506*** (2013.01); ***H01L 21/26586*** (2013.01); ***H01L 21/266*** (2013.01)
USPC **438/480**; 438/481; 438/506

(58) **Field of Classification Search**
USPC 438/480, 481, 506; 257/E21.132
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,855,009	A *	12/1974	Lloyd et al.	438/480
5,334,864	A *	8/1994	Tokunaga et al.	257/78
5,425,808	A *	6/1995	Tokunaga et al.	117/95
6,429,466	B2 *	8/2002	Chen et al.	257/183
7,341,929	B2 *	3/2008	Tseng et al.	438/506
7,767,977	B1	8/2010	Godet et al.	
2001/0046754	A1 *	11/2001	Takasu	438/440
2006/0172501	A1 *	8/2006	Ueno et al.	438/300
2006/0286779	A1 *	12/2006	Booth et al.	438/480
2010/0065865	A1 *	3/2010	Byun et al.	257/94
2010/0323508	A1	12/2010	Adibi et al.	

FOREIGN PATENT DOCUMENTS

JP 01065834 A * 3/1989 .... H01L 21/205

OTHER PUBLICATIONS

K. Hiramatsu, Epitaxial Lateral Overgrowth Techniques Used in Group III Nitride Epitaxy, J. of Phys.: Condensed Matter, 2001, pp. 6961-6975, vol. 13, Inst. of Phys. Publ'g.

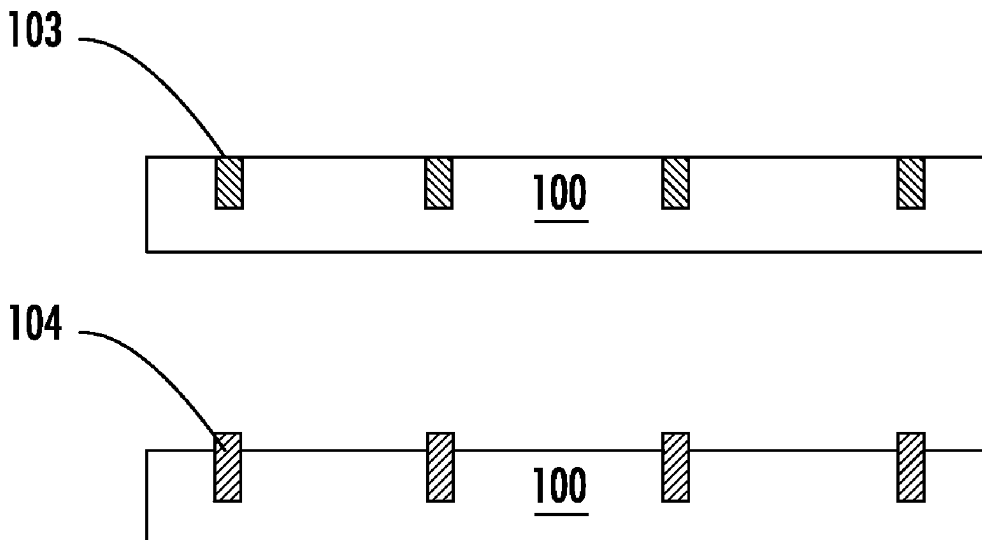
(Continued)

Primary Examiner — George Fourson, III

(57) **ABSTRACT**

Oxygen, silicon, germanium, carbon, or nitrogen is selectively implanted into a workpiece. The workpiece is annealed to incorporate the ions into the workpiece. A compound semiconductor is then formed on the workpiece. For example, gallium nitride may be formed on a silicon, silicon carbide, or sapphire workpiece. The width of the implanted regions can be configured to compensate for any shrinkage during annealing.

20 Claims, 4 Drawing Sheets



(56) **References Cited**

OTHER PUBLICATIONS

Oliver et al., Scanning Capacitance Microscopy Studies of GaN Grown by Epitaxial Layer Overgrowth, J. of Phys.: Conf. Series, 16th Int'l Conf. on Microscopy of Semiconducting Materials, 2010, pp. 1-4 vol. 209, Inst. of Phys. Publ'g.

