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(54) TECHNIQUE FOR THE GROWTH OF PLANAR SEMI-POLAR GALLIUM NITRIDE

VERFAHREN FÜR DAS WACHSTUM VON PLANAREM HALBPOLAREM GALLIUMNITRID

TECHNIQUE POUR LA CROISSANCE DE NITRURE DE GALLIUM PLANAIRE SEMI-POLAIRE

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- **JIN SOO HWANG, ALEXANDER V. KUZNETSOV, SUN SOOK LEE, HYANG SOOK KIM, JOONG GILL CHOI, PAUL JOE CHONG: "Heteroepitaxy of gallium nitride on (0001), (-1012) and (10-10) sapphire surfaces" JOURNAL OF CRYSTAL GROWTH, vol. 142, 1 September 1994 (1994-09-01), pages 5-14, XP002509067**
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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention.

[0001] The present invention relates to a technique for the growth of planar semi-polar gallium nitride.

2. Description of the Related Art.

[0002] The usefulness of gallium nitride (GaN), and its ternary and quaternary compounds incorporating aluminum and indium (AlGaN, InGaN, AlInGaN), has been well established for fabrication of visible and ultraviolet optoelectronic devices and high-power electronic devices. These devices are typically grown epitaxially using growth techniques including molecular beam epitaxy (MBE), metalorganic chemical vapor deposition (MOCVD), and hydride vapor phase epitaxy (HVPE).

[0003] GaN and its alloys are most stable in the hexagonal würtzite crystal structure, in which the structure is described by two (or three) equivalent basal plane axes that are rotated 120° with respect to each other (the a-axes), all of which are perpendicular to a unique c-axis. Group III and nitrogen atoms occupy alternating c-planes along the crystal's c-axis. The symmetry elements included in the würtzite structure dictate that III-nitrides possess a bulk spontaneous polarization along this c-axis, and the würtzite structure exhibits piezoelectric polarization.

[0004] Current nitride technology for electronic and optoelectronic devices employs nitride films grown along the polar c-direction. However, conventional c-plane quantum well structures in III-nitride based optoelectronic and electronic devices suffer from the undesirable quantum-confined Stark effect (QCSE), due to the existence of strong piezoelectric and spontaneous polarizations. The strong built-in electric fields along the c-direction cause spatial separation of electrons and holes that in turn give rise to restricted carrier recombination efficiency, reduced oscillator strength, and red-shifted emission.

[0005] One approach to eliminating the spontaneous and piezoelectric polarization effects in GaN optoelectronic devices is to grow the devices on non-polar planes of the crystal. Such planes contain equal numbers of Ga and N atoms and are charge-neutral. Furthermore, subsequent non-polar layers are equivalent to one another so the bulk crystal will not be polarized along the growth direction. Two such families of symmetry-equivalent non-polar planes in GaN are the {1120} family, known collectively as a-planes, and the {1100} family, known collectively as m-planes. Unfortunately, despite advances made by researchers at the University of California, for example, as described in the applications cross-referenced above, growth of non-polar GaN remains challenging and has not yet been widely adopted in the III-nitride industry.

[0006] Another approach to reducing or possibly eliminating the polarization effects in GaN optoelectronic devices is to grow the devices on semi-polar planes of the crystal. The term "semi-polar planes" can be used to refer to a wide variety of planes that possess both two nonzero h, i, or k Miller indices and a nonzero 1 Miller index. Some commonly observed examples of semi-polar planes in c-plane GaN heteroepitaxy include the {1122}, {1011}, and {1013} planes, which are found in the facets of pits. These planes also happen to be the same planes that the inventors have grown in the form of planar films. Other examples of semi-polar planes in the wurtzite crystal structure include, but are not limited to, $\{10\bar{1}2\}$, $\{20\bar{2}1\}$, and {1014}. The nitride crystal's polarization vector lies neither within such planes or normal to such planes, but rather lies at some angle inclined relative to the plane's surface normal. For example, the $\{10\bar{1}1\}$ and $\{10\bar{1}3\}$ planes are at 62.98° and 32.06° to the c-plane, respectively.

