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(54) GROUP-III NITRIDE BASED HIGH ELECTRON MOBILITY TRANSISTOR (HEMT) WITH BARRIER/SPACER LAYER

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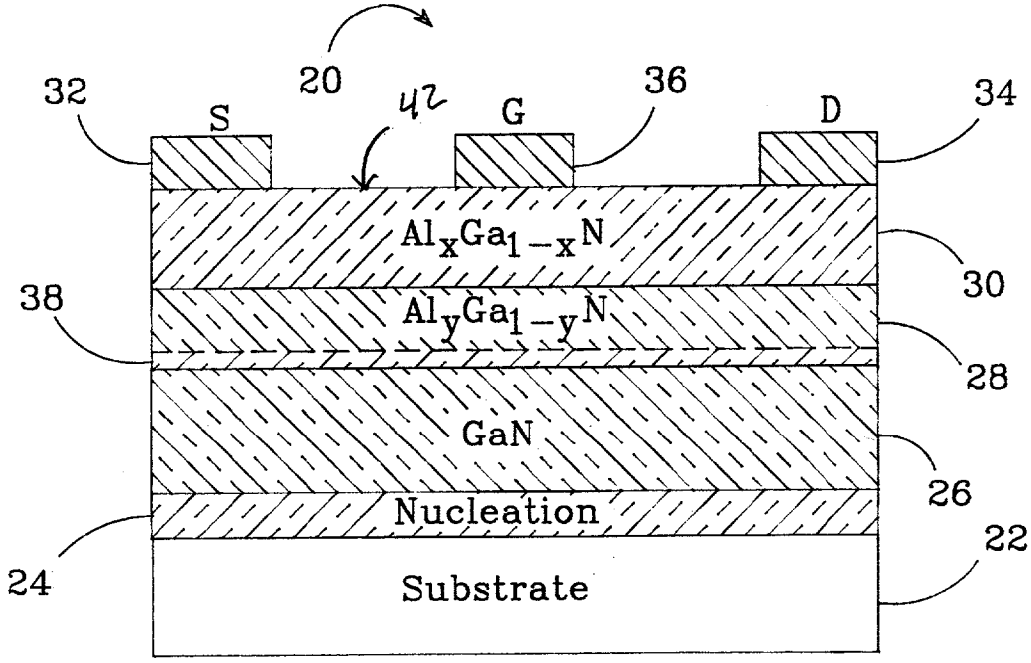
(52) **U.S. Cl.** **257/194**; 257/192

(57) **ABSTRACT**

A Group III nitride based high electron mobility transistors (HEMT) is disclosed that provides improved high frequency performance. One embodiment of the HEMT comprises a GaN buffer layer, with an $Al_yGa_{1-y}N$ (y=1 or y 1) layer on the GaN buffer layer. An $Al_xGa_{1-x}N$ ($0 \leqq x \leqq 0.5$) barrier layer on to the $Al_yGa_{1-y}N$ layer, opposite the GaN buffer layer, $Al_yGa_{1-y}N$ layer having a higher Al concentration than that of the $Al_xGa_{1-x}N$ barrier layer. A preferred $Al_yGa_{1-y}N$ layer has y=1 or $y \simeq 1$ and a preferred $Al_xGa_{1-x}N$ barrier layer has $0 \leqq x \leqq 0.5$. A 2DEG forms at the interface between the GaN buffer layer and the $Al_yGa_{1-y}N$ layer. Respective source, drain and gate contacts are formed on the $Al_xGa_{1-x}N$ barrier layer. The HEMT can also comprising a substrate adjacent to the buffer layer, opposite the $Al_yGa_{1-y}N$ layer and a nucleation layer between the $Al_xGa_{1-x}N$ buffer layer and the substrate.



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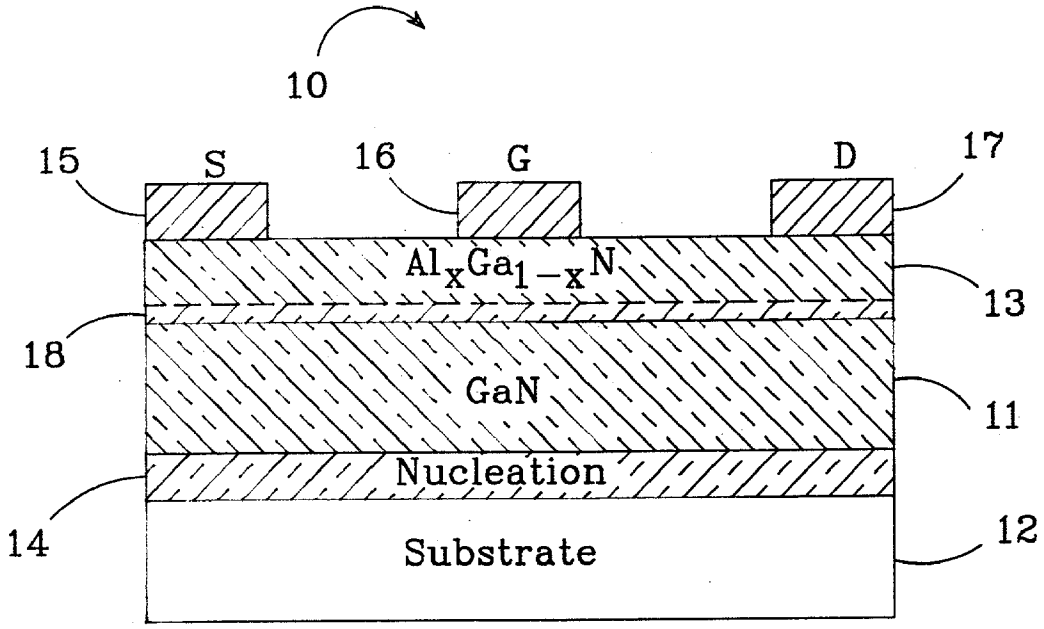