Kim et al., Epitaxial Lateral Overgrowth of GaN on Si (111) Substrates Using High-Dose, N+ Ion Implantation, Chem. Vap. Deposition, 2010, pp. 80-84, vol. 16, Wiley.

Kim, Bumjoon, et al. Expitaxial Lateral Overgrowth of GaN Using High-dose N+-ion-implantation, ECS Transactions, 2010, vol. 25, Issue 33, pp. 169-174.

Sasaki, T., et al., Surface smoothing effect in patterened SOI fabrication with SIMOX Technology, 2003 IEEE International SOI Conference Proceedings, Jan. 1, 2003, pp. 48-49, IEEE, Piscataway, New Jersey, USA.

* cited by examiner

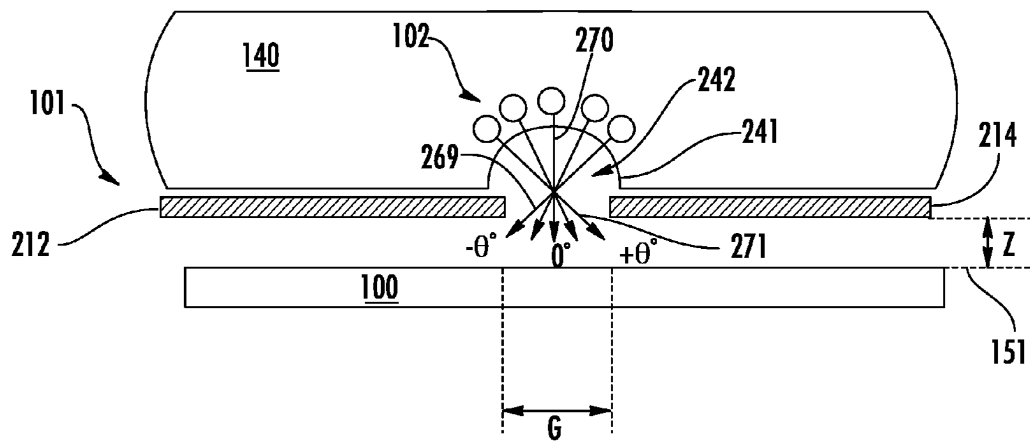


FIG. 1

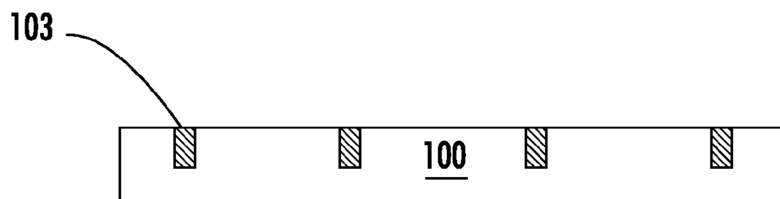


FIG. 2A

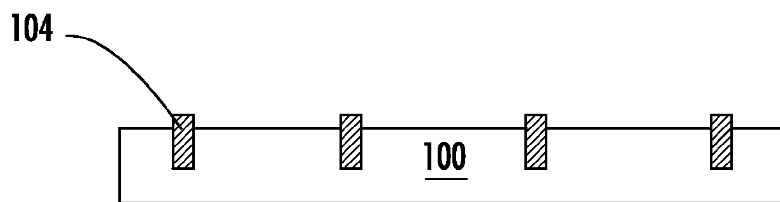


FIG. 2B

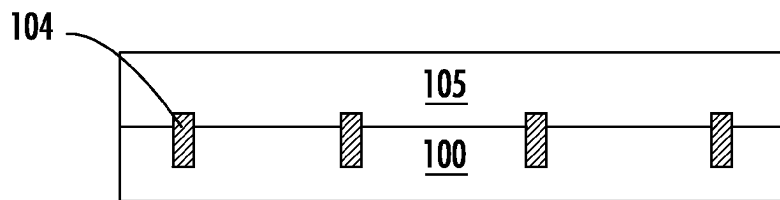


FIG. 2C

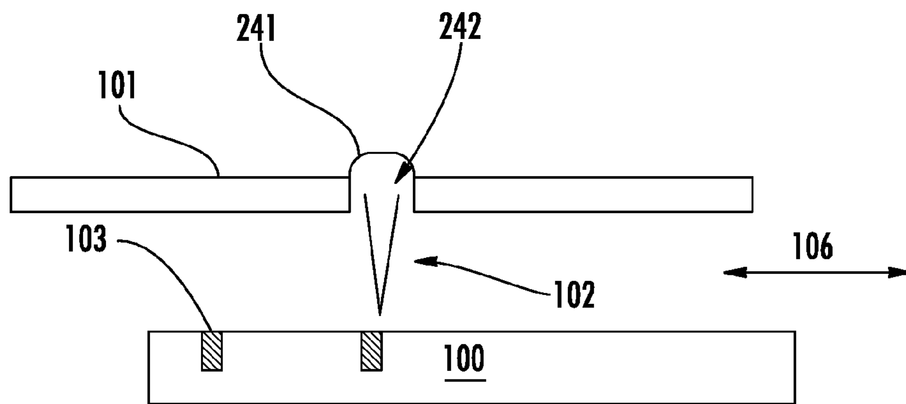


FIG. 3

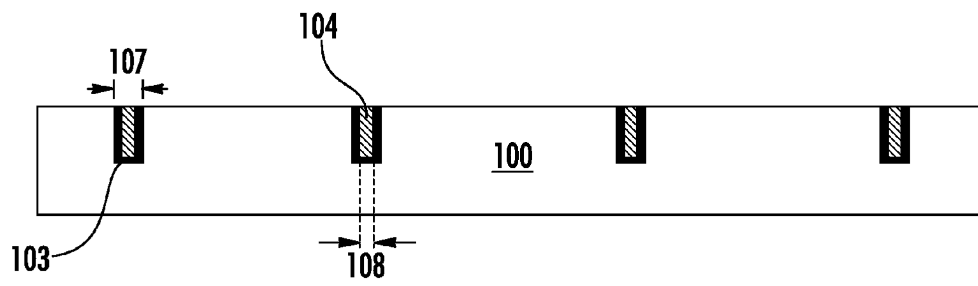


FIG. 4

METHOD FOR EPITAXIAL LAYER OVERGROWTH

CROSS-REFERENCE TO RELATED APPLICATIONS

This claims priority to the provisional patent application entitled "Method for Epitaxial Layer Overgrowth," filed Apr. 11, 2011 and assigned U.S. App. No. 61/473,984, the disclosure of which is hereby incorporated by reference.

FIELD

This invention relates to epitaxial layer overgrowth (ELOG) and, more particularly, to ELOG using ion implantation.

BACKGROUND

Ion implantation is a standard technique for introducing conductivity-altering impurities into a workpiece. A desired impurity material is ionized in an ion source, the ions are accelerated to form an ion beam of prescribed energy, and the ion beam is directed at the surface of the workpiece. The energetic ions in the beam penetrate into the bulk of the workpiece material and are embedded into the crystalline lattice of the workpiece material to form a region of desired conductivity.

