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(54) Title: ALUMINUM GALLIUM NITRIDE/GALLIUM NITRIDE HIGH ELECTRON MOBILITY TRANSISTORS HAVING A GATE CONTACT ON A GALLIUM NITRIDE BASED CAP SEGMENT AND METHODS OF FABRICATING SAME

(57) Abstract: High electron mobility transistors (HEMTs) and methods of fabricating HEMTs are provided Devices according to embodiments of the present invention include a gallium nitride (GaN) channel layer and an aluminum gallium nitride (AlGaN) barrier layer on the channel layer. A first ohmic contact is provided on the barrier layer to provide a source electrode and a second ohmic contact is also provided on the barrier layer and is spaced apart from the source electrode to provide a drain electrode. A GaN-based cap segment is provided on the barrier layer between the source electrode and the drain electrode. The GaN-based cap segment has a first sidewall adjacent and spaced apart from the source electrode and may have a second sidewall adjacent and spaced apart from the drain electrode. A non-ohmic contact is provided on the GaN-based cap segment to provide a gate contact. The gate contact has a first sidewall which is substantially aligned with the first sidewall of the GaN-based cap segment. The gate contact extends only a portion of a distance between the first sidewall and the second sidewall of the GaN-based cap segment.

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ALUMINUM GALLIUM NITRIDE/GALLIUM NITRIDE HIGH ELECTRON MOBILITY TRANSISTORS HAVING A GATE CONTACT ON A GALLIUM NITRIDE BASED CAP SEGMENT AND METHODS OF FABRICATING SAME

Related Applications

The present application is related to and claims priority from United States Provisional Application Serial No. 60/250,755, filed December 1, 2000 and entitled *"AlGaN/GaN HEMT with Improved Gate Barrier Layer and Low Access Resistance"* the disclosure of which is incorporated herein as if set forth fully herein.

Statement of Government Interest

The present invention was developed, at least in part, under Office of Naval Research Contract No. N00014-99-C-0657. The Government has certain rights in this invention.

Field of the Invention

The present invention relates to High Electron Mobility Transistor (HEMT) and more particularly to aluminum gallium nitride (AlGaN)/gallium nitride (GaN) HEMTs.

Background of the Invention

AlGaN/GaN HEMT (High Electron Mobility Transistor) devices are well known in the semiconductor field. U.S. Patents 5,192,987 and 5,296,395 describe AlGaN/GaN HEMT structures and methods of manufacture. Improved HEMT structures are disclosed in commonly assigned U.S. Patent Application Serial No. 09/096,967 filed June 12, 1998 and entitled *"NITRIDE BASED TRANSISTORS ON SEMI-INSULATING SILICON CARBIDE SUBSTRATES"* which is incorporated by reference in its entirety.

A typical AlGaN/GaN HEMT structure **110** is illustrated in **Figure 1**. A GaN channel layer **114** is formed on buffer layer **113** on a substrate **112**. An AlGaN barrier layer **116** is formed on the GaN channel layer **114**. A source electrode **118** and a drain electrode **120** form ohmic contacts through the surface of the AlGaN layer **116** to the electron layer that is present at the top of the GaN channel layer **114**. In a conventional AlGaN/GaN HEMT, a gate electrode **122** forms a non-ohmic contact to the surface of the AlGaN layer **116**.

Because of the presence of aluminum in the crystal lattice, AlGaN has a wider bandgap than GaN. Thus, the interface between the GaN channel layer **114** and the AlGaN barrier layer **116** forms a heterostructure. **Figure 2** is a band diagram showing the energy levels in the device along a portion of section A-A' of **Figure 1**. As illustrated in **Figure 2**, the conduction and valence bands Ec and Ev in the AlGaN barrier layer **116** are distorted due to polarization effects. Consequently, a two dimensional electron gas (2DEG) sheet charge region **115** is induced at the heterojunction between the GaN channel layer **114** and the AlGaN barrier layer **116**, while the AlGaN barrier layer **116** is depleted of mobile carriers due to the shape of the conduction band. As shown in **Figure 2**, the conduction band Ec dips below the Fermi level (Ef) in the area of the GaN channel layer **114** that is immediately adjacent to AlGaN barrier layer **116**.

Electrons in the 2DEG sheet charge region **115** demonstrate high carrier mobility. The conductivity of this region is modulated by applying a voltage to the gate electrode **122**. When a reverse voltage is applied, the conduction band in the vicinity of the sheet charge region **115** is elevated above the Fermi level, and a portion of the sheet charge region **115** is depleted of carriers, thereby preventing the flow of current from source **118** to drain **120**.

As illustrated in **Figure 1**, AlGaN/GaN HEMTs have typically been fabricated with coplanar metal contacts. That is, the ohmic contacts for the source **118** and drain **120** electrodes are on the same epitaxial layer (namely, the AlGaN layer **116**) as the gate electrode **122**. Given that ohmic contacts are intended to provide low resistance, non-rectifying contacts to a material, while the gate contact is intended to be a non-ohmic contact that blocks current at large reverse voltages, forming all three contacts on the same epitaxial layer may result in compromises between these characteristics. Stated another way, in a conventional AlGaN/GaN HEMT device, there is a tradeoff in device design when selecting the doping and composition of the AlGaN barrier layer **116** between optimizing the source and drain ohmic contacts on one hand and optimizing the non-ohmic gate contact on the other hand.

In addition, consideration should be given to providing as much current-carrying capability as possible to the sheet charge region **115** under the gate electrode **122**, again, while allowing the gate to block at as high a voltage as possible. Thus, it may be advantageous to have differences in the regions between the source and gate, under the gate, and between the gate and drain in order to modify the amount of band-bending and, thus, the amount of charge. Modifying band-bending will change the amount of charge in the sheet charge region **115** as well as the electric fields present within the device.

In conventional Gallium Arsenide (GaAs) and Indium Phosphorous (InP-based) HEMT devices, an additional GaAs or Indium Gallium Arsenide (InGaAs) layer is formed on the surface of the barrier layer. Source and drain contacts are made to the additional layer, while the gate electrode is recessed down to the barrier layer. This approach, however, may not be suitable for AlGaN/GaN HEMT structures, because the top surface of GaN is generally not conductive, and there is no benefit to recessing the gate down to the barrier layer.

