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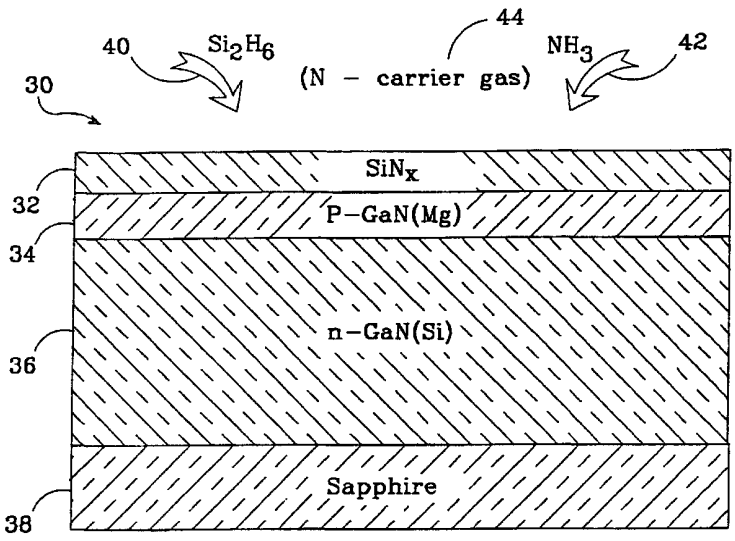
(54) Title: FABRICATION OF SEMICONDUCTOR MATERIALS AND DEVICES WITH CONTROLLED ELECTRICAL CONDUCTIVITY



(57) Abstract: A method for protecting the surface of a semiconductor material (30, 50) from damage and dopant passivation is described. A barrier layer (32, 52) of dense or reactive material is deposited on the semiconductor material shortly after growth in a growth reactor (10) such as a MOCVD reactor, using the MOCVD source gasses. The barrier layer (32, 52) blocks the diffusion of hydrogen into the material. The reactor (10) can then be cooled in a reactive or non-reactive gas ambience. The semiconductor material can then be removed from the reactor (10) with little or no passivation of the dopant species. The barrier layer (32, 52) can be removed using a variety of etching processes, including wet chemical etching or can be left at the semiconductor material for surface protection. The barrier layer (32, 52) can also be a gettering layer that chemically binds hydrogen trapped in the semiconductor material and/or blocks hydrogen diffusion into the material.

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FABRICATION OF SEMICONDUCTOR MATERIALS AND DEVICES WITH CONTROLLED ELECTRICAL CONDUCTIVITY

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method for achieving the desired electrical conductivity in doped semiconductor materials that are affected by dopant passivation. The invention specifically teaches methods of fabricating passivation-barrier layers to prevent or reduce doping species passivation during the semiconductor growth process, thus eliminating the need for in-situ or ex-situ annealing steps.

Description of the Related Art

Semiconductor materials are essential for producing light emitting diodes (LEDs), laser diodes (LDs) and other optoelectronic and electronic devices because the electrical and optical properties of the material can be controlled through composition and structural variation. To achieve this control, it is important to produce semiconductor material free of undesired impurities. Gallium nitride (GaN) is one of the most promising semiconductor materials for application to blue, violet and ultraviolet (UV) LEDs and LDs as well as other electronic devices.

During growth of GaN p-n junction diodes using Metal-Organic Chemical Vapor Deposition (MOCVD), it is difficult to grow a p-type material with good structural, optical, and electrical integrity. The p-type region of a GaN junction diode is commonly grown in a MOCVD reactor by adding magnesium (Mg) to achieve the desired conductivity.

However, a common problem is electrical passivation of acceptors like Mg, zinc (Zn), carbon (C) and others by hydrogen atoms. The smaller hydrogen atoms diffuse into the GaN material, where they neutralize the Mg acceptors and the holes produced by the Mg. The passivation process leaves the Mg acceptors inactive, resulting in the material becoming insulating or weakly p-type in its as grown state. The passivation of the p-type region results in critical performance problems for the diode. Hydrogen passivation of acceptors and donors has been reported for a wide variety of semiconductors including silicon [S.J. Pearton et. al., Appl. Phys. A **43**, 153 (1987)], gallium arsenide [N.M. Johnson et. al., Phys. Rev. B **33**, 1102 (1986); W.C. Dautremont-Smith, Mater. Res. Soc. Symp. Proc. **104**, 313 (1988)], indium phosphide [G.R. Antell et. al., Appl. Phys. Lett., **53**, 758 (1988)], and cadmium telluride [L. Svob et. al., J. Cryst. Growth **86**, 815 (1988)]. Passivation has been demonstrated both intentionally and unintentionally as a result of the epitaxial growth process.

The growth of GaN diodes represents one example where hydrogen passivation plays an important role. It has been shown that passivation of acceptors occurs after growth, during the reactor cooling stage. [G.R. Antell et al., Appl. Phys. Lett. 73, 2953 (1998)]. Hydrogen is common in a MOCVD reactor during growth of the GaN material and subsequent reactor cooling, generally coming from two sources. Hydrogen is commonly used during growth as a carrier gas for the growth source gasses. In addition, ammonia (NH_3) is used as a source gas for nitrogen (N) during growth of the GaN material and is also used to stabilize the GaN material during reactor cooling. Hydrogen is produced as a by-product of the ammonia decomposition

during growth and cooling. In the conventional GaN growth process, there is sufficient hydrogen in the reactor to cause passivation of the p-type region during cooling.

Passivation of the p-type region could be avoided by removing the hydrogen source from the reactor prior to cool down. See U.S. Patent No. 5,891,790, to Keller et. al. However, the GaN crystal is unstable at growth temperatures and the p-type GaN region is susceptible to decomposition which results in surface damage. The conventional method for avoiding this decomposition is to maintain the flow of NH_3 during reactor cooling. However, the presence of NH_3 during reactor cooling produces hydrogen and leads to passivation. As such, it was thought that the removal of all hydrogen sources was not practical and that passivation during reactor cooling could not be avoided.