In order for light-emitting diodes (LEDs) to gain more of the lighting market, improvements in efficiency and manufacturing cost may be required. LEDs, laser diodes, or other devices may be fabricated on compound semiconductors, such as GaN. One method of improving the efficiency of compound semiconductor devices is ELOG. ELOG uses a periodic mask structure to block the growth of GaN in some areas. Then some GaN will grow more laterally when it joins neighboring areas. This may result in a higher quality solid layer of GaN. Previous methods used a photoresist (PR) mask to block a portion of the implanted ions, but this adds cost and complexity. Accordingly, there is a need in the art for improved methods of ELOG.

SUMMARY

According to a first aspect of the invention, a method of workpiece processing is provided. The method comprises selectively implanting ions into a plurality of implanted regions in a workpiece. The ions comprise oxygen, silicon, germanium, carbon, or nitrogen. The workpiece is annealed such that the ions are incorporated into the implanted regions. A compound semiconductor is formed on the workpiece.

According to a second aspect of the invention, a method of workpiece processing is provided. The method comprises determining a width of an implanted region to compensate for shrinkage of the width during annealing. Oxygen ions are selectively implanted into a plurality of the implanted regions in a workpiece. Each of the implanted regions has a box profile beginning at a surface of the workpiece and has the width. The workpiece comprises silicon. The workpiece is annealed to form silicon oxide on the implanted regions. A compound semiconductor is formed on the workpiece.