FIG.1
(Prior Art)

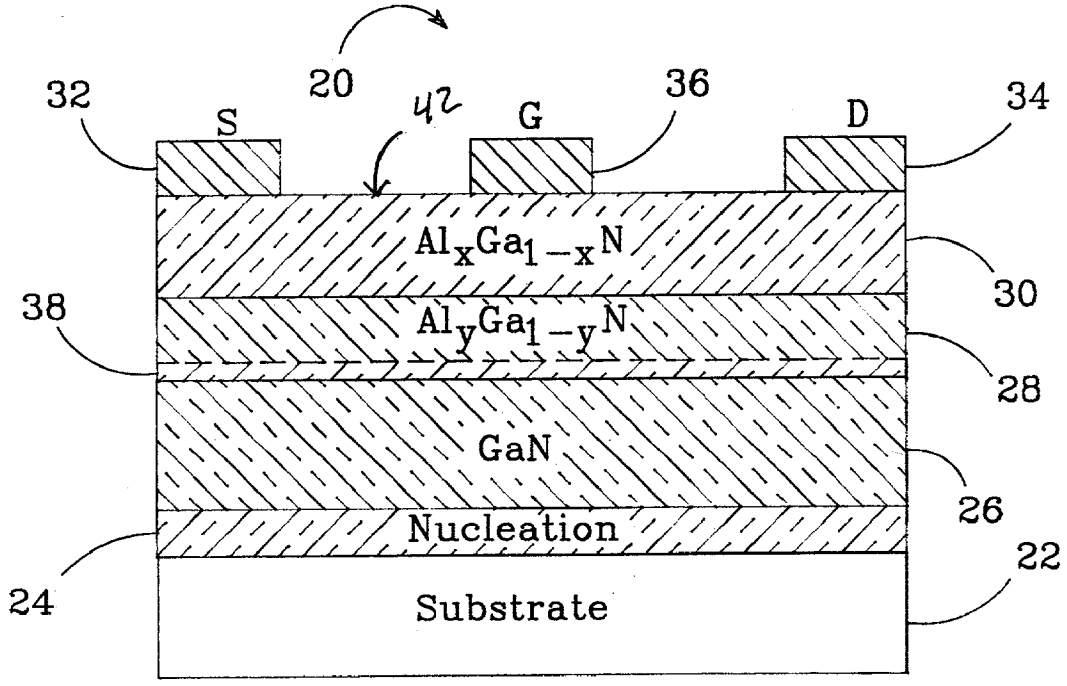

FIG.2

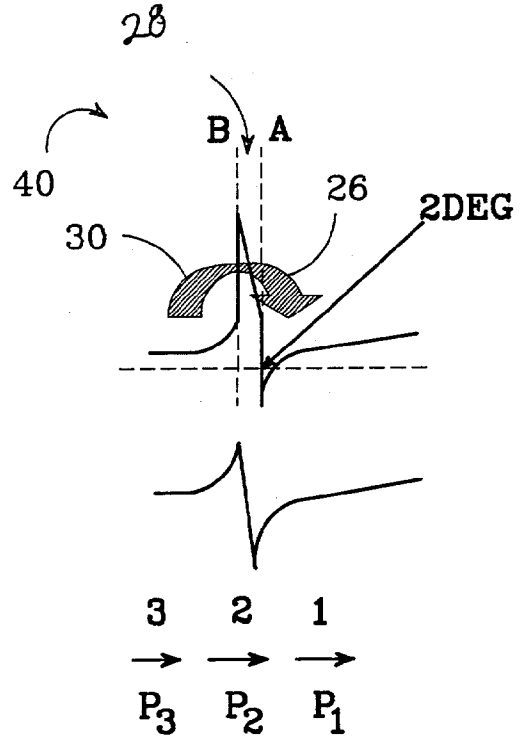
28
40
B
A
26
2DEG
30
3
2
1
P3
P2
P1

FIG.3

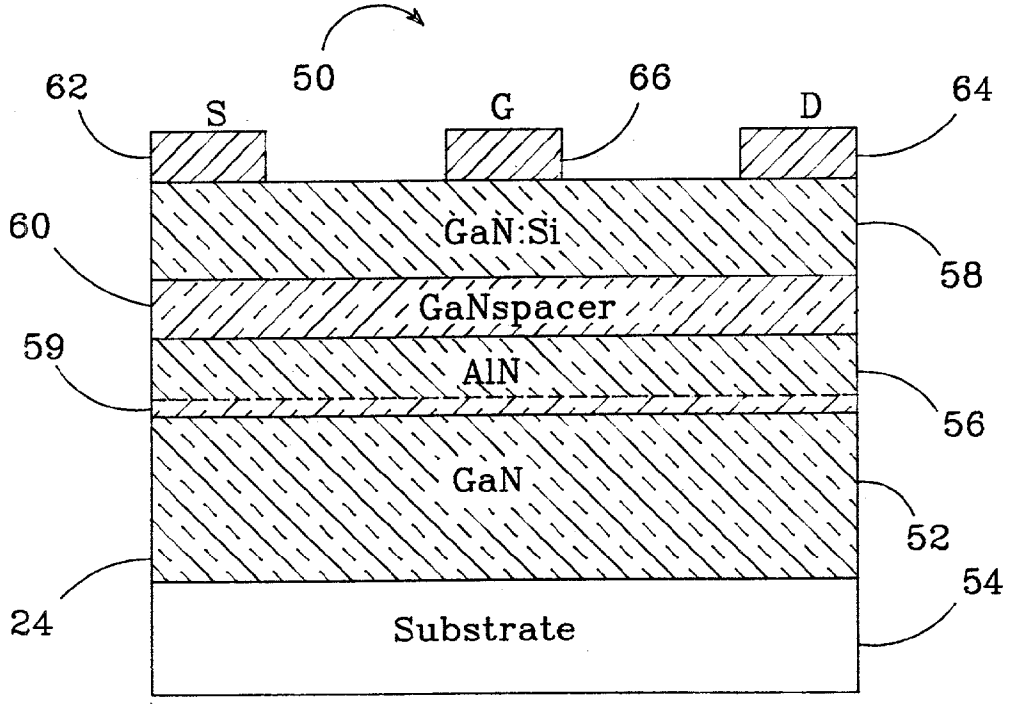
50
62
S
G
66
D
64
60
GaN:Si
58
GaNspacer
59
AlN
56
GaN
52
24
54
Substrate