Thus, there is the need in the art for improvements in AlGaN/GaN HEMT structures and methods of fabricating AlGaN/GaN HEMTs.

Summary of the Invention

Embodiments of the present invention provide high electron mobility transistors (HEMTs) and methods of fabricating HEMTs. Devices according to embodiments of the present invention include a gallium nitride (GaN) channel layer and an aluminum gallium nitride (AlGaN) barrier layer on the channel layer. A first ohmic contact is provided on the barrier layer to provide a source electrode and a second ohmic contact is also provided on the barrier layer and is spaced apart from the source electrode to provide a drain electrode. A cap segment is provided on the barrier layer between the source electrode and the drain electrode. The cap segment has a first sidewall adjacent and spaced apart from the source electrode. The cap segment may also have a second sidewall adjacent and spaced apart from the drain electrode. A non-ohmic contact is provided on the cap segment to provide a gate contact. The gate contact has a first sidewall which is substantially aligned with the first sidewall of the cap segment. The gate contact extends only a portion of the distance between the first sidewall and the second sidewall of the cap segment. In particular embodiments, the cap segment is a GaN cap segment.

In further embodiments of the present invention, the non-ohmic contact extends to, but not past, the first sidewall of the GaN cap segment. The GaN cap segment may have a thickness of from about 10 to about 60 Å. The GaN cap segment may also be undoped GaN.

In particular embodiments of the present invention, the source electrode and the drain electrode are spaced apart a distance of from about 2 to about 4 μm. Furthermore, the first sidewall of the GaN cap segment is preferably as close a possible and may, for example, be from about 0 to about 2 μm from the source electrode. The second sidewall of the GaN cap segment may be from about 0.5 to about 1 μm from the gate electrode.

In additional embodiments of the present invention, the AlGaN barrier layer is between about 15% and about 40% aluminum. The AlGaN barrier layer may also be doped with silicon at a concentration of up to about $4\text{x}10^{18}$ cm^{-3} or higher an preferably provides a total sheet concentration of up to about $5\text{x}10^{12}$ cm^{-2} and may have a thickness of from about 15 to about 40 nm and, preferably, about 25 nm.

In still further embodiments of the present invention, the GaN channel layer is provided on a substrate. The substrate may be silicon carbide, sapphire or the like. In particular embodiments, the substrate is 4H silicon carbide or 6H silicon carbide. Furthermore, a GaN buffer layer may be disposed between the GaN channel layer and the substrate.

In yet additional embodiments of the present invention, the gate electrode is a T-shaped gate electrode.

In method embodiments of the present invention, methods of fabricating a high electron mobility transistor (HEMT) is provided by forming a first gallium nitride (GaN) layer on a substrate, forming an aluminum gallium nitride (AlGaN) layer on the first GaN layer. A second GaN layer is patterned on the AlGaN layer to provide a GaN segment on the AlGaN layer and to expose portions of the AlGaN layer. A first ohmic contact is formed to the AlGaN layer adjacent and spaced apart from the GaN segment to provide a source electrode and a second ohmic contact is formed to the AlGaN layer adjacent and spaced apart from the GaN segment and opposite first ohmic contact such that the GaN segment is disposed between the first ohmic contact and the second ohmic contact to provide a drain electrode. A non-ohmic contact is patterned on the GaN segment to provide a gate contact. The gate contact has a first sidewall which is substantially aligned with the a first sidewall of the GaN segment adjacent the source contact. The gate contact extends only a portion of the distance between the first sidewall and a second sidewall of the GaN segment adjacent the drain contact.

In further embodiments of the present invention, the patterning of the second GaN layer and the patterning the non-ohmic contact may be provided by forming a second GaN layer on the AlGaN layer, forming a non-ohmic contact on the second GaN layer and patterning the non-ohmic contact and the second GaN layer to provide the GaN segment and the gate contact. Such patterning may further be provided by forming a mask that covers portions of the non-ohmic contact and the second GaN layer so as to define a sidewall of the non-ohmic contact and the GaN segment adjacent the source contact and a sidewall of the GaN segment adjacent the drain contact and etching the non-ohmic contact and the second GaN layer to expose portions of the AlGaN layer.

Brief Description of the Drawings

Figure 1 is a cross sectional illustration of a conventional AlGaN/GaN HEMT device;

Figure 2 is a schematic illustration of the band energies present in a conventional AlGaN/GaN HEMT device;

Figure 3 is a cross sectional illustration of an AlGaN/GaN HEMT device according to embodiments of the present invention;

Figures 4A through **4C** illustrate aspects of a method of fabricating a device according to embodiments of the present invention;

Figures 5A and **5B** illustrate potential gate electrode misalignment; and

Figures 6A through **6C** illustrate aspects of a method of fabricating a device according to additional embodiments of the present invention.

Detailed Description of the Invention

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. As illustrated in the Figures, the sizes of layers or regions are exaggerated for illustrative purposes and, thus, are provided to illustrate the general structures or the present invention. Like numbers refer to like elements throughout. It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

As described above, it is well known that large electron concentrations may appear at buried AlGaN/GaN interfaces under equilibrium conditions. These large electron concentrations may form a high carrier mobility two-dimensional electron gas (2DEG) which may be advantageously exploited in a HEMT device structure. Moreover, the addition of a GaN cap on the AlGaN barrier layer of such a structure can increase the size of the barrier to electron conduction to or from the top surface of the structure. However, the presence of the GaN cap may decrease the electron concentration in the 2DEG conduction layer assuming that the surface potential is the same in both cases (*i.e.* with or without the cap).

Although it has been suggested by Yu *et al.* that HEMT's may be fabricated on GaN/AlGaN/GaN structures, the improvement in gate performance in such a structure appears to be offset by increases in channel resistance due to lower carrier concentration in the conduction layer under the GaN cap. *See* E. T. Yu, *et al.*, "Schottky barrier engineering in III-V nitrides via the piezoelectric effect," Appl. Phys. Lett. 73, 1880 (1998).