According to a third aspect of the invention, a method of workpiece processing is provided. The method comprises determining a width of an implanted region to compensate for shrinkage of the width during annealing. Nitrogen ions are selectively implanted into a plurality of implanted regions in a workpiece. Each of the implanted regions has a box profile beginning at a surface of the workpiece and has the width. The workpiece comprises silicon. The workpiece is annealed to form silicon nitride on the implanted regions. A compound semiconductor is formed on the workpiece.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present disclosure, reference is made to the accompanying drawings, which are incorporated herein by reference and in which:

FIG. **1** is a block diagram of a plasma processing apparatus having a plasma sheath modifier;

FIGS. **2A-2C** are cross-sectional side views of a first embodiment of FLOG using implantation;

FIG. **3** is a side view of an embodiment of selective ion implantation; and

FIG. **4** is a cross-sectional side view illustrating shrinkage of the implanted areas.

DETAILED DESCRIPTION

The embodiments are described herein in connection with formation of a compound semiconductor such as GaN, but these embodiments also may be used with other III/V compound semiconductors, compound semiconductors, or other materials known to a person skilled in the art. While one specific type of implanter is disclosed, other ion implantation systems known to those skilled in the art that can focus an ion beam or that can implant particular regions of a workpiece without a mask on the workpiece may be used in the embodiments described herein. For example, this may involve a stencil or shadow mask disposed a distance from the workpiece in an alternate embodiment. Beamline implanters, plasma doping implanters, flood implanters, or focused ion beam implanters may be used. Thus, the invention is not limited to the specific embodiments described below.

FIG. **1** is a block diagram of a plasma processing apparatus. The plasma **140** is generated as is known in the art. This plasma **140** is generally a quasi-neutral collection of ions and electrons. The ions typically have a positive charge while the electrons have a negative charge. The plasma **140** may have an electric field of, for example, approximately 0 V/cm in the bulk of the plasma **140**. In a system containing the plasma **140**, ions **102** from the plasma **140** are attracted toward a workpiece **100**. These ions **102** may be attracted with sufficient energy to be implanted into the workpiece **100**. The plasma **140** is bounded by a region proximate the workpiece **100** referred to as a plasma sheath **242**. The plasma sheath **242** is a region that has fewer electrons than the plasma **140**. Hence, the differences between the negative and positive charges cause a sheath potential in the plasma sheath **242**. The light emission from this plasma sheath **242** is less intense than the plasma **140** because fewer electrons are present and, hence, fewer excitation-relaxation collisions occur. Thus, the plasma sheath **242** is sometimes referred to as "dark space."

The sheath modifier **101** is configured to modify an electric field within the plasma sheath **242** to control a shape of a boundary **241** between the plasma **140** and the plasma sheath **242**. Accordingly, ions **102** that are attracted from the plasma **140** across the plasma sheath **242** may strike the workpiece **100** at a large range of incident angles. This sheath modifier **101** also may be referred to as, for example, a focusing plate or sheath engineering plate and may be a semiconductor, insulator, or conductor.

In the embodiment of FIG. **1**, the sheath modifier **101** includes a pair of panels **212** and **214** defining an aperture therebetween having a horizontal spacing (G). In other

embodiments, the sheath modifier **101** may include only one panel or more than two panels. The panels **212** and **214** may be a pair of sheets having a thin, flat shape. In other embodiments, the panels **212** and **214** may be other shapes such as tube-shaped, wedge-shaped, and/or have a beveled edge proximate the aperture. The panels **212** and **214** also may be positioned a vertical spacing (Z) above the plane **151** defined by the front surface of the workpiece **100**. In one embodiment, the vertical spacing (Z) may be about 1.0 to 10.0 mm.

Ions **102** may be attracted from the plasma **140** across the plasma sheath **242** by different mechanisms. In one instance, the workpiece **100** is biased to attract ions **102** from the plasma **140** across the plasma sheath **242**. In another instance, a plasma source that generates the plasma **140** and walls surrounding the plasma **140** are biased positively and the workpiece **100** may be grounded. The biasing may be pulsed in one particular embodiment. In yet another instance, electric or magnetic fields are used to attract ions **102** from the plasma **140** toward the workpiece **100**.