FIG.4

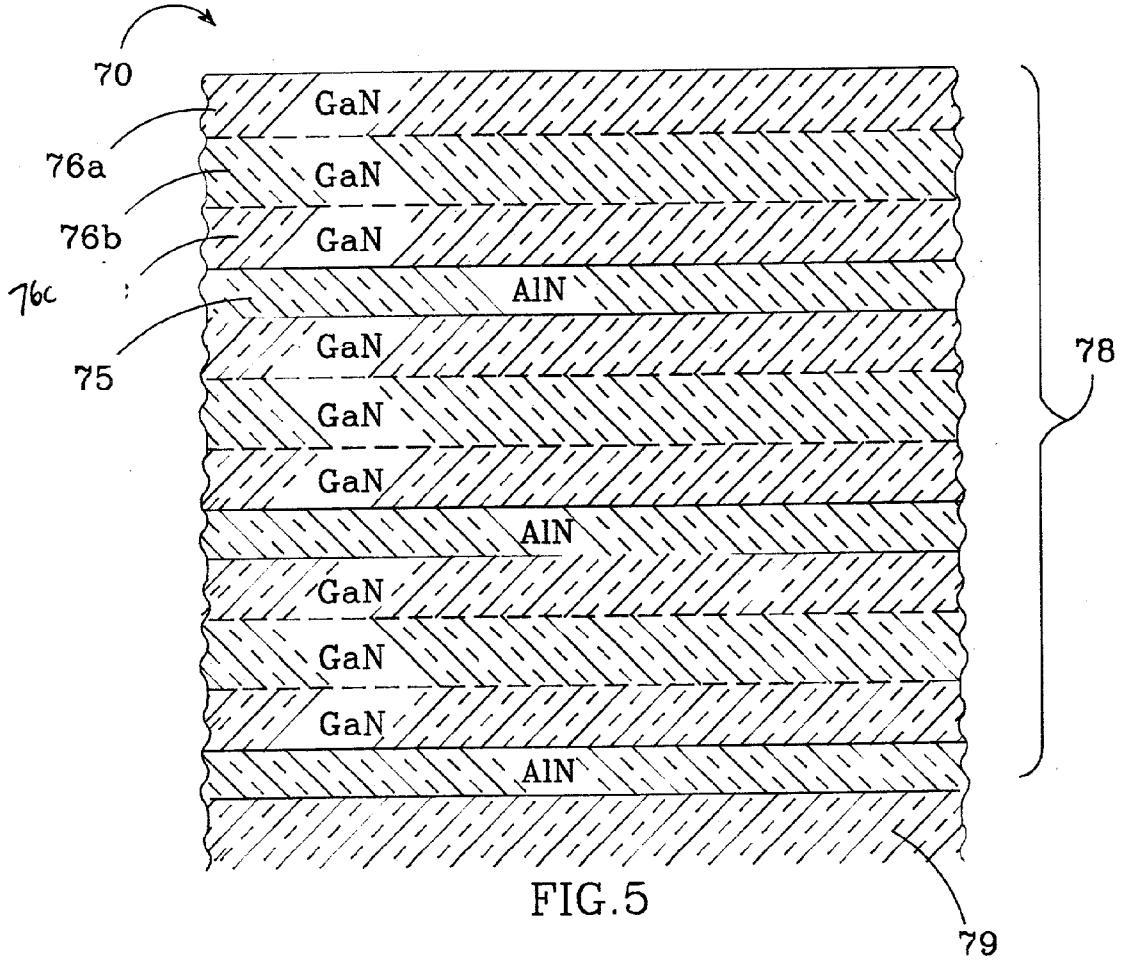
70
76a
76b
76c
75
GaN
GaN
GaN
AlN
GaN
GaN
GaN
AlN
GaN
GaN
GaN
AlN
78
79