Embodiments of the present invention provide improved AlGaN/GaN HEMT devices and methods of fabricating such devices. In particular embodiments of the present invention, the trade-offs between low-resistance source and drain contacts, current flow through the device, and blocking capability of the gate contact may be reduced or avoided by providing a GaN cap segment on the AlGaN barrier layer and providing a non-ohmic contact on the cap segment to provide the gate contact. In further embodiments, the gate contact and cap segment are arranged so as to provide an AlGaN/GaN HEMT structure with reduced internal electric fields, which may result in higher operating voltages and power levels. Thus, embodiments of the present invention may provide the benefits of low contact resistance found in AlGaN/GaN HEMT structures with the gate performance improvements associated with GaN/AlGaN/GaN structures.

Figure 3 illustrates a device **11** according to embodiments of the present invention. The device **11** includes a substrate **12** and an optional buffer layer **13** on the substrate **12**. The substrate **12** may be silicon carbide, sapphire, silicon, bulk gallium nitride or any other suitable substrate for supporting nitride-based electronic devices. Preferably, the substrate is semi-insulating 4H-silicon carbide (0001) or 6H-SiC (0001). For substrates other than bulk GaN, the optional buffer layer **13** provides a surface on which high-quality gallium nitride may be grown. The composition and fabrication of the buffer layer **13** may depend on the type of substrate used. Suitable buffer layers are well known in the art and need not be described further. A GaN channel layer **14** is also provided on the buffer layer **13** if the buffer layer **13** is present or on the substrate **12** if the buffer layer **13** is not present. The channel layer **14** and subsequent GaN-based layers may be formed by MOCVD, MBE, and/or any other suitable growth technique. The channel layer **14** is preferably undoped, but may be doped with various substances in order to modify the electron concentration in the sheet charge region **15** or the behavior of the conduction band Ec and valence band Ev in the area below the sheet charge region.

An AlGaN barrier layer **16** is provided on the GaN channel layer **14**, thereby forming a heterojunction **15** between the channel layer **14** and the barrier layer **16**. The AlGaN barrier layer **16** preferably has an aluminum composition of between 15% and 60% and may be doped with silicon at a doping concentration of up to about $4x10^{18}$ cm^{-3} to provide a total sheet concentration of up to about $5x10^{12}$ cm^{-2} or more. The barrier layer **16** may be between about 15 nm and 40 nm in thickness, and is preferably about 25 nm thick.

As described above, because of the AlGaN/GaN heterobarrier at the junction **15**, a two dimensional electron gas is formed within the vicinity of the junction **15**. Ohmic source **18** and drain **20** electrodes are provided on the surface of the AlGaN barrier layer **16**. Source **18** and drain **20** electrodes may be Ti/Si/Ni, Ti/Al/Ni or any other suitable material that forms an ohmic contact to n-type AlGaN. Appropriate ohmic contacts for AlGaN/GaN HEMT devices are described in S. T. Sheppard, W. L. Pribble, D. T. Emerson, Z. Ring, R. P. Smith, S. T. Allen and J. W. Palmour, "High Power Demonstration at 10 GHz with GaN/AlGaN HEMT Hybrid Amplifiers," Presented at the 58th Device Research Conference, Denver, CO June 2000, and S. T. Sheppard, K. Doverspike, M. Leonard, W. L. Pribble, S. T. Allen and J. W. Palmour, "Improved 10-GHz Operation of GaN/AlGaN HEMTs on Silicon Carbide," Mat. Sci. Forum, Vols. 338-342 (2000), pp. 1643-1646, the disclosures of which are incorporated herein by reference as if set forth fully herein. The distance between the source electrode **18** and the drain electrode **20** may, typically, be from about 2-4 μm.

As is further illustrated in **Figure 3**, a thin GaN-based cap segment **30**, preferably of GaN, is provided on the surface of the AlGaN layer **16** between the source electrode **18** and the drain electrode **20**. The cap segment **30** is preferably between about 10-60Å in thickness, and is preferably undoped. The cap segment **30** is preferably formed of gallium nitride, however, other suitable materials may also be utilized. For example, a graded or reduced aluminum content AlGaN layer may be utilized such that the percentage of aluminum decreases with distance from the channel layer. Such an AlGaN layer could be formed, for example, by etching, to provide the cap segment **30**. As used herein, the term GaN-based refers to a material having gallium and nitrogen and includes GaN and AlGaN.

The gate electrode **26** is provided on the cap segment **30**. The gate electrode **26** is preferably formed of platinum, nickel or any other suitable metal that forms a non-ohmic contact to n-type or "intrinsic" GaN. The gate electrode **26** may be capped with an additional metal layer in a T-shaped gate configuration, or, in particular embodiments, a T-shaped gate may be formed in one process step. A T-shaped gate configuration may be particularly suitable for RF and microwave devices.

Because of the polarization effects in GaN/AlGaN structures grown on the gallium or aluminum face of AlGaN or GaN, the barrier to conduction under the gate electrode **22** is greatly enhanced. Thus, gate leakage may be reduced or even minimized.

Preferably, the source-side sidewall **31** of the cap segment **30** is substantially aligned to the source-side sidewall **27** of the gate electrode **26**. Since the presence of the cap segment **30** may reduce the concentration of carriers in the 2DEG region **15** underneath it, it may be undesirable to have the cap segment **30** extend substantially between the source electrode **18** and the gate electrode **26**, since that may result in increased resistance. Thus, it is preferable to have the cap segment **30** be spaced apart from the source electrode **18** as small a distance as is reasonable in light of manufacturing limitations. Thus, a distance of from about 0 to about 2 μm may be suitable, for example, distances of from about 0.3 to about 1.5 μm may possible with conventional masking and fabrication techniques. Conversely, it may be advantageous to extend the drain-side sidewall **32** of the cap segment **30** past the drain-side sidewall **28** of the gate electrode **26** for a predetermined distance, preferably from about 0.5 to about 1 μm. Thus, the drain-side sidewall **32** of the cap segment **30** may extend to a distance of from about 0 to about 3 μm from the drain electrode **20**. In the event the distance from the drain-side sidewall **32** to the drain electrode **20** is 0 μm, there may be no drain-side sidewall **32** but the cap segment **30** may extend to under the drain electrode **20**. However, such may not be preferred. Thus, in preferred embodiments of the present invention, the distance from the drain-sidewall **32** to the drain electrode **20** be about 0.5 μm or greater.