[0007] The other cause of polarization is piezoelectric polarization. This occurs when the material experiences a compressive or tensile strain, as can occur when (Al, In, Ga, B)N layers of dissimilar composition (and therefore different lattice constants) are grown in a nitride heterostructure. For example, a thin AlGaN layer on a GaN template will have in-plane tensile strain, and a thin InGaN layer on a GaN template will have in-plane compressive strain, both due to lattice matching to the GaN. Therefore, for an InGaN quantum well on GaN, the piezoelectric polarization will point in the opposite direction than that of the spontaneous polarization of the InGaN and GaN. For an AlGaN layer latticed matched to GaN, the piezoelectric polarization will point in the same direction as that of the spontaneous polarization of the AlGaN and GaN.

[0008] The advantage of using semi-polar planes over c-plane nitrides is that the total polarization will be reduced. There may even be zero polarization for specific alloy compositions on specific planes. Such scenarios will be discussed in detail in future scientific papers. The important point is that the polarization will be reduced compared to that of c-plane nitride structures.

[0009] Bulk crystals of GaN are not available, so it is not possible to simply cut a crystal to present a surface for subsequent device regrowth. Commonly, GaN films are initially grown heteroepitaxially, i.e. on foreign substrates that provide a reasonable lattice match to GaN.

[0010] Semi-polar GaN planes have been demonstrated on the sidewalls of patterned c-plane oriented stripes. Nishizuka et al. have grown $\{11\bar{2}2\}$ InGaN quantum wells by this technique. (See Nishizuka, K., Applied Physics Letters, Vol. 85, No. 15, 11 October 2004.) They have also demonstrated that the internal quantum efficiency of the semi-polar plane {1122} is higher than that of the c-plane, which results from the reduced polarization.

[0011] However, this method of producing semi-polar planes is drastically different than that of the present invention; it is an artifact from epitaxial lateral overgrowth

(ELO). ELO is used to reduce defects in GaN and other semiconductors. It involves patterning stripes of a mask material, often SiO_2 for GaN. The GaN is grown from open windows between the mask and then grown over the mask. To form a continuous firm, the GaN is then coalesced by lateral growth. The facets of these stripes can be controlled by the growth parameters. If the growth is stopped before the stripes coalesce, then a small area of semi-polar plane can be exposed. The surface area may be 10 μm wide at best. Moreover, the semi-polar plane will be not parallel to the substrate surface. In addition, the surface area is too small to process into a semi-polar LED. Furthermore, forming device structures on inclined facets is significantly more difficult than forming those structures on normal planes.

[0012] A. TEMPEL, W. SEIFERT, J. HAMMER, E. BUTTER: "Zur epitaxie von Galliumnitrid auf nichtstöchiometrischem Spinell im system GaCI/NH3/He" KRISTALL UND TECHNIK, vol. 10, 1975, pages 747-758, discloses a method to grow epitaxially GaN {10-11} film on a {100} oriented spinel substrate. This method consists first in nitriding the substrate by flowing NH_3 at 1000°C upon the substrate and then in reacting a GaCl gas with NH_3 upon a spinel substrate to form GaN. Additionally, the growth occurs preferably along the <110> direction of the substrate.

[0013] JIN SOO HWANG, ALEXANDER V. KUZNETSOV, SUN SOOK LEE, HYANG SOOK KIM, JOONG GILL CHOI, PAUL JOE CHONG: "Heteroepitaxy of gallium nitride on (0001), (-1012) and (10-10) sapphire surfaces" JOURNAL OF CRYSTAL GROWTH, vol. 142, 1 September 1994 (1994-09-01), pages 5-14, discloses a method to grow epitaxially GaN {10-13} or {1-212} film on a {10-10} oriented sapphire substrate, the size of which is 10*15*1 mm^3.