As opposed to avoiding passivation, various methods were developed to reverse the passivation after material growth and reactor cooling. Much of the early studies of dopant passivation revealed the utility of thermal annealing for removal of the hydrogen and "activation" of the dopants [G.R. Antell et. al., Appl. Phys. Lett., **53**, 758 (1988); W.C. Dautremont-Smith, Mater. Res. Soc. Symp. Proc. **104**, 313 (1988); T. Zundel and J. Weber, Phys. Rev. B **39**, 13549 (1988); W.C. Dautremont-Smith et.al., J. Appl. Phys. **66**, 1993 (1989)]. Once the phenomenon of hydrogen passivation was recognized, it became evident that the hydrogen could be diffused into and out of the semiconductor at elevated temperatures, resulting in passivation or activation of the dopants. Consequently, thermal annealing was utilized as a method for acceptor and donor activation in group IV, III - V, and II - VI semiconductor materials. Acceptor passivation in Gallium Nitride could also be reversed using Low-Energy Electron

Beam Irradiation (LEEBI)[Amano et. al., Japanese Journal of Applied Physics, Vol. 28, No. 12, pp. L2112-L2114 (Dec. 1989)]. In LEEBI treatment, the passivated GaN material is irradiated with an electron beam to activate the acceptors. While these procedures effectively activate the passivated region, they are conducted ex situ, introducing another step in the fabrication process that increases cost and reduces yield. Damage can be caused from handling, and impurities can be introduced by atmospheric conditions. Both processes expose the GaN material to high temperature, which can also damage the material.

In addition, the annealing process occurs prior to p-contact metalization. In devices such as GaN LEDs and LDs, it is important to provide reproducible low-resistance contacts. Metal contacts to p-type GaN have been found to be highly sensitive to surface quality. [J. Kim et. al. Appl. Phys. Lett. 73, 2953 (1998)]. Thus, any damage to the p-type surface during annealing or handling will adversely impact the p-type metal contacts.

Another method for reducing passivation of acceptors during reactor cooling is capping the p-type material with a thin n-type layer. [S. Manigawa and M. Kondo, J. Electron. Mater. Vol.19 No.6, pp. 597-599 (1990)]. The solubility of hydrogen in the n-type material is low compared to the p-type material, so diffusion of hydrogen during reactor cooling is greatly reduced. However, this process does not completely eliminate the passivation of the p-type material and removal of the n-type material by etching is difficult and can damage the p-type surface.

SUMMARY OF THE INVENTION

The present invention provides a novel method of achieving the desired electrical conductivity in doped semiconductor materials that experience passivation of the doping species by hydrogen atoms. Passivation occurs by hydrogen being incorporated into the semiconductor material in association with doping species.

The invention specifically teaches methods of fabricating barrier layers to prevent or reduce the diffusion and incorporation of hydrogen into the semiconductor material, thus preventing or reducing dopant passivation. The barrier layers are fabricated in the same growth chamber that is used for the semiconductor material growth. Shortly after the growth of the material, while it is in the reactor and the reactor is at a temperature about equal to or lower than the growth temperature, the diffusion barrier layer is deposited on the material. The barrier layer is formed from dense, inert compounds that block the diffusion and incorporation of hydrogen into the material. Examples for barrier layers are Si, Ge, MgOx, MgNx, ZnO, SiNx, SiOx, alloys or layer sequences thereof.

The barrier layer can also be a hydrogen binding layer, also referred to as a hydrogen-gettering layer. The hydrogen-gettering layer chemically binds hydrogen trapped in the semiconductor or prevents hydrogen from reaching the semiconductor surface from the ambient gas phase, thus preventing hydrogen diffusion into the semiconductor. The composition of the gettering layer compounds can be adjusted during growth to contain an excess of the gettering component. The preferred gettering layer materials contain components that have a high binding energy to atomic hydrogen. The binding energy is also preferably higher than the binding energy between hydrogen

and the acceptor or donor species. Thus, the layer can be effective in preventing the passivation of doping species by gettering the hydrogen. The layer can have multiple layers that can be a repeated sequence of multiple gettering materials.

After cool-down, any of the barrier layers may be removed by one of a variety of etching techniques for subsequent processing of the semiconductor material.

Eliminating passivation of the semiconductor material also can eliminate or reduce the need for additional processing steps such as thermal or electron beam annealing. The method also provides superior quality and yield in semiconductor materials, preserving the material in its pristine as grown state.

These and other further features and advantages of the invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic of a MOCVD reactor used in growing semiconductor material;

FIG. 2 is a sectional view of a p-n junction diode with the with a barrier SiN_x layer;

FIG. 3 is a sectional view of the p-n junction diode of FIG. 2 immersed in HF to remove the protective SiN_x layer; and

Fig. 4 is a sectional view of p-n junction diode with a hydrogen-binding (gettering) layer.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a novel method for preventing the passivation of dopant species in semiconductor materials by atomic hydrogen. A barrier layer is grown soon after the growth of the semiconductor material, prior to or during reactor cooling, or at a temperature lower than the growth temperature of the semiconductor material. The barrier layer functions as a dense barrier for diffusion of hydrogen into the semiconductor. The barrier layer can also serve as a gettering layer to chemically bind hydrogen. In both cases the passivation of doping species is prevented or reduced. Following reactor cooling and prior to further processing of the materials, the barrier layer can be removed by known procedures such as etching.

The barrier or gettering layer can be deposited on the semiconductor material using MOCVD, plasma chemical vapor deposition (CVD), hot-filament CVD, or other deposition processes. The preferred method is deposition in a MOCVD reactor.