The presence of the cap segment **30** underneath the gate electrode **26** need not adversely affect the operation of the device, since the gate bias can be adjusted to compensate for the effect of the cap segment **30** on carrier concentration in the 2DEG region **15** under the gate. In operation, electrons flow from the source electrode **18** to the drain electrode **20** through the 2DEG region **15**. While not being bound by any particular theory of operation, it is believed that the presence of the cap segment **30** over the 2DEG region between the gate electrode **22** and the drain electrode **20** does not adversely affect the operation of the device because the conductivity of the device is not dominated by the equilibrium electron concentration in the portion of the 2DEG region **15** between the gate electrode **22** and the drain electrode **20**. In fact, extending the cap segment **30** past the drain-side sidewall **28** of the gate electrode **26** for a predetermined distance may improve device performance by reducing internal electric fields in the device, thus permitting operation at higher voltages and power levels. Breakdown voltages in FETs are limited by the maximum internal electric field which normally occurs on the drain-side of the gate contact and can induce avalanche and other unwanted currents through the gate. Extending the cap segment towards the drain reduces the total amount of charge under that cap that results from polarization effects. Solving Poisson's equation for such a transistor shows that a transistor with less charge in the region under the gate and towards the drain can be operated at a higher bias for a given assumed maximum permissible electric field.

While **Figure 3** illustrates embodiments of the present invention as discrete devices, as will be appreciated by those of skill in the art, **Figure 3** may be considered unit cells of devices having multiple cells. Thus, for example, additional unit cells may be incorporated into the devices illustrated in **Figures 3** by mirroring the device about a vertical axis at the periphery of the device illustrated in **Figure 3** (the vertical edges of the devices illustrated in **Figures 3**). Accordingly, embodiments of the present invention include devices such as those illustrated in **Figures 3** as well as devices having a plurality of unit cells incorporating the cap segment and gate contact illustrated in **Figure** 3.

A method for manufacturing an AlGaN/GaN HEMT according to the present invention which utilizes a GaN cap segment is illustrated in **Figures 4A** through **4C** and, optionally, includes forming a buffer layer **13** on a substrate **12**. A GaN channel layer **14** is formed on the buffer layer **13** and an AlGaN barrier layer **16** is formed on the channel layer. A thin GaN cap layer **30'** is formed on the barrier layer **16**. The layers may be formed by MOCVD, MBE and/or any other suitable method known to those of skill in the art.

The GaN cap layer **30'** is patterned to provide the GaN cap segment **30** for the gate electrode. For example, as illustrated in **Figure 4A**, an etch mask **40** may be formed on the GaN cap layer **30'**, and portions of the GaN cap layer **30'** removed, for example, by using a conventional etch process, to the barrier layer **16**, leaving the GaN cap segment **30** as illustrated in **Figure 4B**. However, other techniques, such as selective epitaxial growth may also be used.

As shown in **Figure 4C**, the source electrode **18** and drain electrode **20** are formed on the exposed portions of the barrier layer **16** using conventional techniques. A gate electrode **22** is formed on the GaN segment **30**. In the embodiments shown in **Figures 4A** through **4C**, the source-side sidewall of the gate contact is aligned with the source-side sidewall of the GaN cap segment **30** using conventional photolithographic techniques and mask alignment tools. In the embodiments illustrated in **Figures 4A** through **4C**, the gate electrode **22** is not self-aligned to the source-side sidewall of the GaN cap segment **30**. Therefore, it is possible that the gate electrode **22** may be misaligned to the source-side or the drain side, as shown in **Figures 5A** and **5B**, respectively. Although slight misalignment may not adversely affect the operation of the device, severe misalignment may be detrimental to the device. Thus, it is preferred that the source-side sidewall of the gate electrode **22** be aligned with the source-side of the GaN cap segment **30** as illustrated in **Figure 4C**, however, the source-side sidewall of the gate electrode **22** may only be substantially aligned with the source-side sidewall of the GaN cap segment **30** as illustrated in **Figures 5A** and **5B** and still benefit from the teachings of the present invention. Thus, as used herein, the term substantial alignment or substantially aligned refers to a range of alignments which may include misalignment.

Another method for manufacturing a device according to embodiments of the present invention is illustrated in **Figures 6A** through **6C**. In these embodiments, the source-side sidewall of the GaN cap segment **30** is self-aligned to the source-side sidewall of the gate electrode **22**.

Referring to **Figure 6A**, optionally, the buffer layer **13** is formed on a substrate **12**. The GaN channel layer **14** is formed on the GaN buffer layer **13** or the substrate **12** and the AlGaN barrier layer **16** is formed on the GaN channel layer **14**. The thin GaN cap layer **30'** is formed on the AlGaN barrier layer **16** as described above. A gate metal **22'** is formed on the GaN cap layer **30'** and the gate metal **22'** is partially patterned so as to provide the drain-side sidewall of the gate electrode **22** and to provide a portion of the gate metal **22'** which extends past the source-side sidewall of the gate electrode **22**. An etch mask **44** is deposited on the GaN cap layer **30'** which partially overlaps the gate metal **22'** so as to define the source-side sidewall of the gate electrode **22** and the GaN cap segment **30** and the drain-side sidewall of the GaN cap segment **30**.

As illustrated in **Figure 6B**, the exposed portion of the GaN cap layer **30'** is etched away, leaving one sidewall of the GaN cap segment **30** self-aligned with a sidewall of gate electrode **22** and to expose portions of the AlGaN barrier layer **16**. The mask **44** is afterward removed. As illustrated in **Figure 6C**, the source electrode **18** and the drain electrode **20** are then formed on the exposed portions of the AlGaN barrier layer **16**, and the remainder of the device is processed in a conventional fashion.