[0014] EP-A-0 383215 discloses a wurtzite type Group III nitride, e.g. {10-13} GaN, epitaxially grown on a {10-10} oriented sapphire substrate as well as a group III mixed single crystal film grown on the substrate, an insulating film formed on the single crystal film and a metal electrode formed on the insulating film. A light emitting diode is disclosed comprising manufacturing steps of a n-type In_xGayAl_{1-x-y} N, an active layer of $In_xGa_yAl_{1-x-y}N$, i.e. quantum well, and a p-type $In_xGa_yAl_{1-x-y}N$, with x and x+y having values lying within 0 and 1.

[0015] J. BAUER, L. BISTE, D. BOLZE: "Optical properties of aluminium nitride prepared by chemical and plasmachemical vapour deposition" PHYSICA STATUS SOLIDI (A), vol. 39, 16 January 1977 (1977-01-16), pages 173-181, discloses that {0001} AlN can be deposited on {100} spinel substrate between 600°C-1000°C, but that at higher temperature another preferred orientation occurs, such as for GaN, having the {10-10} between 950°C and 1110°C.

[0016] US-B1-6 218 280 discloses a method and a device for producing large area single crystalline III-V nitride compounds semiconductor substrates with a composition of $In_xGayAl_{1-x-y}N$ by MOVPE and HVPE methods using for example spinel ($MgAl_2O_4$) substrate.

[0017] The present invention describes a technique for the growth of planar films of semi-polar nitrides, in which a large area of (Al, In, Ga)N is parallel to the substrate surface. For example, samples are often grown on 10 mm x 10 mm or 50 mm (2 inch) diameter substrates compared to the few micrometer wide areas previously demonstrated for the growth of semi-polar nitrides.

SUMMARY OF THE INVENTION

[0018] The present invention relates to a method of growing a planar, single crystal, semi-polar Gallium Nitride (GaN) film, comprising: (a) loading a substrate in a reactor, wherein the reactor is evacuated to remove oxygen, and then backfilled with nitrogen; (b) ramping a temperature of the reactor; (c) performing a gas flow of nitrogen, hydrogen, or ammonia over the substrate at atmospheric pressure; (d) reducing the reactor's pressure when the furnace reaches a growth temperature, wherein the reactor's pressure is reduced from atmospheric pressure when the furnace reaches the growth temperature; (e) growing GaN on a surface of a substrate, by hydride vapor phase epitaxy in the reactor, and flowing ammonia, and initiating a flow of hydrogen chloride (HCl) over gallium (Ga) to start the growth of the GaN, wherein: the growth temperature is between 900°C and 1200°C, and a pressure in the reactor is between 10 torr and 1000 torr; (f) cooling down the reactor after the growth of the GaN, wherein the HCl flow is stopped, and the reactor is cooled down while flowing ammonia to preserve the GaN; and (g) the growth surface of the planar, single crystal, semi-polar GaN film is parallel to the surface of the substrate, and the growth surface of the semi-polar GaN film has a surface area of at least 10 mm x 10 mm; wherein either (A) the substrate is sapphire and the surface is a $\{1\bar{1}00\}$ surface of the sapphire, and (i) only hydrogen and nitrogen are flowed during the temperature ramping step, and the substrate is then subjected to a high temperature nitridation with ammonia flow at the growth temperature, to obtain a planar, semi-polar GaN film that is $\{10\bar{1}3\}$ GaN, or (ii) ammonia is flowed while the furnace is ramping to the growth temperature, so that nitridation occurs at low temperature, to obtain the planar, single crystal, semi-polar GaN film that is $\{11\bar{2}2\}$ GaN; or (B) the substrate is a spinel substrate and the surface is a {110} surface of the spinel, and the ramping of the temperature is under conditions to encourage nitridization of the surface of the spinel, to obtain the planar, single crystal, semi-polar GaN film that is $\{10\bar{1}3\}$ GaN; or (C) the substrate is a spinel substrate and the surface is a {100} surface of the spinel miscut in a <011> direction, and the ramping of the temperature is under conditions to encourage nitridization of the surface of the spinel, to obtain a planar, single crystal, semi-polar GaN film that is $\{10\bar{1}1\}$ GaN.