FIG.5

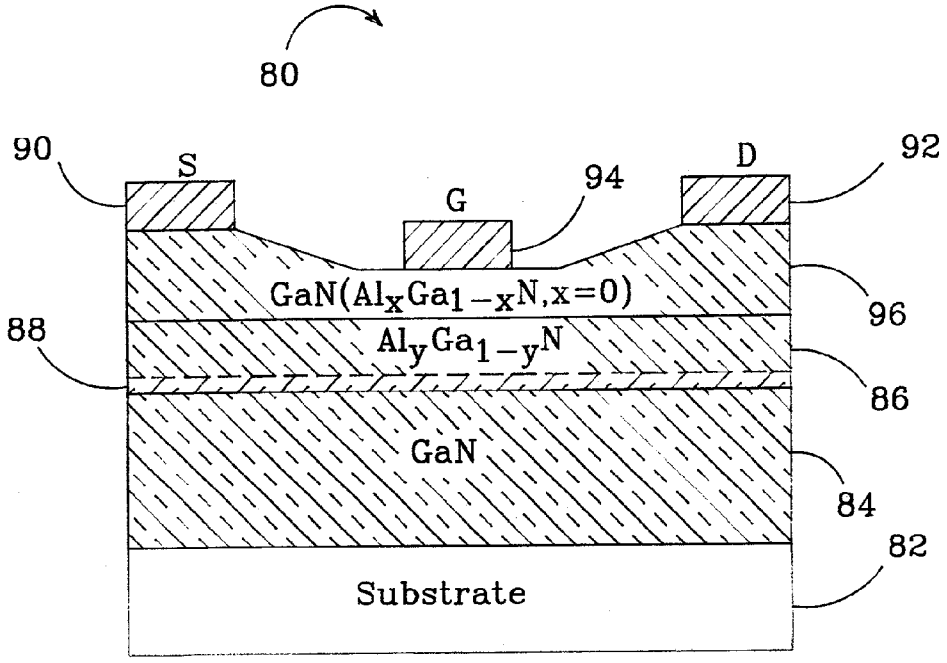
80
90
S
G
94
D
92
GaN($Al_xGa_{1-x}N$,x=0)
96
88
$Al_yGa_{1-y}N$
86
GaN
84
82
Substrate

FIG.6

GROUP-III NITRIDE BASED HIGH ELECTRON MOBILITY TRANSISTOR (HEMT) WITH BARRIER/SPACER LAYER

[0001] This application claims the benefit of provisional application Serial No. 60/290,195 to Smorchkova et al., which was filed on May 11, 2001.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates to high frequency solid state transistors, and more particularly to Group-III nitride based high electron mobility transistors (HEMTs).

[0004] 2. Description of the Related Art

[0005] HEMTs are a common type of solid state transistor that are regularly fabricated from semiconductor materials such as Silicon (Si) or Gallium Arsenide (GaAs). One disadvantage of Si is that it has low electron mobility (approximately 1450 cm^2/V-s), which produces a high source resistance. This resistance can degrade the Si based HEMT's high performance gain. [CRC Press, *The Electrical Engineering Handbook,* Second Edition, Dorf, p.994, (1997)]

[0006] GaAs based HEMTs have become the standard for signal amplification in civil and military radar, handset cellular, and satellite communications. GaAs has a higher electron mobility (approximately 6000 cm^2/V-s) and a lower source resistance than Si, which allows GaAs based devices to function at higher frequencies. However, GaAs has a relatively small bandgap (1.42 eV at room temperature) and relatively small breakdown voltage, which prevents GaAs based HEMTs from providing high power at high frequencies.

[0007] Improvements in the manufacturing of AlGaN/GaN semiconductor materials have focused interest on the development of AlGaN/GaN HEMTs for high frequency, high temperature and high power applications. AlGaN/GaN has large bandgaps, high peak and saturation electron velocity values [B. Belmont, K. Kim and M. Shur, *J.Appl.Phys.* 74, 1818 (1993)]. AlGaN/GaN HEMTs can also have 2DEG sheet densities in excess of $10^{13}/cm^2$ and relatively high electron mobility (up to 2019 cm^2/Vs) [R. Gaska, J. W. Yang, A. Osinsky, Q. Chen, M. A. Khan, A. O. Orlov, G. L. Snider and M. S. Shur, *Appl.Phys.Lett.,* 72, 707 (1998)]. These characteristics allow AlGaN/GaN HEMTs to provide high power at higher frequencies.

[0008] AlGaN/GaN HEMTs have been grown on sapphire substrates and have shown a power density of 4.6 W/mm and a total power of 7.6 W [Y. F. Wu et al., *IEICE Trans.Electron.,* E-82-C, 1895 (1999)]. More recently, AlGaN/GaN HEMTs grown on SiC have shown a power density of 9.8 W/mm at 8 GHz [Y. F. Wu, D. Kapolnek, J. P. Ibbetson, P. Parikh, B. P. Keller and U. K. Mishra, *IEEE Trans.Electron.Dev.,* 48, 586 (2001)] and a total output power of 22.9 at 9 GHz [M. Micovic, A Kurdoghlian, P. Janke, P. Hashimoto, D. W. S. Wong, J. S. Moon, L. McCray and C. Nguyen, *IEEE Trans.Electron.Dev.,* 48, 591 (2001)].

[0009] U.S. Pat. No. 5,192,987 to Khan et al. discloses GaN/AlGaN based HEMTs grown on a buffer and a substrate. Other AlGaN/GaN HEMTs and field effect transistors (FETs) have been described by Gaska et al., "High-Temperature Performance of AlGaN/GaN HFET's on SiC Substrates,"*IEEE Electron Device Letters,* Vol. 18, No 10, October 1997, Page 492; and Ping et al., "DC and Microwave Performance of High Current AlGaN Heterostructure Field Effect Transistors Grown on P-type SiC Substrates, "*IEEE Electron Devices Letters,* Vol. 19, No. 2, February 1998, Page 54. Some of these devices have shown a gain-bandwidth product (f_T) as high as 67 gigahertz [K. Chu et al. WOCSEMMAD, Monterey, Calif. (February 1998)] and high power densities up to 2.84 W/mm at 10 GHz [G. Sullivan et al., "High Power 10-GHz Operation of AlGaN HFET's in Insulating SiC,"*IEEE Electron Device Letters,* Vol. 19, No. 6, Page 198 (June 1998); and Wu et al., IEEE Electron Device Letters, Volume 19, No. 2, Page 50 (February 1998)].