While embodiments of the present invention have been described with reference to particular sequences of operations, as will be appreciated by those of skill in the art, certain operations within the sequence may be reordered while still benefiting from the teachings of the present invention. Furthermore, certain operations may be combined into a single operation or separated into multiple operations while still benefiting from the teachings of the present invention. Accordingly, the present invention should not be construed as limited to the exact sequence of operations described herein.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

That which is claimed is:

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

a gallium nitride (GaN) channel layer;

an aluminum gallium nitride (AlGaN) barrier layer on the channel layer;

a first ohmic contact on the barrier layer to provide a source electrode;

a second ohmic contact on the barrier layer and spaced apart from the source electrode to provide a drain electrode;

a GaN-based cap segment on the barrier layer between the source electrode and the drain electrode, the GaN-based cap segment having a lower concentration of aluminum than the barrier layer and having a first sidewall adjacent and spaced apart from the source electrode; and

a non-ohmic contact on the GaN cap segment to provide a gate contact, the gate contact having a first sidewall which is substantially aligned with the first sidewall of the GaN cap segment and the gate contact extending only a portion of a distance between the first sidewall and the second sidewall of the GaN cap segment.

2. A HEMT according to Claim 1, wherein the GaN based cap segment has a second sidewall adjacent and spaced apart from the drain electrode.

3. A HEMT according to Claim 1, wherein the GaN based cap segment comprises a GaN cap segment.

4. A HEMT according to Claim 3, wherein the non-ohmic contact extends to, but not past, the first sidewall of the GaN cap segment.

5. A HEMT according to Claim 3, wherein the GaN cap segment has a thickness of from about 10 to about 60 Å.

6. HEMT according to Claim 5, wherein the GaN cap segment comprises undoped GaN.

7. HEMT according to Claim 2 wherein the source electrode and the drain electrode are spaced apart a distance of from about 2 to about 4 μm.

8. A HEMT according to Claim 3 wherein the first sidewall of the GaN cap segment is less than about 2 μm from the source electrode.

9. HEMT according to Claim 8, wherein the first sidewall of the GaN cap segment is from about 0.3 to about 1.5 μm from the source electrode.

10. A HEMT according to Claim 2, wherein the second sidewall of the GaN cap segment is from about 0.5 to about 1 μm from the gate electrode.

11. A HEMT according to Claim 3, wherein the AlGaN barrier layer comprises between about 15% and about 60% aluminum.

12. A HEMT according to Claim 11, wherein the AlGaN barrier layer is doped with silicon to provide a total sheet concentration of up to about 5×10^{12} cm^{-2}.

13. A HEMT according to Claim 11, wherein the AlGaN barrier layer has a thickness of from about 15 to about 40 nm.

14. A HEMT according to Claim 13 wherein the AlGaN barrier layer has a thickness of about 25 nm.

15. A HEMT according to Claim 3, further comprising a substrate, and wherein the GaN channel layer is on the substrate.

16. A HEMT according to Claim 15, wherein the substrate comprises silicon carbide.

17. A HEMT according to Claim 15, wherein the substrate comprises sapphire.

18. A HEMT according to Claim 15, wherein the substrate comprises at least one of 4H silicon carbide and 6H silicon carbide.

19. A HEMT according to Claim 15, further comprising a GaN buffer layer disposed between the GaN channel layer and the substrate.

20. A HEMT according to Claim 1, wherein the gate electrode comprises a T-shaped gate electrode.

21. A method of fabricating a high electron mobility transistor (HEMT), comprising:

forming a first gallium nitride (GaN) layer on a substrate;

forming an aluminum gallium nitride (AlGaN) layer on the first GaN layer;

forming a GaN-based segment on the AlGaN layer, the GaN-based segment having an aluminum concentration of less than the AlGaN layer;

forming a first ohmic contact to the AlGaN layer adjacent and spaced apart from the GaN segment to provide a source electrode;

forming a second ohmic contact to the AlGaN layer adjacent and spaced apart from the GaN segment and opposite first ohmic contact such that the GaN segment is disposed between the first ohmic contact and the second ohmic contact to provide a drain electrode; and

forming a non-ohmic contact on the GaN segment to provide a gate contact, the gate contact having a first sidewall which is substantially aligned with the a first sidewall of the GaN segment adjacent the source contact and the gate contact extending only a portion of a distance between the first sidewall the second ohmic contact.

22. A method according to Claim 21, wherein the non-ohmic contact extends only a portion of a distance between the first sidewall and a second sidewall of the GaN segment adjacent the drain contact.

23. A method according to Claim 22, wherein forming a GaN-based segment comprises forming a GaN segment on the AlGaN layer.

24. A method according to Claim 23, wherein the forming a GaN segment and forming a non-ohmic contact comprises:

forming a second GaN layer on the AlGaN layer;

forming a non-ohmic contact on the second GaN layer;

patterning the non-ohmic contact and the second GaN layer to provide the GaN segment and the gate contact.

25. A method according to Claim 24, wherein patterning the non-ohmic contact and the second GaN layer comprises:

forming a mask layer on the non-ohmic contact and the second GaN layer so that the mask covers portions of the non-ohmic contact and the second GaN layer so as to define a sidewall of the non-ohmic contact and the GaN segment adjacent the source contact and a sidewall of the GaN segment adjacent the drain contact;

etching the non-ohmic contact and the second GaN layer to expose portions of the AlGaN layer.

26. A method according to Claim 23, wherein the GaN segment is formed to a thickness of from about 10 to about 60 Å.

27. A method according to Claim 26, wherein the GaN segment comprises undoped GaN.

28. A method according to Claim 23, wherein forming a first ohmic contact and forming a second ohmic contact comprises forming a first ohmic contact and a second ohmic contact which are spaced apart a distance of from about 2 to about 4 μm.

29. A method according to Claim 23, wherein the first ohmic contact is formed a distance of less than about 2 μm from the GaN segment.

30. A method according to Claim 29, wherein the first ohmic contact is formed a distance of from about 0.3 to about 1.5 μm from the GaN segment.

31. A method according to Claim 23, wherein the non-ohmic contact is patterned so that a sidewall of the non-ohmic contact is from about 0.5 to about 1 μm from the second sidewall of the GaN segment.