[0019] Hereinafter is described a method for growing semi-polar nitrides as planar films, such as $\{10\bar{1}1\}$,

$\{10\bar{1}3\}$, and $\{11\bar{2}2\}$ planar films of GaN. Growth of semi-polar nitride semiconductors offer a means of reducing polarization effects in wurtzite-structure III-nitride device structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIGS. 1A, 1B and 1C are optical micrographs of GaN on (100) spinel with substrate miscuts of FIG. 1A (no miscut), FIG. 1B (miscut in <010>), and FIG. 1C (miscut in <011>).

FIG. 2 is a flowchart illustrating the process steps of the preferred embodiment of the present invention.

FIG. 3 is a photograph of an LED grown by MOCVD on a $\{10\bar{1}1\}$ GaN template grown by HVPE.

DETAILED DESCRIPTION OF THE INVENTION

[0021] In the following description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Overview

[0022] Growth of semi-polar nitride semiconductors, for example, $\{10\bar{1}1\}$, $\{10\bar{1}3\}$ and $\{11\bar{2}2\}$ planes of GaN, offer a means of reducing polarization effects in würtzite-structure III-nitride device structures. The semiconductor term nitrides refers to (Ga,Al,In,B)N and any alloy composition of these semiconductors. Current nitride devices are grown in the polar [0001] c-direction, which results in charge separation along the primary conduction direction in vertical devices. The resulting polarization fields are detrimental to the performance of current state of the art optoelectronic devices. Growth of these devices along a semi-polar direction could improve device performance significantly by reducing built-in electric fields along the conduction direction.

[0023] Until now, no means existed for growing large area, high quality films of semi-polar nitrides suitable for use as device layers, templates, or substrates in device growth. The novel feature of this invention is the establishment that semi-polar nitrides can be grown as planar films. As evidence, the inventors have grown $\{10\bar{1}1\}$, $\{10\bar{1}3\}$, and $\{11\bar{2}2\}$ planar films of GaN. However, the scope of this idea is not limited to solely these examples. This idea is relevant to all semi-polar planar films of nitrides.

Technical Description

[0024] The present invention comprises a method for growing planar nitride films in which a large area of the semi-polar nitrides is parallel to a substrate surface. Examples of this are $\{10\bar{1}1\}$ and $\{10\bar{1}3\}$ GaN films. In this particular embodiment, $MgAl_2O_4$ spinel substrates are used in the growth process. It is critically important that the spinel is miscut in the proper direction for growth of $\{10\bar{1}1\}$ GaN. $\{10\bar{1}1\}$ GaN grown on {100} spinel that is on-axis and that is miscut toward the <001> direction will have two domains at 90° to each other. This is apparent in the optical micrographs of GaN on (100) spinel shown in FIG. 1A (no miscut) and FIG. 1B (a miscut in <010>), respectively.

[0025] However, $\{10\bar{1}1\}$ single crystal GaN grows on {100} spinel that is miscut in the <011>, as shown in the optical micrograph of GaN on (100) spinel in FIG. 1C (a miscut in <011>) X-ray diffraction (XRD) was used to verify that the films grown on (100) spinel with miscut toward <011> direction are single crystal and that the films grown on-axis or miscut toward <010> direction have two domains.

[0026] $\{10\bar{1}3\}$ single crystal GaN was grown on nominally on-axis (lacking an intentional miscut) {110} spinel. XRD was used to verify that the $\{10\bar{1}3\}$ GaN is single crystal.

[0027] Also, planar films of $\{11\bar{2}2\}$ GaN and $\{10\bar{1}3\}$ GaN have been grown on m-plane sapphire, $\{1\bar{1}00\}$ Al_2O_3. It is uncommon in semiconductor growth for one substrate to be used for growth of two distinct planes of the same epitaxial material. However, the plane can be reproducibly selected by flowing ammonia at different temperatures before the GaN growth. Again, XRD was used to confirm the single crystal character of the films.