FIG. 1 shows a MOCVD reactor **10** used in the new method to grow the semiconductor material and to apply the barrier layer. The reactor **10** comprises a reaction chamber **11** having growth platform **12** supported by a rotary shaft **13**. In most applications a single crystal **14** such as sapphire is disposed on the growth platform **12**, although other crystals may be used such as ( ), AlGaN, or GaAs. During growth, the platform **12** is heated by heater **15** to maintain substrate **14** at a predetermined temperature. The temperature is typically between 400 and 1200 degrees centigrade (°C), but can be higher or lower depending on the type of growth desired. The heater **15** can be a variety of

heating devices but is usually a radio frequency (RF) or resistance coil.

A carrier gas **16** is supplied to a gas line **17**, the carrier gas being a gas such as hydrogen or nitrogen. The carrier gas **16** is also supplied through mass flow controllers **18a-c** to respective bubblers **19a-c**. Bubbler **19a** has a growth compound, typically an alkylated compound having a methyl or ethyl group, e.g. trimethyl gallium TMG), trimethyl aluminum (TMA) or trimethyl indium (TMI). Bubblers **19b** and **19c** may also contain a similar metalorganic compound to be able to grow an alloy of a Group III compound. The bubblers **19a-c** are typically maintained at a predetermined temperature by constant temperature baths **20a-c** to ensure a constant vapor pressure of the metal organic compound before it is carried to the reaction chamber **11** by the carrier gas **16**.

The carrier gas **16** which passes through bubblers **19a-c** is mixed with the carrier gas **16** flowing within the gas line **17** by opening the desired combination of valves **21a-c**. The mixed gas is then introduced into the reaction chamber **11** through a gas inlet port **22** formed at the upper end of the reaction chamber **11**.

A nitrogen containing gas **26** such as ammonia is supplied to the gas line **17** through a mass flow controller **27** and the flow of nitrogen containing gas is controlled by valve **28**. If the carrier gas **16** is mixed with the nitrogen containing gas **26**, and the TMG vapor within the gas line **17** is introduced into the reaction chamber **11**, the elements are present to grow gallium nitride on the substrate **14** through thermal decomposition of the molecules in the TMG and ammonia containing gas.

To dope alloys of gallium nitride on the substrate **14**, one of the bubblers **19a-c** not being used for the TMG is used for a dopant material, which is usually Magnesium (Mg) or Silicon (Si), but can be other material such as beryllium, calcium, zinc, or carbon. Bubbler **19b** or **19c** is used for an alloy material such as boron, aluminum, indium, phosphorous, arsenic or other materials. Once the dopant and alloy are selected and the valve **21a**, **21b** or **21c** is opened to allow the dopant to flow into gas line **17** with the gallium and nitrogen containing gas **26**, the growth of the doped layer of gallium nitride takes place on substrate **14**.

The gas within the reaction chamber **11** can be purged through a gas purge line **23** connected to a pump **24** operable under hydraulic pressure. Further, a purge valve **25** allows gas pressure to build up or be bled off from the reaction chamber **11**.

The growth process is typically stopped by shutting off the gallium and dopant sources by closing valves **21a** and **21b**, and keeping the nitrogen containing gas and the carrier gas flowing. Alternatively, the reaction chamber **11** can be purged with a gas **29** that can be controlled through a mass flow controller **30** and valve **31**. The purge is aided by opening valve **25** to allow the pump **24** to evacuate the reaction chamber **11** of excess growth gasses. Typically, the purge gas **29** is hydrogen, but can be other gasses. Turning off the heater **15** power then cools the substrate **14**.

In the new method, the application of the barrier layer occurs after growth of the semiconductor material and prior to or during cooling of the reaction chamber **11**. Following growth of the semiconductor material in a reactor

chamber **11**, the flow of undesired growth gasses is discontinued by closing the appropriate combination of valves **21a-c**. A short purge of the reactor may be completed to remove the undesirable gasses as described above. Gasses are then flowed into the reactor to deposit an epitaxial, poly-crystalline, or amorphous barrier layer on the device. In the preferred method, the gasses used for the barrier layer are provided from typical MOCVD sources.

The barrier layer should be a dense material that uniformly covers the semiconductor surface and that should not adversely impact the properties and performance of the semiconductor material and device. The composition and thickness of the barrier layer or barrier layer sequence is chosen such that hydrogen is effectively prevented from passivating the doping species in the semiconductor material or significantly reducing the extent of the passivation. Examples of some of the compounds that can be used in the invented process include Si, Ge, MgO_x, MgN_x, ZnO, SiN_x, SiO_x, and alloys thereof. Multiple layer and repeated stacks of layers of suitable materials can be used as barrier layers as well, such as SiN_x/Si, MgN_x/SiN_x or MgN_x/MgO_x. The different barrier layers can be formed from the following source gasses: Si from silane or disilane, Ge from germane, MgN_x from cyclopentadienyl magnesium or methyl-cyclopentadienyl magnesium and ammonia, MgO from cyclopentadienyl magnesium or methyl-cyclopentadienyl magnesium and nitrous oxide, ZnO from dimethyl zinc or diethyl zinc and nitrous oxide or water, SiN_x from silane or disilane and ammonia or nitrous oxide, and SiO_x formed from silane or disilane and nitrous oxide.

After the protective barrier layer is applied, the semiconductor material can be cooled in the reaction chamber **11** without or with reduced dopant passivation. The

semiconductor material can then be removed from the cooled reaction chamber **11**.

When the structure is ready for additional processing such as metalization, the barrier layer can be removed by a number of different methods including but not limited to wet chemical hydrofluoric acid (HF) etching, reactive ion etching, or plasma etching.