[0010] **FIG. 1**, shows a typical AlGaN/GaN HEMT **10** that comprises a GaN buffer layer **11** adjacent to a sapphire or silicon carbide substrate **12** and a $Al_xGa_{1-x}N$ ($x \simeq 0.1$-0.5) layer **13** adjacent to the GaN buffer layer **11**, opposite the substrate **12**. A nucleation layer **14** can be included between the substrate **12** and the GaN buffer layer **11**, to reduce the lattice mismatch between the two layers. The HEMT **10** also includes source, gate and drain contacts **15**, **16**, **17**. The Al content in the $Al_xGa_{1-x}N$ creates a piezoelectric charge that accumulates at the interface with the GaN layer to form a two-dimensional electron gas (2DEG) **18**. As the Al content in the $Al_xGa_{1-x}N$ layer is increased, the piezoelectric charge is also increased, which results in a beneficial increase the HEMT's 2DEG and transconductance.

[0011] However, the 2DEG's mobility is generally limited by the interface roughness and piezoelectric scattering at the interface between the GaN and $Al_xGa_{1-x}N$ layers **11**, **13**, which are the result of localized randomness in the $Al_xGa_{1-x}N$ layer **13** near the interface.

[0012] By substituting an $Al_yGa_{1-y}N$ ($y=1$ or $y \simeq 1$) layer for the $Al_xGa_{1-x}N$ ($x \simeq 0.1$-0.5) layer **13**, certain advantages can be achieved. The 2.4% lattice mismatch between AlN ($Al_yGa_{1-y}N$ for $y=1$) and GaN results in the maximum possible piezoelectric charge at the interface between the two layers. Using an AlN layer also reduces the piezoelectric scattering between the layers that can limit the 2DEG mobility.

[0013] However, the high lattice mismatch between AlN and GaN dictates that the thickness of the AlN layer should be less than 50 Å. If the layer is thicker, the device can experience problems with its ohmic contacts, the material quality in the layer begins to degrade, the device's reliability decreases, and the material is more difficult to grow. However, a HEMT with a 50 Å or less AlN layer is susceptible to high gate leakage.

SUMMARY OF THE INVENTION

[0014] The present invention provides improved Group-III nitride based HEMTs with improved 2DEG mobility that are preferably formed of AlGaN/GaN. A HEMT constructed in accordance with the present invention comprises a GaN buffer layer with an $Al_yGa_{1-y}N$ layer on the GaN buffer layer. An $Al_xGa_{1-x}N$ barrier layer is included on the $Al_yGa_{1-y}N$ layer opposite the GaN buffer layer, the $Al_yGa_{1-y}N$ layer having a higher Al content than the $Al_xGa_{1-x}N$ barrier layer. A 2DEG at formed the interface between the GaN buffer

layer and the $Al_yGa_{1-y}N$ layer. A preferred $Al_yGa_{1-y}N$ layer has y=1 or y≃1, and a preferred $Al_xGa_{1-x}N$ barrier layer has $0 \leqq x \leqq 0.5$.

[0015] The HEMT also has respective source, drain and gate contacts contacting its $Al_xGa_{1-x}N$ barrier layer. The HEMT can also be formed on a substrate made from a material from the group consisting of sapphire, silicon carbide, gallium nitride and silicon. The substrate is arranged adjacent to the buffer layer, opposite the $Al_yGa_{1-y}N$ layer. The HEMT can also have a nucleation layer between its GaN buffer layer and substrate

[0016] The HEMT's $Al_yGa_{1-y}N$ layer on the GaN layer provides a high piezoelectric charge and a reduction in piezoelectric scattering at the interface between the two layers. The $Al_yGa_{1-y}N$ layer should be relatively thin because of the high lattice mismatch between AlN and GaN. The $Al_xGa_{1-x}N$ layer on the thin $Al_yGa_{1-y}N$ layer keeps the HEMT's gate leakage low.

[0017] These and other further features and advantages of the invention would be apparent to those skilled in the art from the following detailed description, taking together with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] **FIG. 1** is a sectional view of a prior art AlGaN/GaN HEMT;

[0019] **FIG. 2** is a sectional view of an embodiment of an AlGaN/GaN HEMT according to the present invention;

[0020] **FIG. 3** is a band diagram of the AlGaN/GaN HEMT shown in **FIG. 2**;

[0021] **FIG. 4** is a sectional view of a second embodiment of an AlGaN/GaN HEMT according to the present invention;

[0022] **FIG. 5** is a sectional view of the barrier layer in the HEMT of **FIG. 2**, that is fabricated using a digital method; and

[0023] **FIG. 6** is a sectional view of a third embodiment of a HEMT according to the present invention, with the barrier layer having a recessed gate structure.

DETAILED DESCRIPTION OF THE INVENTION

[0024] **FIG. 2** shows one embodiment of a HEMT **20** constructed in accordance with the present invention. It comprises a substrate **22** that can be made of different materials such as sapphire (Al_2O_3), silicon carbide (SiC), gallium nitride (GaN), or silicon (Si). The preferred substrate is a 4H polytype of silicon carbide. Other silicon carbide polytypes can also be used including 3C, 6H and 15R polytypes.