[0028] Thus, there has been experimentally proven four examples of planar semi- polar nitride films:

1) $\{10\bar{1}1\}$ GaN on {100} spinel miscut in a <011> direction,
2) $\{10\bar{1}3\}$ GaN on {110} spinel,
3) $\{11\bar{2}2\}$ GaN on $\{1\bar{1}00\}$ sapphire, and
4) {1013} GaN on {1100} sapphire.

[0029] These films were grown using an HVPE system in Shuji Nakamura's lab at the University of California, Santa Barbara. A general outline of growth parameters for both {1011} and {1013} is a pressure between 10 torr and 1000 torr, and a temperature between 900°C and 1200°C. This wide range of pressure shows that these planes are very stable when growing on the specified substrates. The epitaxial relationships should hold true regardless of the type of reactor. However, the reactor conditions for growing these planes will vary according to individual reactors and grow methods (HVPE, MOCVD, and MBE, for example).

Process Steps

[0030] FIG. 2 is a flowchart illustrating the process steps of the preferred embodiment of the present invention. Specifically, these process steps comprise a method for growing planar, semi-polar nitride films in which a large area of the planar, semi-polar nitride film is parallel to the substrate's surface.

[0031] Block 10 represents the optional step of preparing the substrate. For example, the preparation may involve performing a miscut of the substrate. For the growth of {1011} GaN, a (100) spinel substrate is used with a miscut in the <011> direction. For the growth of {1013} GaN, an on-axis (110) spinel substrate is used. The (110) spinel may or may not have a miscut in any direction, but a miscut is not necessary as it is to grow {1011} GaN on (100) spinel.

[0032] Block 12 represents the step of loading the substrate into an HTVPE reactor. The reactor is evacuated to at least 9E-2 torr to remove oxygen, then it is backfilled with nitrogen.

[0033] Block 14 represents the step of turning on the furnace and ramping the temperature of the reactor under conditions to encourage nitridization of the surface of the substrate.

[0034] Block 16 represents the step of performing a gas flow. The process generally flows nitrogen, hydrogen, and/or ammonia over the substrate at atmospheric pressure.

[0035] Block 18 represents the step of reducing the pressure in the reactor. The furnace setpoint is 1000°C, and when it reaches this temperature, the pressure of the reactor is reduced to 62.5 torr.

[0036] Block 20 represents the step of performing a GaN growth. After the pressure is reduced, the ammonia flow is set to 1.0 slpm (standard liters per minute), and HCl (hydrogen chloride) flow over Ga (gallium) of 75 sccm (standard cubic centimeters per minute) is initiated to start the growth of GaN.

[0037] Block 22 represents the step of cooling down the reactor. After 20 to 60 minutes of GaN growth time, the HCl flow is stopped, and the reactor is cooled down while flowing ammonia to preserve the GaN film.

[0038] The end result of these steps comprises a planar, semi-polar nitride film in which a large surface area (at least 10 mm x 10 mm or a 50 mm (2 inch) diameter) of the planar, semi-polar nitride film is parallel to the substrate's surface.

[0039] Although the process steps are described in conjunction with a spinel substrate, m-plane sapphire can be used to grow either $\{11\bar{2}2\}$ GaN or $\{10\bar{1}3\}$ GaN. The process is the same as described above, with one exception. For growth of $\{11\bar{2}2\}$ GaN, ammonia is flowed while the furnace is ramping to the growth temperature, thus the nitridation occurs at low temperature. To select for $\{10\bar{1}3$ GaN, only hydrogen and nitrogen can be flowed during the ramp temperature step. The substrate should then be subjected to a high temperature nitridation with ammonia flow at the growth temperature.

[0040] After the semi-polar film has been grown using the HVPE system, Block 22 represents the step of growing device layers on the substrate using MOCVD or MBE. This step usually involves doping the nitride layers with n-type and p-type, and growing one or several quantum wells in the regrowth layer. An LED can be made in this step using standard LED processing methods in a cleanroom.

[0041] FIG. 3 is a photograph of a green LED grown by MOCVD on a $\{10\bar{1}1\}$ GaN template grown by HVPE. Specifically, the template was grown by the previously described HVPE growth process, and the LED structure was grown by MOCVD. This is the first $\{10\bar{1}1\}$ GaN LED.