32. A method according to Claim 23, wherein forming an AlGaN layer comprises forming an AlGaN layer having between about 15% and about 60% aluminum.

33. A method according to Claim 32, wherein forming an AlGaN layer comprises forming an AlGaN layer doped with silicon to provide a total sheet concentration of up to about 5×10^{12} cm^{-2}.

34. A method according to Claim 32, wherein forming an AlGaN layer further comprises forming an AlGaN layer to a thickness of from about 15 to about 40 nm.

35. A method according to Claim 34, wherein forming an AlGaN layer comprises forming an AlGaN layer to a thickness of about 25 nm.

36. A method according to Claim 23, wherein the substrate comprises silicon carbide.

37. A method according to Claim 23, wherein the substrate comprises sapphire.

38. A method according to Claim 23, wherein the substrate comprises at least one of 4H silicon carbide and 6H silicon carbide.

39. A method according to Claim 23, further comprising forming a third GaN layer disposed between the first GaN layer and the substrate.

40. A method according to Claim 23, further comprising forming a metallization layer on the non-ohmic contact to provide a T-shaped gate.

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

a gallium nitride (GaN) channel layer;

an aluminum gallium nitride (AlGaN) barrier layer;

ohmic contacts on the AlGaN barrier layer to provide source and drain contacts;

a non-ohmic gate contact disposed between the source and drain contacts; and

means, operably associated with the non-ohmic gate contact and the AlGaN barrier layer, for reducing a resistance of the ohmic contacts and increasing a blocking voltage of the gate contact as compared to a device without the means for reducing a resistance of the ohmic contacts and increasing a blocking voltage of the gate contact.

42. A HEMT according to Claim 41, wherein the means for reducing a resistance of the ohmic contacts and increasing a blocking voltage of the gate contact comprises a segment of GaN between the gate contact and the AlGaN barrier layer, the segment of GaN having the gate contact on a portion of the segment of GaN adjacent the source contact and the segment of GaN extending past the gate contact toward the drain contact.

43. A HEMT according to Claim 42, wherein the gate contact extends to but not past a sidewall of the segment of GaN adjacent but spaced apart from the source electrode.

44. A HEMT according to Claim 42, wherein the segment of GaN extends a distance of from about 0.5 to about 1 μm.

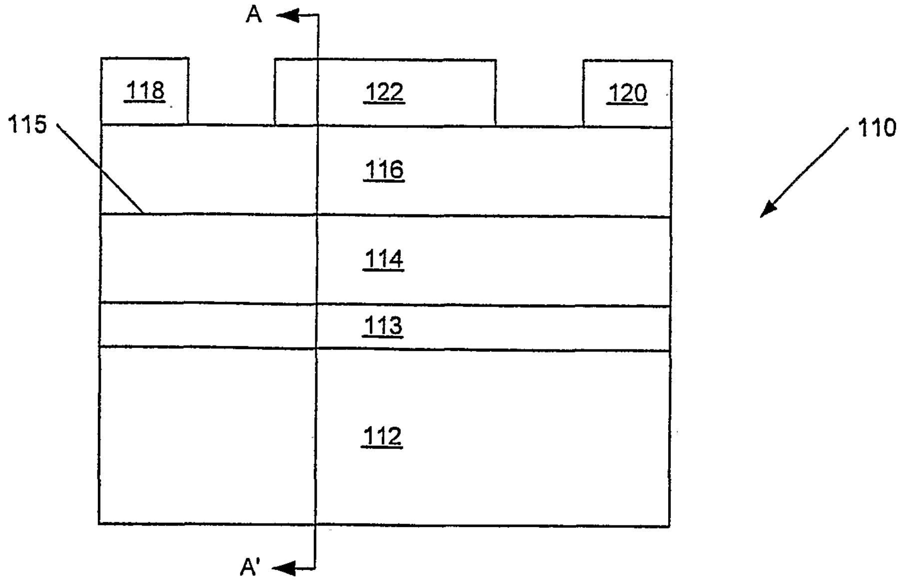

Figure 1
(PRIOR ART)