[0025] Silicon carbide has a much closer crystal lattice match to Group III nitrides than sapphire and results in Group III nitride films of higher quality. Silicon carbide also has a very high thermal conductivity so that the total output power of Group III nitride devices on silicon carbide is not limited by the thermal dissipation of the substrate (as may be the case with some devices formed on sapphire). Also, the availability of silicon carbide substrates provides the capacity for device isolation and reduced parasitic capacitance that make commercial devices possible. SiC substrates are available from Cree Research, Inc., of Durham, N.C. and methods for producing them are set forth in the scientific literature as well as in a U.S. Patents, Nos. Re. 34,861; 4,946,547; and 5,200,022.

[0026] The new HEMT **20** can be fabricated using many different material systems but is preferably fabricated using Group III nitride based material systems. Group III nitrides refer to those semiconductor compounds formed between nitrogen and the elements in the Group III of the periodic table, usually aluminum (Al), gallium (Ga), and indium (In). The term also refers to ternary and tertiary compounds such as AlGaN and AlInGaN. The spontaneous and piezoelectric polarization in wurtzite group III-nitrides are found to be approximately 10 times larger than in conventional Group III-V and II-VI semiconductor compounds.

[0027] A nucleation layer **24** can be included on the substrate **22** to reduce the lattice mismatch between the substrate **22** and the next layer in the HEMT **20**. The nucleation layer **24** should be approximately 1000 angstroms (Å) thick, although other thicknesses can be used. It can be made of different semiconductor materials with one suitable material being $Al_zGa_{1-z}N$ ($0 \leqq z \leqq 1$) that is preferably AlN ($Al_zGa_{1-z}N$ for z=1)

[0028] A GaN layer **26** is included on the nucleation layer **24**, opposite the substrate **22**. The GaN layer **26** should be in the range of approximately 0-5 μm thick, although other thicknesses can be used. In one of the preferred embodiments of the HEMT **20**, the GaN layer **26** is 2 μm thick. Alternatively, the GaN layer **26** can be made of $Al_wGa_{1-w}N$ ($0 \leqq w \leqq 1$)

[0029] An $Al_yGa_{1-y}N$ (y=1 or y 1) layer **28** is included on the GaN layer **26**, opposite the nucleation layer **24**. The layer **28** should be less than 50 Å thick, but in different arrangement other thicknesses can be used. The preferred thickness is approximately 20 Å. The ($Al_yGa_{1-y}N$ for y=1) layer **28** can be formed of multiple monolayers of AlN, with each monolayer being in the range of approximately 5-20 Å thick. For example, a layer **28** formed of 4 monolayers that are 5 Å thick would be 20 Å thick.

[0030] An $Al_xGa_{1-x}N$ barrier layer **30** is included on the $Al_yGa_{1-y}N$ layer **28**, opposite the GaN layer **26**. The preferred composition of the layer **30** is with $0 \leqq x \leqq 0.5$, although the composition can be varied, with x being between 0 and 1. Layer **30** should be in the range of approximately 100 to 1000 Å thick, although other thicknesses can be used. The thickness of the layer **30** is dependent upon the layer's Al composition, the higher the Al composition the thinner the layer **30** can be. In one embodiment of the HEMT **20**, the layer **30** is approximately 300 Å thick and has a composition of $Al_xGa_{1-x}N$ (x≃0.33). If the barrier layer is too thin (less than approximately 100 Å) the layer **30** does not produce an effective 2DEG in the HEMT **20**.

[0031] The HEMT **20** includes source, drain and gate contacts **32**, **34**, **36**. The source and drain contacts **32**, **34** can be made of different materials including but not limited to alloys of titanium, aluminum, or nickel. The gate cantact **36** can also be made of different materials including but not limited to titanium, platinum, chromium, alloys of titanium and tungsten, or platinum silicide.

[0032] A 2DEG **38** forms at the junction between the $Al_yGa_{1-y}N$ layer **28** and the GaN layer **26**. As described above, the 2.4% lattice mismatch between AlN ($Al_yGa_{1-y}N$ for y=1) layer **28** and GaN layer **26** results in the maximum possible piezoelectric charge at the interface between the two layers. The AlN ($Al_yGa_{1-y}N$ for y=1) layer **28** also reduces the piezoelectric scattering between the layers that can limit the 2DEG mobility.

[0033] By having a AlN ($Al_yGa_{1-y}N$ for y=1) layer **28** on the GaN layer **26**, the HEMT's 2DEG **38** has icreased mobility. By having a thicker $Al_xGa_{1-x}N$ 30 on the AlN ($Al_yGa_{1-y}N$ for y=1) layer **28** the HEMT **20** does not experience the high gate leakage that would be experienced by having only the AlN ($Al_yGa_{1-y}N$ for y=1) layer **28**.

[0034] A HEMT **20** according to the present invention, having a 20 Å $Al_yGa_{1-y}N$ layer (y=1) with a 200 Å $Al_xGa_{1-x}N$ (x=0.25) layer on it, can have a 2DEG density of $7.45\times10^{12}/cm^2$ and a mobility of 2195 cm^2/Vs. A HEMT **20** having a 20 Å $Al_yGa_{1-y}N$ layer (y=1) with a 230 Å $Al_xGa_{1-x}N$ (x=0.33) layer on it, can have a 2DEG density of $1.10\times10^{13}/cm^2$ and a mobility of 2082 cm^2/Vs. The 2DEG sheet density increases as the aluminum composition of the $Al_xGa_{1-x}N$ barrier layer increases.