Possible Modifications and Variations

[0042] The scope of this invention covers more than just the particular examples cited. This idea is pertinent to all nitrides on any semi-polar plane. For example, one could grow $\{10\bar{1}1\}$ AlN, InN, AlGaN, InGaN, or AlInN on a miscut (100) spinel substrate. Another example is that one could grow {1012} nitrides, if the proper substrate is found. These examples and other possibilities still incur all of the benefits of planar semi-polar films.

[0043] The research that was performed in Shuji Nakamura's Lab at University of California, Santa Barbara, was done using HVPE; however, direct grow of semi-polar planes of nitrides should be possible using MOCVD and MBE as well. The epitaxial relations should be the same for most growth method, although it can vary as seen in the example of GaN on m-plane sapphire. For example, an MOCVD grown {1011} GaN LED could be grown directly on miscut (100) spinel without an HVPE template. This idea covers any growth technique that generates a planar semi-polar nitride film.

[0044] The reactor conditions will vary by reactor type and design. The growth described here is only a description of one set of conditions that has been found to be useful conditions for the growth of semi-polar GaN. It was also discovered that these films will grow under a wide parameter space of pressure, temperature, gas flows, etc., all of which will generate planar semi-polar nitride film.

[0045] There are other steps that could vary in the growth process. A nucleation layer has been found unnecessary for our reactor conditions; however, it may or may not be necessary to use a nucleation layer for other reactors, which is common practice in the growth of GaN films. It has also been found that nitridizing the substrate improves surface morphology for some films, and determines the actual plane grown for other films. However, this may or may not be necessary for any particular growth technique.

Advantages and Improvements

[0046] The existing practice is to grow GaN with the c-plane normal to the surface. This plane has a spontaneous polarization and piezoelectric polarization which are detrimental to device performance. The advantage of semi-polar over c-plane nitride films is the reduction in polarization and the associated increase in internal quantum efficiency for certain devices.

[0047] Non-polar planes could be used to completely eliminate polarization effects in devices. However, these planes are quite difficult to grow, thus non-polar nitride devices are not currently in production. The advantage of semi-polar over non-polar nitride films is the ease of growth. It has been found that semi-polar planes have a large parameter space in which they will grow. For example, non-polar planes will not grow at atmospheric pressure, but semi-polar planes have been experimentally demonstrated to grow from 62.5 torr to 760 torr, but probably have an even wider range than that. {1100} GaN is grown at low pressure, but when the pressure is increased to 760 torr, all other things being equal, c-plane GaN will result. This is probably related to the outline of the unit cell for the two planes. A further difficulty of {1120} GaN is In incorporation for InGaN devices. Results have found In incorporation to be quite favorable for {1011} GaN.

[0048] The advantage of planar semi-polar films over ELO sidewall is the large surface area that can be processed into an LED or other device. Another advantage is that the growth surface is parallel to the substrate surface, unlike that of ELO sidewall semi-polar planes.

[0049] In summary, the present invention establishes that planar semi-polar films of nitrides can be grown. This has been experimentally confirmed for four separate cases. The previously discussed advantages will be pertinent to all planar semi-polar films.

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[0050] The following references are incorporated by reference herein:

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Conclusion

[0051] This concludes the description of the preferred embodiment of the present invention. The foregoing description of one or more embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

Claims

1. A method of growing a planar, single crystal, semi-polar Gallium Nitride (GaN) film, comprising:

(a) loading a substrate in a reactor, wherein the reactor is evacuated to remove oxygen, and then backfilled with nitrogen;
(b) ramping a temperature of the reactor;
(c) performing a gas flow of nitrogen, hydrogen, or ammonia over the substrate at atmospheric pressure;
(d) reducing the reactor's pressure when the furnace reaches a growth temperature, wherein the reactor's pressure is reduced from atmospheric pressure when the furnace reaches the growth temperature;
(e) growing GaN on a surface of a substrate, by hydride vapor phase epitaxy in the reactor, and flowing ammonia, and initiating a flow of hydrogen chloride (HCl) over gallium (Ga) to start the growth of the GaN, wherein:

the growth temperature is between 900°C and 1200°C, and
a pressure in the reactor is between 10 torr and 1000 torr;