The invention applies to devices such as high electron mobility transistors (HEMTs) and metal-semiconductor field effect transistors (MESFETs), semiconductor laser diodes, light emitting diodes (LEDs), optical detectors, and bipolar junction transistors (BJTs).

A preferred application of this method is passivation prevention or reduction in GaN p-n junction diodes. FIG. 2 shows a layer diagram of a GaN p-n junction diode **30** with the barrier layer **32** applied. Although a variety of barrier layer compounds may be applied, the preferred passivation barrier compounds are MgN_x, Si and SiN_x for a number of reasons; the necessary source gasses are already present in the reactor, they are chemically inert to GaN, and they are easily removed by etching. The barrier layer **32** is deposited on the p-type GaN region **34** doped with Mg. Also shown is the n-type GaN region **36** doped with Si grown on a sapphire substrate **38** as described above.

In the preferred method, the GaN crystal is grown in the reaction chamber **11** at temperatures of about 1000°C. Following growth, the flow of source gasses used to grow the GaN material are stopped at valves **21a-c**. The flow of nitrogen containing gas (NH_3) **26** is maintained because of the unstable nature of GaN at high temperature. A short reactor purge of approximately 1-3 seconds may be performed using valve **25** and pump **24** to remove the source gasses used

in the growth of GaN. The short purge provides a distinct junction between the SiN_x protective layer **32** and the p-type GaN **34** region, which helps to prevent Si doping of the p-type region **34**. The barrier layer is then deposited on the GaN material. For the fabrication of a SiN_x layer 32 silane (SiH_4) or disilane (Si_2H_6) gas **40** is used in combination with ammonia (NH_3) **42** at the growth temperature of the semiconductor material or at a different temperatures down to approximately 700°C or lower. For the fabrication of Si, the NH_3 flow **42** is terminated and SiH_4 or Si_2H_6 **40** are sourced into the reaction chamber. For the fabrication of MgN_x, cyclopentadienyl magnesium ($Mecp_2Mg$) and NH_3 are sourced into the reaction chamber **11**, respectively. The silicon, magnesium, and ammonia sources are typically installed in MOCVD systems and used for the growth of group III nitride based semiconductors such as GaN and its alloys with indium and aluminum. No additional source materials need to be added to the MOCVD system for the fabrication of the preferred barrier layers. Thus an easier, and more cost effective method is provided to prevent the passivation of doping species in semiconductor material grown by MOCVD compared to prior art.

In the preferred embodiment, a nitrogen carrier gas **44** is used during growth of the protective layer, although other gasses could also be used. Hydrogen is not used because passivation of the p-type layer **34** may occur in the short time between the end of growth of the diode 30 and the deposition of the sufficiently thick barrier layer **32**. A 2-500 nm thick barrier layer **32** is usually sufficient to protect the GaN surface, so the deposition can be performed quickly if sufficient barrier layer source gasses are provided. A variety of barrier layer thicknesses can be

used. In some applications a barrier layer only a few angstroms thick would be sufficient. The thicker the barrier layer or barrier layer stack, the more effective the passivation of doping species is prevented. However, if too thick a barrier layer **32** is applied, damage to the diode **30** may occur during barrier growth or reactor cooling.

A wide range of reactor chamber **11** conditions can be used for the MgN_x, Si, or SiN_x deposition, so the protective layer **32** can usually be deposited using the same growth conditions as the final diode layer. Reaction chamber **11** conditions may also be varied during deposition of the protective layer **32** to provide the greatest benefit for the application. As an example, the deposition may be performed during reaction chamber cooling in order to minimize the thermal residence time of the device. Alternatively, the temperature may be maintained during deposition if thermal residence is not a critical issue.

Once the passivation barrier layer **32** is deposited, the reaction chamber ambient may be modified to suit the limitations of the device application. In one preferred method, once the MgNx, Si, and SiNx barrier layer or layer sequence has been deposited, the ambient gas can be changed to a non-reactive gas such as nitrogen, helium, argon, or mixtures thereof. This ambient change can facilitate the purging of source gasses from the reactor chamber and the stabilization of either the semiconductor or barrier layer material during the cool down process. In the preferred method the ambient is nitrogen, helium, argon or a mixture of these gases. This process allows significant flexibility in reactor conditions following the deposition of the barrier layer **32** without the danger of damaging the

semiconductor or the barrier layer material. In another preferred embodiment, after completion of the barrier layer the ambient gas may be changed to reactive gasses like nitrous oxide, oxygen, hydrogen, mixtures thereof or mixtures with non-reactive gasses.

After the reactor is cooled and the semiconductor device is removed from the reaction chamber **11** the passivation barrier layer **32** can remain on the surface. This offers the added benefit of preserving the grown semiconductor material and sensitive surface properties from contamination prior to the subsequent device fabrication steps.

The barrier layer **32** may be removed immediately prior to further processing steps such as metalization of contacts. In the preferred method, the barrier layer **32** is removed with wet chemical hydrofluoric acid (HF) etching. FIG 3 shows the diode **30** in the HF wet chemical **46** that will dissolve the protective layer. The use of a wet chemical etching is preferred because it leaves the semiconductor surface pristine, while other etching processes may introduce impurities or cause damage to the material surface. Any processing steps should be conducted as soon as possible after removal of the barrier layer **32** to avoid damage to the surface from handling or exposure to atmospheric conditions.

The new method provides other benefits beyond those already discussed. If the device is exposed to extreme conditions following growth such as diffusion of an impurity, or annealing for defect reduction, the barrier layer **32** should retard damage to the surface. If slow, highly controlled cooling is desired to minimize residual thermal stresses the additional thermal budget should not

affect the device surface once the barrier layer **32** is deposited. Diffusion of other impurities from the reactor ambient into the device following growth will be eliminated. Densities of surface electron states resulting from surface damage should be significantly reduced. Surface damage of p-type layers that can result in the formation of thin n-type layers (which increases contact resistance) are minimized.