[0035] **FIG. 3** shows a band diagram **40** for the HEMT **20** in **FIG. 2**, taken at point **42** and vertically through the $Al_xGa_{1-x}N$ barrier layer **30**, $Al_yGa_{1-y}N$ layer **28**, the 2DEG **32** and the GaN layer **26**. Each of the layers **26**, **28** and **30** has a respective non-zero total polarization P_1, P_2 and P_3 pointing in the same direction. The magnitude of the total polarization in the $Al_yGa_{1-y}N$ layer **28** is higher than the surrounding layers **26** and **30** because of its increased Al content. This gradient of polarization results in polarization induced sheet charges at interfaces A and B between the three layers. A positive polarization sheet charge is located at the interface A between layers GaN layer **26** and the $Al_yGa_{1-y}N$ layer **28**. A negative polarization sheet charge is located at the interface between $Al_xGa_{1-x}N$ barrier layer **30** and the $Al_yGa_{1-y}N$ layer **28**. There is a resulting non-zero electric field in the $Al_yGa_{1-y}N$ layer **28**. As a result, the conduction band edge of $Al_xGa_{1-x}N$ barrier layer **30** at the interface B with $Al_yGa_{1-y}N$ layer **28** is positioned above the conduction band edge of GaN layer **26**. The middle layer **28** is relatively thin and is almost transparent to electrons even if the conduction band discontinuities between the layers are relatively large. As a result, electrons can transfer from the top layer into the bottom layer and form a 2DEG channel at the interface A between layers **26** and **28**. This staggered bandgap can be achieved between layers of the same semiconductor material by changing the element compositions in the layers.

[0036] **FIG. 4** shows another embodiment of a HEMT **50** fabricated pursuant to the present invention that is also made from Group III-nitride semiconductor materials. An unintentionally doped or semi-insulating GaN buffer layer **52** is formed on a sapphire substrate **54**. A relatively thin (~1 nm) AlN layer **56** is formed on top of GaN buffer layer **52** and then capped with Si-doped GaN layer **58**. The surface of the AlN layer **56** is GaN-terminated **60**, so that spontaneous polarization in all the layers points toward the substrate **54**. In addition, the piezoelectric polarization in the layers points in the same direction as the spontaneous polarization. The magnitude of both spontaneous and piezoelectric polarization increases with Al concentration of the layers and the AlN layer **56** has the highest Al concentration and the highest total polarization. The staggered bandgap line-up shown in **FIG. 3** is achieved between the HEMT's layers with a 2DEG **59** formed at the interface between the AlN layer and the GaN layer. The HEMT **50** also includes source, drain and gate contacts **62**, **64**, **66**.

[0037] HEMT structures according to the present invention can be fabricated using all Group III nitrides and their alloys with P, As and Sb can also be used. The sequence of the layers should be such that the gradient of polarization results in a strong electric field in the very thin layer in the middle. The HEMTs can be fabricated using different processes including but not limited to, metallorganic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE) or vapor-phase epitaxy (VPE). The $Al_xGa_{1-x}N$ barrier layer **30** and the $Al_yGa_{1-y}N$ layer **28** can be grown in hydrogen, nitrogen or ammonia carrier gasses.

[0038] **FIG. 5** shows a HEMT **70** with an $Al_xGa_{1-x}N$ barrier layer **78** and an $Al_yGa_{1-y}N$ layer **79** that are similar to same layers **30** and **28** in the HEMT **20** in **FIG. 2**. However, in this embodiment, the barrier layer **78** is fabricated in a digital fashion to obtain the desired Al and Ga concentrations. The barrier layer **78** can have multiple layer sets of 4 layers per set, wherein one is an AlN layer **75** and three are GaN layers **76***a-c*. A barrier layer **72** with four layer sets, has four Al layers **75** and twelve GaN layers **76***a-c*. This results in the concentration of the overall barrier layer of 25% Al and 75% GaN. Similarly, a concentration of 33% Al and 67% GaN can be achieved by each layer set having 3 layers, with one Al layer and two GaN layers.

[0039] By fabricating the barrier layer **72** using this method, the flow rates of the different gasses do not need to be finely adjusted to achieve the desired Al and GaN concentrations. This process also leads to a barrier layer **72** having a concentration of the materials is more exact and results in uniformity of material concentrations throughout the barrier layer **72**. The barrier layer **72** can be terminated with either a GaN or AlN layer. This process can also be used to fabricate other HEMT layers.

[0040] **FIG. 6** shows another embodiment of a HEMT **80** constructed in accordance with the present invention. It has a substrate **82**, GaN buffer layer **84**, $Al_yGa_{1-y}N$ (x=1 or x≃1) layer **86**, 2DEG **88**, source contact **90**, drain contact **92** and gate contact **94**, that are all similar to those in the HEMT **20** shown in **FIG. 2**. However, in this embodiment, the barrier layer **96** is comprised of GaN ($Al_xGa_{1-x}N$ with x=0) . The barrier layer **96** can be n-type, either in a uniform or delta doped scheme. With this composition the barrier layer **96** can be made thick (500-1000 Å), which can enable recessed gate structures. In a standard planar HEMT structure the resistance under the gate, drain and source contacts are equivalent. By making the barrier layer **96** thicker, the resistance under each is reduced. However, it is desirable to have an increased resistance under the gate contacts **94** while keeping a low resistance under the source and drain contacts **90** and **92**. The thick barrier layer **96** can be etched so it is thinner under gate contact **94**. This increases the resistance under the gate contact **94** while keeping the resistance under the source and drain contacts **90** and **92** to a minimum.