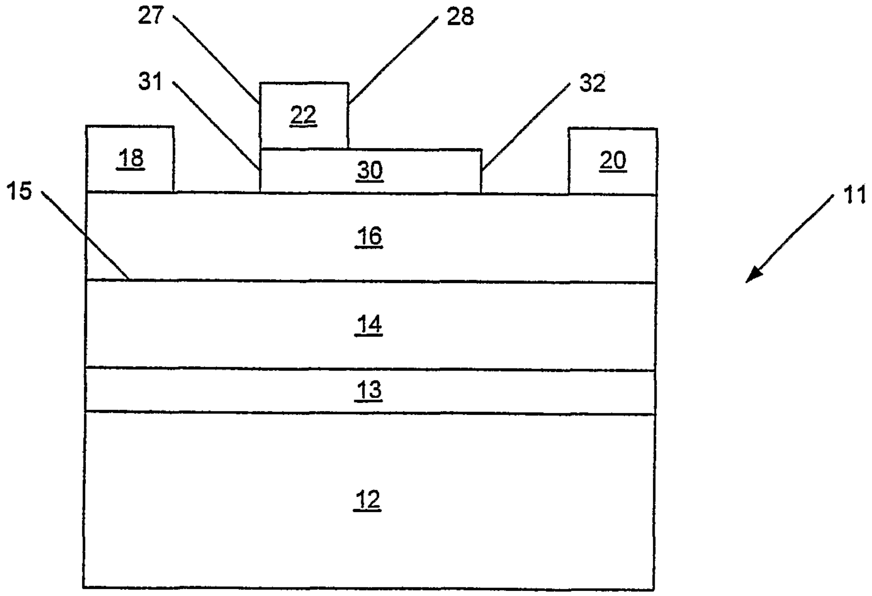

Figure 3

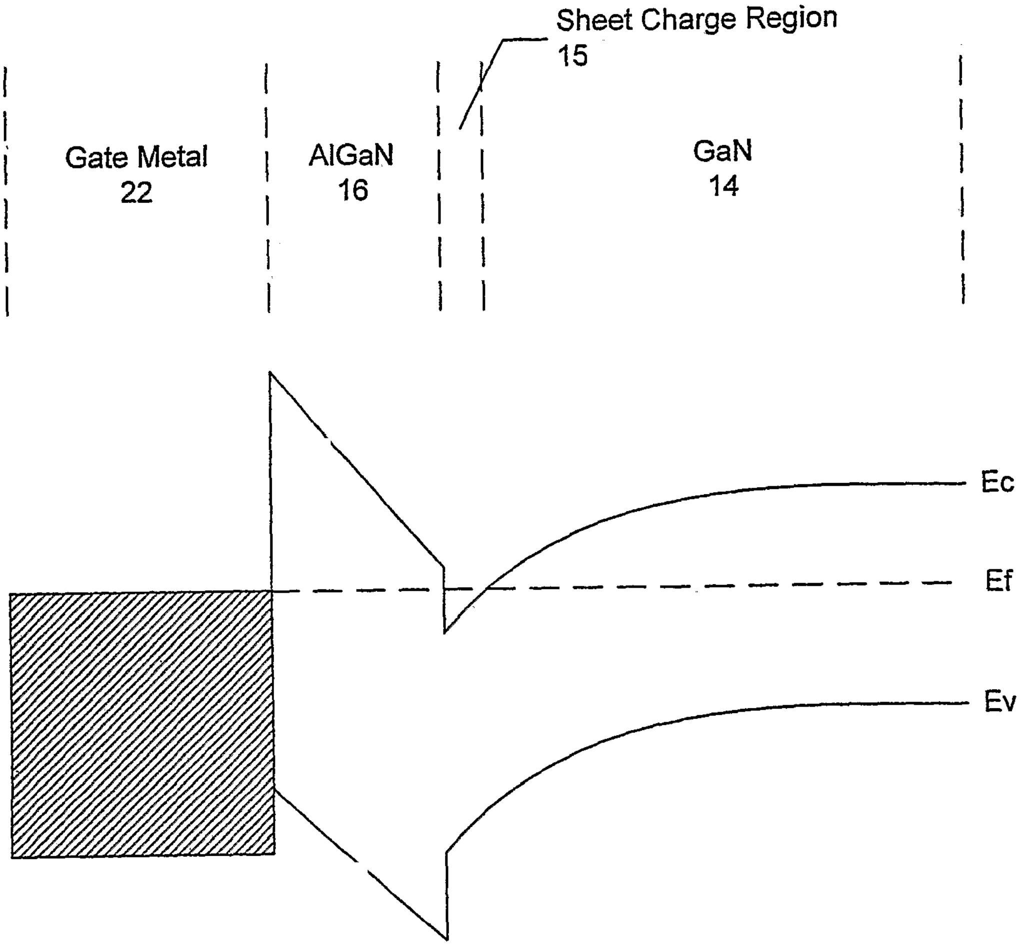

Figure 2

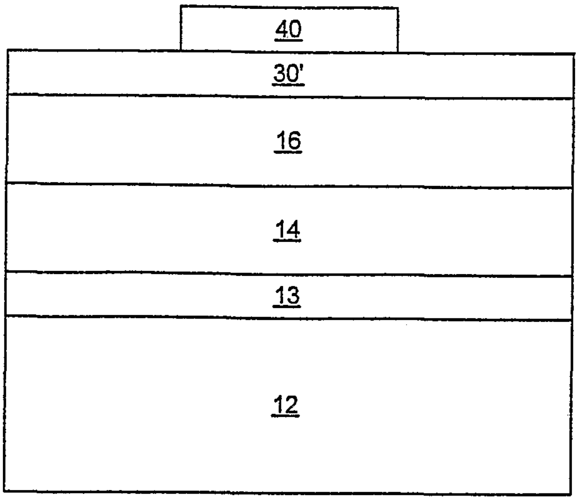

Figure 4A

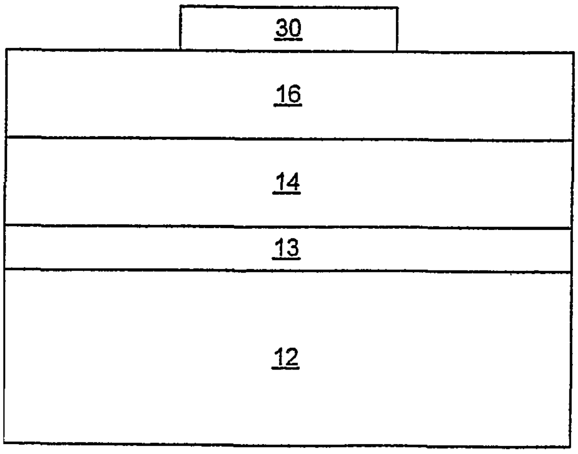

Figure 4B

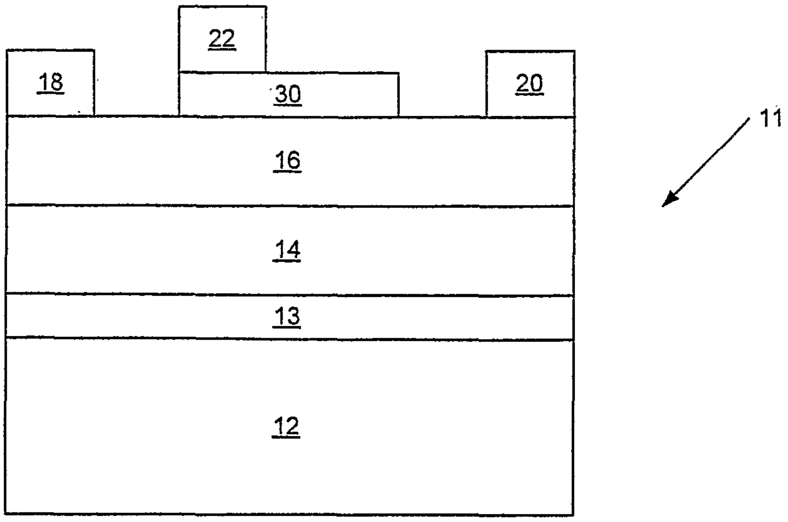

Figure 4C