In another preferred method, the composition of the barrier layer compounds can be adjusted during growth to contain an excess of gettering components by selecting proper ratios of the corresponding source gasses. FIG. 4 shows a p-n junction diode **50** similar to the diode in FIGs. 3 and 4, having a hydrogen binding/gettering layer **52** on its surface. The layer **52** is deposited on diode **50** using MOCVD source gasses in a N or H source gas **54**. The layer **52** is used for blocking or reducing the diffusion of hydrogen into the semiconductor and also for gettering hydrogen at the semiconductor interface with the ambient. The preferred gettering layer material contains components that have a high binding energy to atomic hydrogen and higher than the binding energy between hydrogen and the acceptor or donor species (e.g. Mg-H bond = 126 kJ/mol). In the case of GaN materials, the binding energy between the gettering layer constituents and hydrogen exceeds the energy between Mg and hydrogen (e.g. Si-H = 318kJ/mol; Ge-H= 321kJ/mol; N-H=339kJ/mol; O-H=427kJ/mol). Thus the layers can be effective in preventing the passivation of doping species by gettering the hydrogen. The gettering layer can have different layers that can be a repeated sequence of multiple gettering materials. When further processing of the diode **50** is desired, the gettering layer **52** is removed

by wet chemical HF etching, but can also be removed by other etching processes.

Although the present invention has been described in considerable detail with reference to certain preferred configurations thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to their preferred versions contained therein.

WE CLAIM:

1. A method for preventing or reducing the passivation of acceptor and donor species in semiconductor material during and after its growth comprising:

growing said semiconductor material (30,50) in a reactor (10) at a growth temperature; and

depositing a passivation barrier layer (32) on said semiconductor material (30,50) while it is in said reactor (10).

2. The method of claim 1, wherein said passivation barrier (32,52) layer is deposited by metal organic chemical vapor deposition, plasma chemical vapor deposition, hot-filament chemical vapor deposition or physical vapor deposition.

3. The method of claim 1, wherein said passivation barrier layer (32,52) comprises Si, Ge, MgO_x, MgN_x, ZnO, SiN_x, SiO_x, or alloys thereof.

4. The method of claim 1, where said passivation barrier layer (32,52) comprises at least two layers, each said layer made from Si, Ge, MgO_x, ZnO, SiN_x, MgN_x, SiO_x, or alloys thereof.

5. The method of claim 1, wherein said passivation barrier layer (32,52) comprises Si_3N_4.

6. The method of claim 1, wherein said passivation barrier layer (32,52) is 1-500nm thick.

7. The method of claim 1, wherein said passivation barrier layer (32,52) is a gettering layer that chemically binds hydrogen trapped in said semiconductor material (30,50) and

blocks hydrogen diffusion into said semiconductor material (30,50).

8. The method of claim 7, wherein said gettering layer (32,52) contains components that have a higher binding energy than atomic hydrogen and a higher binding energy than between hydrogen and the acceptor or donor materials.

9. The method of claim 1, wherein said reactor (10) contains an ambient gas after the formation of said passivation barrier layer (32,52), said ambient gas being a non-reactive gas (29).

10. The method of claim 9, wherein said non-reactive gas (29) is nitrogen, helium, argon or mixtures thereof.

11. The method of claim 1, wherein said reactor (10) contains an ambient gas after the formation of said passivation barrier layer, said ambient gas being a reactive gas.

12. The method of claim 11, wherein said reactive gas is nitrous oxide, oxygen, hydrogen, mixtures thereof, or mixtures with said non-reactive gasses.

13. The method of claim 1, wherein high electron mobility transistors (HEMTs), metal-semiconductor field effect transistors (MESFETs), laser diodes (LDs), light emitting diodes (LEDs), optical detectors, and/or bipolar junction transistors (BJTs) or similar semiconductor devices are formed of said semiconductor material (30,50).

14. The method of claim 1, further comprising the step of

removing said passivation barrier layer (32,52) subsequent to cooling said reactor (10).

15. The method of claim 14, wherein said passivation barrier layer (32,52) is removed by etching using wet chemical etching, reactive ion etching or plasma etching.

16. The method of claim 14, wherein said passivation barrier layer (32,52) is removed by wet chemical hydrofluoric acid (HF) etching.

17. A method for preventing the passivation of acceptor and donor species in semiconductor materials (30,50) during and after its growth in a reactor, comprising:

flowing growth source gasses (16,21a-c,26) into said reactor (10) for growth of said semiconductor material (30,50);

stopping the flow of said material growth source gasses (16,26) not necessary for stabilization of the semiconductor;

injection of passivation barrier layer source gasses (16,21a-c) into said reactor (10) to deposit a passivation barrier layer on said semiconductor material (30,50); and

removing said passivation barrier layer (32,52) after cooling of said reactor, to further process said semiconductor material (30,50).

18. The method of claim 17, wherein said passivation barrier layer (32,52) is deposited by MOCVD, plasma CVD, hot-filament CVD or PVD.

19. The method of claim 17, wherein said passivation barrier layer (32,52) comprises Si, Ge, MgOx, MgNx, ZnO,

SiNx, SiOx, and alloys thereof.

20. The method of claim 17, where said passivation barrier layer (32,52) comprises at least two layers, each said layer made from Si, Ge, MgO_x, MgN_x, ZnO, SiN_x, SiO_x, or alloys thereof.

21. The method of claim 17, wherein said passivation barrier layer (32,52) comprises SiN_x.

22. The method of claim 17, wherein said passivation barrier layer (32,52) is 1-500nm thick.

23. The method of claim 17, wherein said passivation barrier (32,52) layer is a gettering layer that chemically binds hydrogen trapped in said semiconductor material (30,50) and blocks hydrogen diffusion into said semiconductor material (30,50).