[0041] Although the present invention has been described in considerable detail with reference to certain preferred

configurations thereof, other versions are possible. Other layers of the HEMT can also be fabricated using a digital layering method. Therefore, the spirit and scope of the appended claims should not be limited to the preferred versions described in the specification.

We claim:

1. A high electron mobility transistor (HEMT), comprising:

a GaN buffer layer;

an $Al_yGa_{1-y}N$ layer on said GaN buffer layer;

an $Al_xGa_{1-x}N$ barrier layer on said $Al_yGa_{1-y}N$ layer opposite said GaN buffer layer, said $Al_yGa_{1-y}N$ layer having a higher Al content than said $Al_xGa_{1-x}N$ barrier layer; and

a 2DEG at the interface between said GaN buffer layer and said $Al_yGa_{1-y}N$ layer.

2. The HEMT of claim 1, wherein said $Al_yGa_{1-y}N$ layer comprises $Al_yGa_{1-y}N$ (y=1 or y 1).

3. The HEMT of claim 1, wherein said $Al_xGa_{1-y}N$ barrier layer comprises $Al_xGa_{1-x}N$ ($0 \leqq x \leqq 0.5$).

4. The HEMT of claim 1, further comprising respective source, drain and gate contacts on said $Al_xGa_{1-x}N$ barrier layer.

5. The HEMT of claim 1, further comprising a substrate adjacent to said buffer layer, opposite said $Al_yGa_{1-y}N$ layer, said substrate made from a material from the group consisting of sapphire, silicon carbide, gallium nitride and silicon.

6. The HEMT of claim 1, further comprising a nucleation layer between said GaN buffer layer and said substrate.

7. The HEMT of claim 4, wherein said source and drain contacts are made of an alloy from the group consisting of titanium, aluminum, and nickel.

8. The HEMT of claim 4, wherein said gate made of a material from the group consisting of titanium, platinum, chromium, alloys of titanium and tungsten, and platinum silicide.

9. The HEMT of claim 1, wherein said GaN buffer layer is less than approximately 5 μm thick.

10. The HEMT of claim 1, wherein said $Al_yGa_{1-y}N$ layer is less than approximately 50 Å thick.

11. The HEMT of claim 1, wherein said $Al_xGa_{1-x}N$ barrier layer is approximately 100 to 1000 Å thick.

12. The HEMT of claim 4, wherein the resistance under said gate contact is greater than the resistance under said source and drain contacts.

13. The HEMT of claim 4, wherein said barrier layer is thinner under said gate contact.

14. The HEMT of claim 1, wherein said layers can be fabricated digitally.

15. A group III nitride based high electron mobility transistor (HEMT), comprising:

a semiconductor buffer layer;

a high polarization semiconductor layer on said buffer layer;

a semiconductor barrier layer on said high polarization layer so that said high polarization layer is sandwiched between said buffer and barrier layers, each of said layers having a non-zero total polarization pointing in the same direction, the magnitude of said polarization in said high polarization layer higher than the polarization of said buffer and barrier layers; and

a two dimensional electron gas at the interface between said buffer layer and said high polarization layer.

16. The HEMT of claim 15, further comprising respective source, drain and gate contacts that contact said barrier layer.

17. The HEMT of claim 15, further comprising a substrate adjacent to said buffer layer, opposite said high polarization layer, said substrate made from a material from the group consisting of sapphire, silicon carbide, gallium nitride and silicon.

18. The HEMT of claim 15, further comprising a nucleation layer between said buffer layer and said substrate.

19. The HEMT of claim 15, wherein said buffer layer is made of GaN.

20. The HEMT of claim 15, wherein said buffer layer is less than 5 μm thick.

21. The HEMT of claim 15, wherein said high polarization semiconductor layer is made of $Al_yGa_{1-y}N$ (y=1, or y 1).

22. The HEMT of claim 15, wherein said high polarization layer is less than 50 Å thick.

23. The HEMT of claim 15, wherein said barrier layer made of $Al_xGa_{1-x}N$ ($0 \leqq x \leqq 0.5$).

24. The HEMT of claim 15, wherein said barrier layer is 100 to 1000 Å thick.

25. A high electron mobility transistor (HEMT), comprising:

a bottom layer of Group III nitride semiconductor material;

a middle layer of Group III nitride semiconductor material on said bottom layer;

a top layer of Group III nitride semiconductor material on said middle layer, opposite said bottom layer, said middle layer having a higher concentration of a Group III material than said bottom and top layers; and

a 2DEG at the interface between said middle and bottom layer.

26. The HEMT of claim 25, further comprising respective source, drain and gate contacts that contact said top layer.

27. The HEMT of claim 25, further comprising a substrate adjacent to said bottom layer, opposite said top layer

28. The HEMT of claim 25, further comprising a nucleation layer between said bottom layer and said substrate.

29. The HEMT of claim 25, wherein said bottom layer is made of GaN and is less than 5 μm thick.

30. The HEMT of claim 25, wherein said middle layer is made of $Al_yGa_{1-y}N$ (y=1, or y 1) and is less than 50 Å thick.

31. The HEMT of claim 25, wherein said barrier layer made of $Al_xGa_{1-x}N$ ($0 \leqq x \leqq 0.5$) and is 100 to 1000 Å thick.

32. The HEMT of claim 26, wherein the resistance under said gate contact is greater than the resistance under said source and drain contacts.

33. The HEMT of claim 26, wherein said barrier layer is thinner under said gate contact.

34. The HEMT of claim 25, wherein said layers can be fabricated digitally.

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