(f) cooling down the reactor after the growth of the GaN, wherein the HCl flow is stopped, and the reactor is cooled down while flowing ammonia to preserve the GaN; and
(g) the growth surface of the planar, single crys-

tal, semi-polar GaN film is parallel to the surface of the substrate, and the growth surface of the semi-polar GaN film has a surface area of at least 10 mm x 10 mm;

wherein either

(A) the substrate is sapphire and the surface is a $\{1\bar{1}00\}$ surface of the sapphire, and

(i) only hydrogen and nitrogen are flowed during the temperature ramping step, and the substrate is then subjected to a high temperature nitridation with ammonia flow at the growth temperature, to obtain a planar, semi-polar GaN film that is $\{10\bar{1}3\}$ GaN, or
(ii) ammonia is flowed while the furnace is ramping to the growth temperature, so that nitridation occurs at low temperature, to obtain the planar, single crystal, semi-polar GaN film that is $\{11\bar{2}2\}$ GaN;

or
(B) the substrate is a spinel substrate and the surface is a {110} surface of the spinel, and the ramping of the temperature is under conditions to encourage nitridization of the surface of the spinel, to obtain the planar, single crystal, semi-polar GaN film that is $\{10\bar{1}3\}$ GaN;
or
(C) the substrate is a spinel substrate and the surface is a {100} surface of the spinel miscut in a <011> direction, and the ramping of the temperature is under conditions to encourage nitridization of the surface of the spinel, to obtain a planar, single crystal, semi-polar GaN film that is $\{10\bar{1}1\}$ GaN.

2. The method of claim 1, wherein the surface area of the planar, single crystal, semi-polar GaN film has at least a 50 mm (2 inch) diameter is parallel to the substrate's surface.

3. The method of claim 1, wherein the substrate is miscut before being loaded into the reactor.

4. The method of claim 1, wherein, the growth is of planar, single crystal, semi-polar $\{11\bar{2}2\}$ GaN on the $\{1\bar{1}00\}$ surface of the sapphire and the ammonia is flowed while the temperature of the reactor is ramping to the growth temperature, so that nitridation occurs at low temperature.

5. The method of claim 1, wherein, the growth is of planar, single crystal, semi-polar $\{10\bar{1}3\}$ GaN on the $\{1\bar{1}00\}$ surface of the sapphire substrate, and the substrate is subjected to a high temperature nitridation with the ammonia flow at the growth temperature, and only hydrogen and nitrogen are flowed during the temperature ramping step.

6. The method of claim 1, further comprising growing device layers on the substrate using MOCVD or MBE.

7. The method of claim 6, wherein:

the device layers are grown by MOCVD to form a green light emitting diode,
and the planar, single crystal, semi-polar GaN film is $\{10\bar{1}1\}$ GaN.

8. The method of claim 1, wherein the ammonia flow is 1 standard liter per minute and the hydrogen chloride flow 75 standard cubic centimeters per minute.

Patentansprüche

1. Verfahren zum Züchten eines planaren, einkristallinen, halbpolaren Galliumnitrid (GaN)-Films, umfassend:

(a) Beladen eines Reaktors mit einem Substrat, wobei der Reaktor evakuiert wird, um Sauerstoff zu entfernen, und anschließend mit Stickstoff wieder befüllt wird;
(b) Fahren einer Temperaturrampe im Reaktor;
(c) Durchführen eines Gasstroms aus Stickstoff, Wasserstoff oder Ammoniak über das Substrat bei atmosphärischem Druck;
(d) Erniedrigen des Drucks im Reaktor, wenn der Ofen eine Wachstumstemperatur erreicht, wobei der Reaktordruck ausgehend vom atmosphärischen Druck verringert wird, wenn der Ofen die Wachstumstemperatur erreicht;
(e) Züchten von GaN auf einer Oberfläche eines Substrats durch Hydriddampfphasenepitaxie im Reaktor und Durchströmen von Ammoniak sowie Starten eines Chlorwasserstoff (HCl)-Stroms über Gallium (Ga), um das Wachstum von GaN zu starten, wobei:

die Wachstumstemperatur zwischen 900°C und 1200°C liegt und
der Druck im Reaktor zwischen 10 Torr und 1000 Torr liegt;