24. The method of claim 23, wherein said gettering layer (32,52) contains materials that have a higher binding energy than atomic hydrogen and a higher binding energy than between hydrogen and the acceptor or donor materials.

25. The method of claim 17, wherein said reactor (10) contains an ambient gas (29) after the formation of said passivation barrier layer (32,52), said ambient gas being a non-reactive gas.

26. The method of claim 25, wherein said non-reactive gas is nitrogen, helium, argon or mixtures thereof.

27. The method of claim 17, wherein said reactor (10)

contains an ambient gas after the formation of said passivation barrier layer (32,52), said ambient gas being a reactive gas.

28. The method of claim 27, wherein said reactive gas is nitrous oxide, oxygen, hydrogen, mixtures thereof, or mixtures with said non-reactive gasses.

29. The method of claim 17, wherein said passivation barrier layer (32,52) is removed by etching using wet chemical etching, reactive ion etching or plasma etching.

30. The method of claim 17, wherein said passivation barrier layer (32,52) is removed by wet chemical hydrofluoric acid (HF) etching.

31. The method of claim 17, wherein high electron mobility transistors (HEMTs), metal-semiconductor field effect transistors (MESFETs), laser diodes (LDs), light emitting diodes (LEDs), optical detectors, and bipolar junction transistors (BJTs) or similar semiconductor devices are formed in said semiconductor material (30,50).

32. A method for protecting the surface of a semiconductor material, comprising:

depositing an inert passivation barrier layer (32,52) on said semiconductor material (30,50) in a MOCVD reactor (10); and

cooling said reactor (10).

33. The method of claim 32, wherein said semiconductor material (30,50) is GaN or any ternary or quaternary alloy with In or Al.

34. The method of claim 32, wherein said passivation barrier layer (32,52) is deposited by MOCVD, plasma CVD, hot-filament CVD or PVD.

35. The method of claim 32, wherein said passivation barrier layer (32,52) comprises Si, Ge, MgOx, MgNx, ZnO, SiNx, SiOx, and alloys thereof.

36. The method of claim 32, where said passivation barrier layer (32,52) comprises at least two layers, each said layer made from Si, Ge, MgO_x, MgN_x, ZnO, SiN_x, SiO_x, or alloys thereof.

37. The method of claim 32, wherein said passivation barrier layer (32,52) comprises SiN_x.

38. The method of claim 32, wherein said passivation barrier layer (32,52) is 1-500nm.

39. The method of claim 32, wherein said passivation barrier layer (32,52) is a gettering layer that chemically binds hydrogen trapped in said semiconductor material and blocks hydrogen diffusion into said semiconductor material.

40. The method of claim 39, wherein said gettering layer (32,52) contains materials that have a higher binding energy than atomic hydrogen and a higher binding energy than between hydrogen and the acceptor or donor materials.

41. The method of claim 32, wherein said reactor (10) contains an ambient gas after the formation of said passivation barrier layer (32,52), said ambient gas being

a non-reactive gas.

42. The method of claim 41, wherein said non-reactive gas is nitrogen, helium, argon or mixtures thereof.

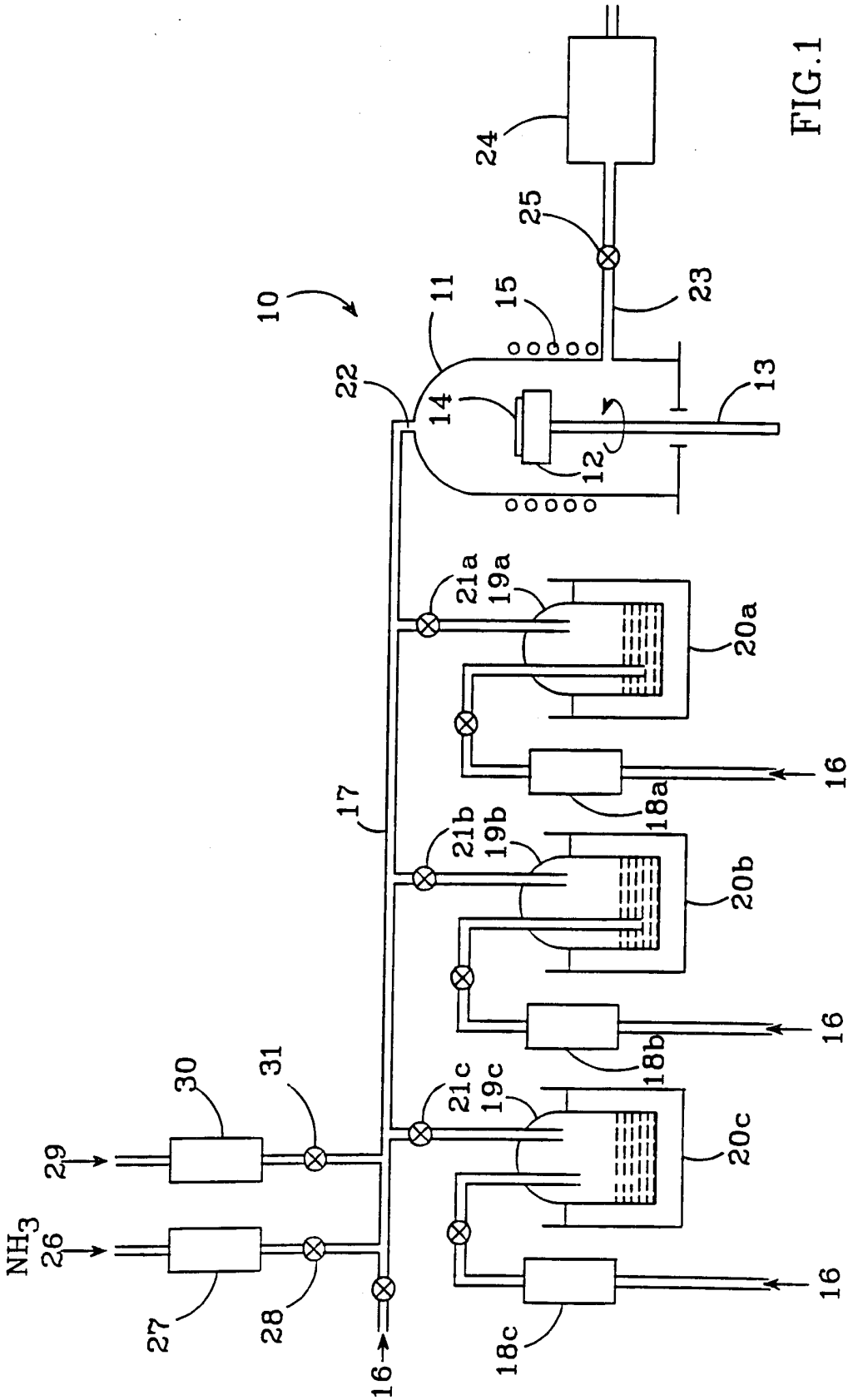
43. The method of claim 32, wherein said reactor (10) contains an ambient gas after the formation of said passivation barrier layer, said ambient gas being a reactive gas.