Advantageously, the sheath modifier **101** modifies the electric field within the plasma sheath **242** to control a shape of the boundary **241** between the plasma **140** and the plasma sheath **242**. The boundary **241** between the plasma **140** and the plasma sheath **242** may have a convex shape relative to the plane **151** or another shape not parallel to the plane **151**. When the workpiece **100** is biased, for example, the ions **102** are attracted across the plasma sheath **242** through the aperture between the panels **212** and **214** at a large range of incident angles. For instance, ions **102** following trajectory path **271** may strike the workpiece **100** at an angle of +θ° relative to the plane **151**. Ions **102** following trajectory path **270** may strike the workpiece **100** at about an angle of 0° relative to the same plane **151**. Ions **102** following trajectory path **269** may strike the workpiece **100** an angle of −θ° relative to the plane **151**. Accordingly, the range of incident angles may be between +θ° and −0° centered about 0°. In addition, some ion trajectories paths such as paths **269** and **271** may cross each other. Depending on a number of factors including, but not limited to, the horizontal spacing (G) between the panels **212** and **214**, the vertical spacing (Z) of the panels **212** and **214** above the plane **151**, the dielectric constant of the panels **212** and **214**, or other process parameters of the plasma **140**, the range of incident angles (θ) may be between +60° and −60° centered about 0°, though other ranges of θ are possible. In another embodiment, the panels **212** and **214** may each have different vertical spacing (Z) relative to the workpiece **100**, which may allow the ions **102** to primarily follow trajectories at an angle relative to the plane **151**.

In one embodiment, the process disclosed herein is used to grow GaN on a workpiece. FIGS. **2A-2C** are cross-sectional side views of a first embodiment of ELOG using implantation. In FIG. **2A**, the workpiece **100**, which may be silicon, sapphire, or another material, is selectively implanted with oxygen to form implanted regions **103**. Four implanted regions **103** are illustrated in FIG. **2A**, but more or fewer are possible. Each implanted region **103** may be between, for example, a few μm to a few mm in dimension and may be a line across the surface of the workpiece **100**. The implanted regions **103** may be formed using the plasma sheath modifier **101** of FIG. **1** in one instance. The workpiece **100** or plasma sheath modifier **101** may be translated or scanned to form the multiple implanted regions **103**. The biasing may be timed with this translation or scanning to form the implanted regions **103**. The embodiment illustrated in FIG. **2A** does not require a mask on the surface of the workpiece **100** to form the implanted regions **103**.

In one particular embodiment, the implanted regions **103** have a box profile beginning at the surface of the workpiece **100**. Thus, the implanted regions **103** may have a surface peak. The implanted regions **103** may be doped to a depth of greater than approximately 100 nm in one instance. In an alternate embodiment, the implanted regions **103** have a curved profile.

In FIG. **2B**, the workpiece **100** is annealed. This incorporates the implanted species into the workpiece. SiO_2 regions **104** are created using some or all of the implanted regions **103**. These SiO_2 regions **104** are then used for FLOG. Then in FIG. **2C** a GaN layer **105** is formed on the workpiece **100** using ELOG. The GaN layer **105** may not grow in a blanket pattern. Instead, the GaN layer **105** may begin growing between the SiO_2 regions **104** and eventually grow together over the SiO_2 regions **104**. This growth pattern may decrease the number of dislocations that occur within the GaN layer **105**. The use of ELOG will result: in a GaN layer **105** of higher quality.

In an alternate embodiment, the workpiece **100** is sapphire or SiC and silicon is implanted to form the implanted regions **103**. During an anneal in an oxygen atmosphere the SiO_2 regions **104** are formed. A GaN layer **105** is then formed on the workpiece **100** using ELOG.

In yet another alternate embodiment, nitrogen is used to form the implanted regions **103** in a workpiece **100**. SiN regions are formed during the anneal instead of SiO_2 regions **104**. A GaN layer **105** is then formed on the workpiece **100** using ELOG.