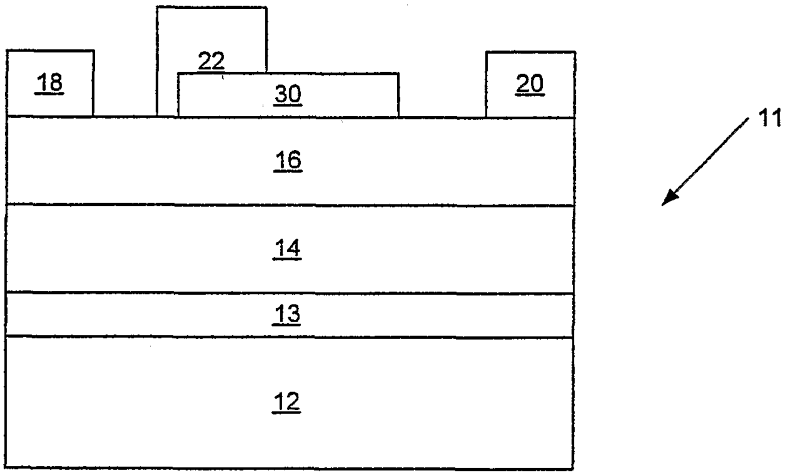

Figure 5A

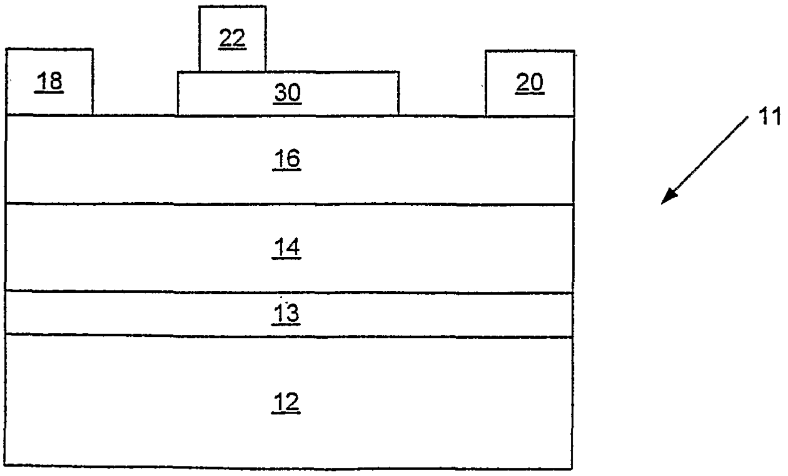

Figure 5B

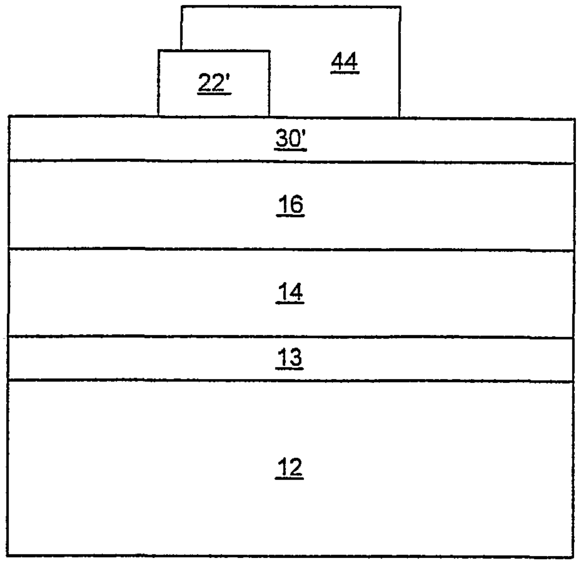

Figure 6A

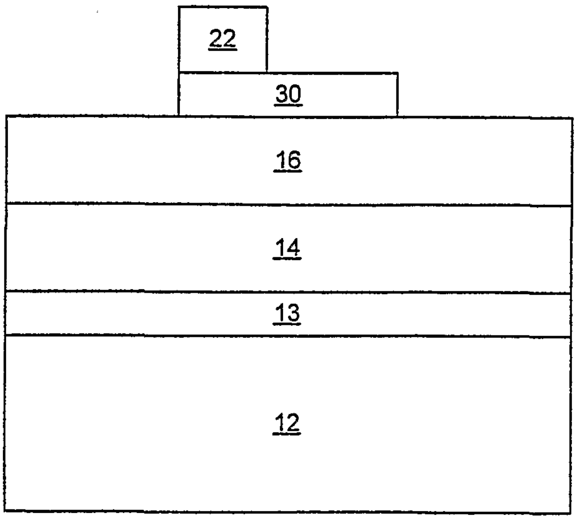

Figure 6B

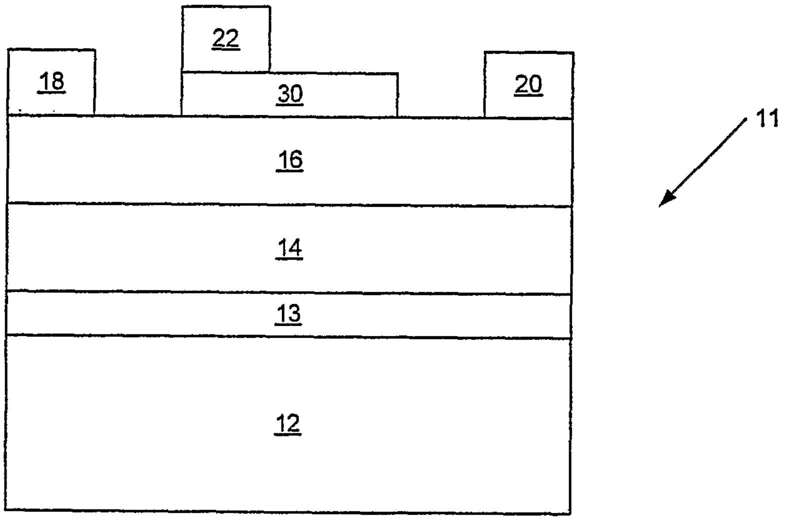

Figure 6C