44. The method of claim 43, wherein said reactive gas is nitrous oxide, oxygen, hydrogen, mixtures thereof, or mixtures with said non-reactive gasses.

45. The method of claim 32, comprising the further step of removing said passivation barrier layer (32,52).

46. The method of claim 45, wherein said passivation barrier layer (32,52) is removed by wet chemical etching, reactive ion etching or plasma etching.

47. The method of claim 45, wherein said passivation barrier layer (32,52) is removed by wet chemical hydrofluoric acid (HF) etching or is left on the semiconductor surface.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19c
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21b
21c
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23
24
25
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27
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30
31
NH3

FIG.1

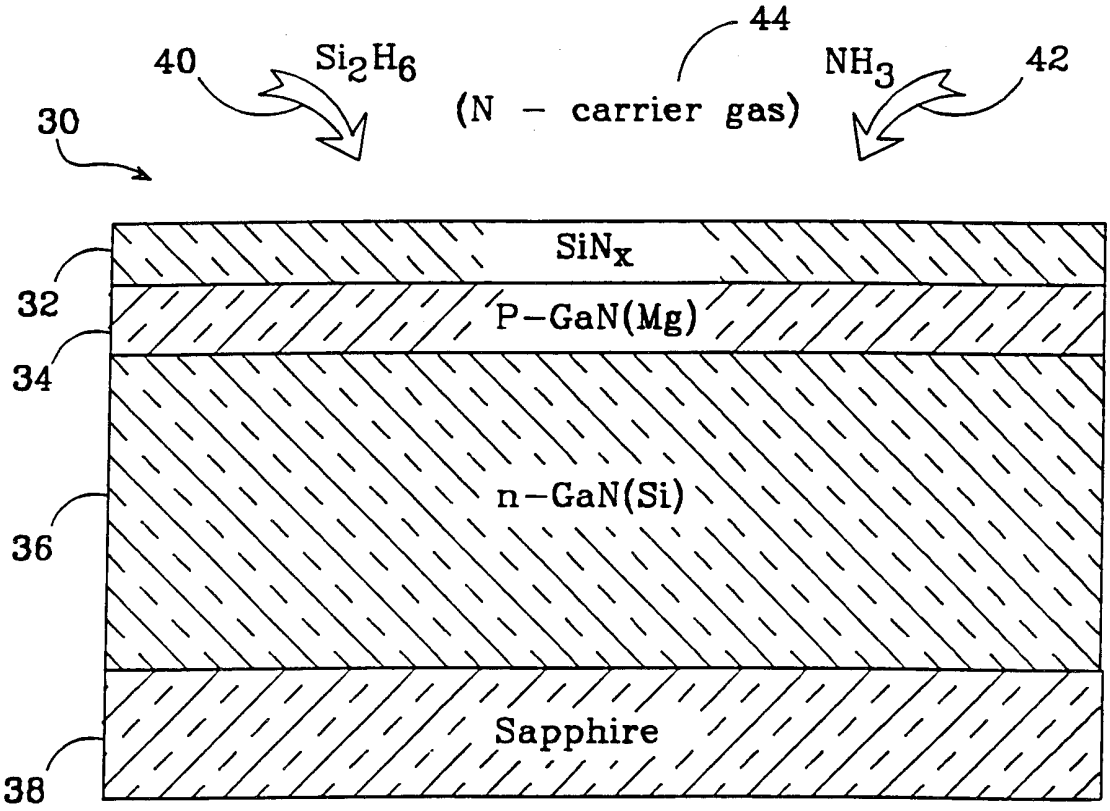
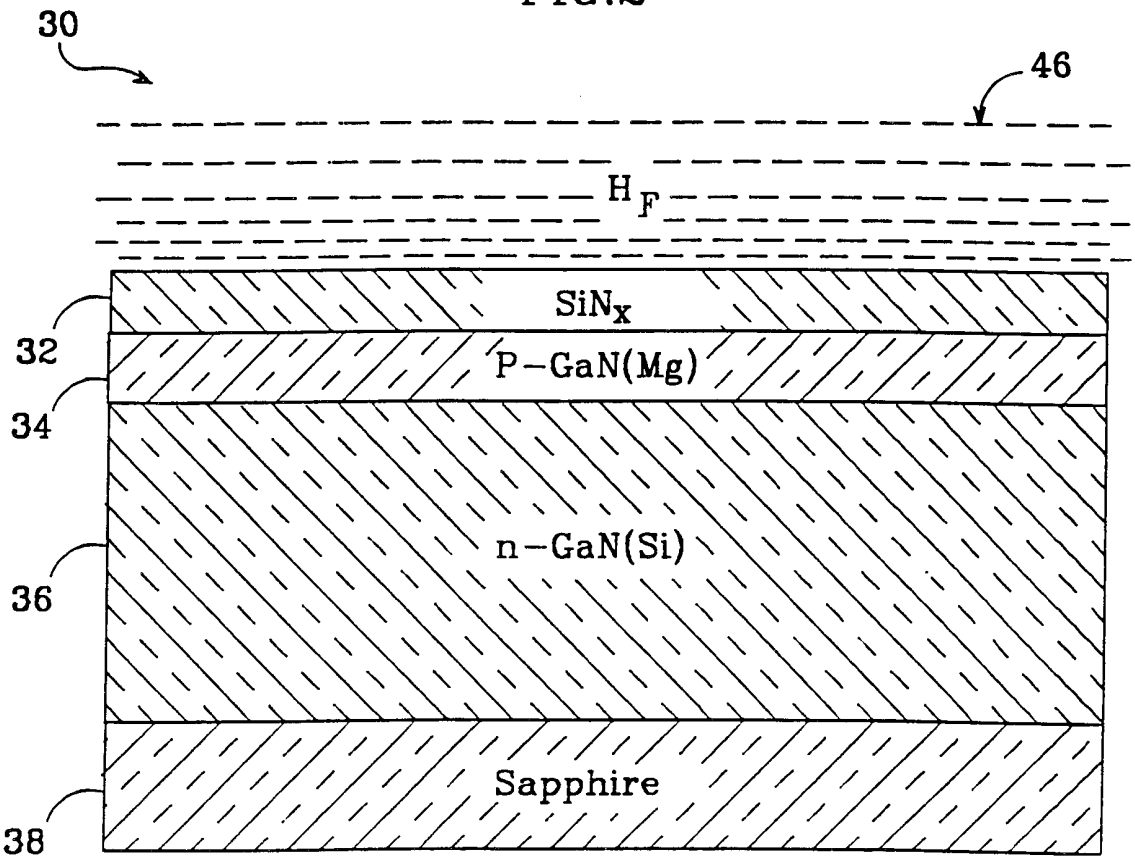