Germanium also may be used to form the implanted regions **103** in the workpiece **100**. SiGe regions are formed during the anneal instead of SiO_2 regions **104**. A GaN layer **105** is then formed on the workpiece **100** using ELOG. The presence of SiGe may cause some strain in the workpiece **100**, which may benefit the growth of the GaN layer **105** during ELOG. For example, the GaN layer **105** may grow above the implanted regions **103** at a different rate than the non-implanted regions.

Carbon also may be used to form the implanted regions **103** in the workpiece **100**. Amorphous regions containing carbon are formed during implantation or anneal instead of the of SiO_2 regions **104**. A GaN layer **105** is then formed on the workpiece **100** using ELOG. The carbon or crystal structure of the implanted regions **103** may prevent or reduce growth of the GaN layer **105** over the implanted regions **103**. These implanted regions **103** may not shrink during an anneal.

In another embodiment, a mixture of ions may be implanted into the workpiece. For example, nitrogen and oxygen may be used to form the implanted regions **103**. Other combinations of species disclosed herein or combinations of species disclosed herein with other species are possible.

FIG. **3** is a side view of an embodiment of selective ion implantation. Implanted regions **103** are formed in the workpiece **100** using the ions **102**. The workpiece **100** is scanned with respect to the sheath modifier **101** or ions **102**, as illustrated by the arrow **106**. This may involve moving the sheath modifier **101**, workpiece **100**, or both. The scanning may be in one dimension or two dimensions. In one particular embodiment, the workpiece **100** is biased when the ions **102** implant the implanted regions **103**. The bias scheme is adjusted to produce the desired pattern of implanted regions **103**. Thus, the workpiece **100** is not biased when the ions **102** would implant between the implanted regions **103**. This eliminates or reduces ions **102** from impacting between the implanted regions **103**. In this manner, the implanted regions **103** may be

formed without a mask or photoresist layer on the workpiece **100**. Alignment, lithography, or photoresist removal steps may be eliminated.

The location of the implanted regions **103** may be carefully controlled because spacing of the implanted regions **103** may affect growth of the GaN layer **105** during ELOG. This spacing may be Optimized for the best GaN layer **105** growth.

The dose rate and focus of the ions **102** can be varied to form the implanted regions **103**. If the workpiece **100** is scanned, then the ions **102** may be switched on and off to form the implanted regions **103**, the dose of the ion **102** may be adjusted to reduce implantation between the implanted regions **103**, or the ions **102** may be focused when implanting the implanted regions **103**. If the ions **102** are focused when implanting the implanted regions **103**, the ions **102** may be less focused over other parts of the workpiece **100**, which reduces implantation between the implanted regions **103**.

FIG. **4** is a cross-sectional side view illustrating shrinkage of the implanted areas. Here, the implanted regions **103** are illustrated as shaded black with a width **107**. The SiO_2 regions **104** are illustrated in cross-hatch with a width **108**, though this also may be used for SiN regions or for other species disclosed herein. The width **108** is less than the width **107**. This is due to the annealing step, which leads to shrinkage. For example, some of the oxygen (or nitrogen) may diffuse from the workpiece **100** during the anneal. In one particular embodiment, a width **107** of an implanted region **103** is determined in order to compensate for shrinkage of the width **107** during annealing to the width **108**. Thus, the width **108** is configured to the desired dimension for ELOG during growth of the GaN layer. In one instance, the width **108** is approximately 30% to 70% less than the width **107** and the width **107** is configured to be larger to compensate for this shrinkage. In one instance, a width **107** of 10 μm shrank to a width **108** 3 μm during anneal.

The anneal conditions also may be varied to improve the later FLOG step. These anneal conditions affect the sharpness of the implanted regions **103**.

In another alternate embodiment, the implanted regions **103** are doped after formation or after anneal. This may change the conductivity of the implanted regions **103**. In another instance, the implanted regions **103** are subsequently doped with silicon after an anneal. For example, silicon may be implanted into the SiO_2 of the implanted regions **103** to improve ELOG. In another example, an ion species such as germanium is implanted into the implanted regions **103** to cause stress in the lattice of the workpiece **100**.