44
40
Si_2H_6
(N – carrier gas)
NH_3
42
30
SiN_x
32
P–GaN(Mg)
34
n–GaN(Si)
36
Sapphire
38

FIG.2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46
H_F
SiN_x
32
P–GaN(Mg)
34
n–GaN(Si)
36
Sapphire
38

FIG.3

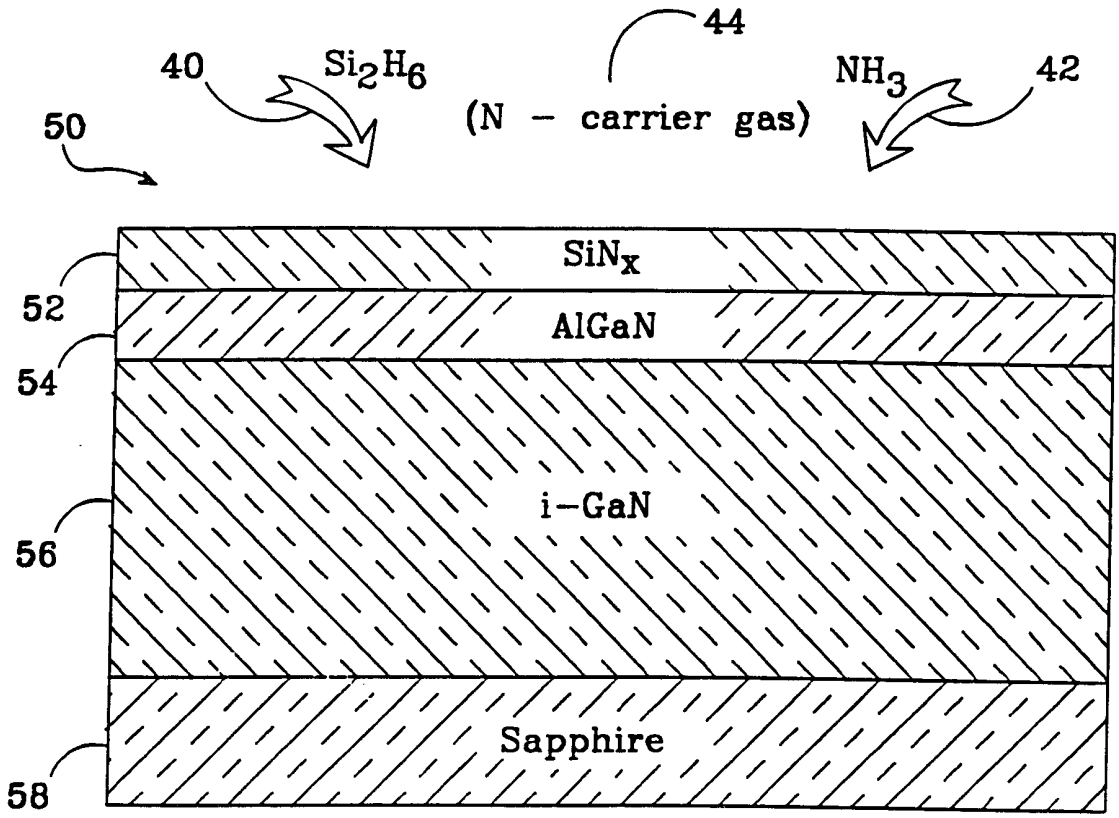
44
40
Si_2H_6
(N – carrier gas)
NH_3
42
50
SiN_x
52
AlGaN
54
i–GaN
56
Sapphire
58

FIG.4