The implants disclosed herein may be performed into a heated workpiece **100**. This workpiece **100** may be at a temperature elevated above room temperature, such as up to about 400° C. or other elevated temperatures. This may affect the incorporation of ion species into the workpiece **100** or affect the required anneal.

The embodiments disclosed herein can be applied to other compound semiconductors besides GaN, such as other II-VI or III-V compound semiconductors. Other workpiece materials, ions, or annealing environments also may be used. This technique enables a higher quality thin film. Patterned or textured workpieces also can be used, which was difficult using previous methods. An angular distribution of ions may be used to treat all the sidewalls of the patterned or textured workpiece. In another instance, multiple implants at different angles may be used to treat all the sidewalls of the patterned or textured workpiece.

The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure,

in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. These other embodiments and modifications are intended to fall within the scope of the present disclosure. Furthermore, although the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not limited thereto and that the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Accordingly, the claims set forth below should be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. A method of workpiece processing comprising:
selectively implanting ions into a plurality of implanted regions in a workpiece, wherein said ions comprise oxygen, silicon, germanium, carbon, or nitrogen;
annealing said workpiece such that said ions are incorporated into said implanted regions; and
forming a compound semiconductor on said workpiece, wherein said compound semiconductor grows over said implanted regions.

2. The method of claim **1**, wherein said workpiece is silicon and said ions comprise oxygen or nitrogen.

3. The method of claim **1**, wherein said workpiece is one of sapphire or silicon carbide and said ions comprise silicon.

4. The method of claim **1**, wherein said compound semiconductor is one of a II-VI semiconductor or a III-V semiconductor.

5. The method of claim **1**, wherein said selectively implanting comprises scanning said workpiece with respect to said ions and increasing a bias to said workpiece to form said implanted regions.

6. The method of claim **1**, wherein said workpiece has a non-planar surface.

7. The method of claim **1**, wherein said ions are implanted in a box profile beginning at a surface of said workpiece.

8. The method of claim **1**, wherein each of said implanted regions has a width and further comprising determining said width to compensate for shrinkage of said width during said annealing.

9. A method of workpiece processing comprising:
determining a width of an implanted region to compensate for shrinkage of said width during annealing;
selectively implanting oxygen ions into a plurality of said implanted regions in a workpiece, each of said implanted regions having a box profile beginning at a surface of said workpiece and each of said implanted regions having said width, said workpiece comprising silicon;
annealing said workpiece to form silicon oxide on said implanted regions; and
forming a compound semiconductor on said workpiece.

10. The method of claim **9**, wherein said selectively implanting comprises scanning said workpiece with respect to said oxygen ions and increasing a bias to said workpiece to form said implanted regions.

11. The method of claim **9**, wherein said compound semiconductor is one of a II-VI semiconductor or a III-V semiconductor.

12. The method of claim **11**, wherein said compound semiconductor is GaN.

13. The method of claim **9**, wherein said workpiece has a non-planar surface.

14. A method of workpiece processing comprising:

determining a width of an implanted region to compensate for shrinkage of said width during annealing;

selectively implanting nitrogen ions into a plurality of implanted regions in a workpiece, each of said implanted regions having a box profile beginning at a surface of said workpiece and each of said implanted regions having said width, said workpiece comprising silicon;

annealing said workpiece to form silicon nitride on said implanted regions; and

forming a compound semiconductor on said workpiece.

15. The method of claim **14**, wherein said selectively implanting comprises scanning said workpiece with respect to said nitrogen ions and increasing a bias to said workpiece to form said implanted regions.

16. The method of claim **14**, wherein said compound semiconductor is one of a II-VI semiconductor or a III-V semiconductor.

17. The method of claim **14**, wherein said compound semiconductor is GaN.

18. The method of claim **14**, wherein said workpiece has a non-planar surface.

19. The method of claim **3**, wherein said annealing is performed in an oxygen atmosphere to form silicon oxide on said implanted regions.

20. The method of claim **1**, wherein said selectively implanting comprises:

increasing a bias to said workpiece to attract ions through an aperture in a sheath modifier to form an implanted region;

translating said workpiece relative to said sheath modifier; and

repeating said increasing and translating a plurality of times to form said plurality of implanted regions.

* * * * *