(f) Abkühlen des Reaktors nach Wachstum des GaN, wobei der HCl-Strom gestoppt wird, und der Reaktor während des Durchströmens von Ammoniak abgekühlt wird, um das GaN zu konservieren; und
(g) die Wachstumsoberfläche des planaren, einkristallinen, halbpolaren GaN-Films ist parallel

zur Oberfläche des Substrats und die Wachstumsoberfläche des halbpolaren GaN-Films besitzt eine Oberfläche von mindestens 10 mm x 10 mm;

wobei entweder

(A) das Substrat Saphir ist und die Oberfläche eine 111;¯00}-Oberfläche des Saphirs ist, und

(i) lediglich Wasserstoff und Stickstoff während des Schritts der Temperaturrampe durchströmen, und das Substrat wird anschließend einer HochtemperaturNitridierung mit Ammoniakfluss bei der Wachstumstemperatur unterworfen unter Erhalt eines planaren, halbpolaren GaN-Films, der {101;¯3}-GaN ist, oder
(ii) man lässt Ammoniak strömen, während der Ofen eine Rampe zur Wachstumstemperatur fährt, so dass die Nitridierung bei niedriger Temperatur geschieht unter Erhalt des planaren, einkristallinen halbpolaren GaN-Films, der {112;¯2}-GaN ist; oder

(B) das Substrat ein Spinellsubstrat ist, und die Oberfläche eine {110}-Oberfläche des Spinells ist, und das Fahren der Temperaturrampe geschieht unter Bedingungen, so dass die Nitridierung der Oberfläche des Spinells gefördert wird, unter Erhalt des planaren, einkristallinen, halbpolaren GaN-Films, der {101;¯3}-GaN ist
oder
(C) das Substrat ein Spinellsubstrat ist, und die Oberfläche eine {100}-Oberfläche des Spinellfehlschnitts in einer <011>-Richtung ist, und das Fahren der Temperaturrampe geschieht unter Bedingungen, so dass die Nitridierung der Oberfläche des Spinells gefördert wird, unter Erhalt eines planaren, einkristallinen, halbpolaren GaN-Films, der {101;¯1}-GaN ist.

2. Verfahren gemäß Anspruch 1, wobei die Oberfläche des planaren, einkristallinen, halbpolaren GaN-Films mit mindestens 50 mm (2 Inch) Durchmesser parallel zur Oberfläche des Substrats ist.

3. Verfahren gemäß Anspruch 1, wobei das Substrat vor dem Beladen in den Reaktor einen Fehlschnitt erhält.

4. Verfahren gemäß Anspruch 1, wobei das Wachstum dasjenige von planarem, einkristallinem, halbpolarem {112;¯2}-GaN auf der {11;¯00}-Oberfläche des Saphirs ist, und der Ammoniak strömt, während die Temperatur des Reaktors eine Rampe zur Wachstumstemperatur fährt, so dass die Nitridierung bei niedriger Temperatur geschieht.

5. Verfahren gemäß Anspruch 1, wobei das Wachstum dasjenige von planarem, einkristallinem, halbpolarem {101;¯3}-GaN auf der {11;¯00}-Oberfläche des Saphirsubstrats ist, und das Substrat wird einer Hochtemperaturnitridierung mit dem Ammoniakstrom bei der Wachstumstemperatur unterworfen, und lediglich Wasserstoff und Stickstoff während des Schritts des Fahrens der Temperaturrampe strömen.

6. Verfahren gemäß Anspruch 1, des Weiteren umfassend Züchten von Vorrichtungsschichten auf dem Substrat unter Verwendung von MOCVD oder MBE.

7. Verfahren gemäß Anspruch 6, wobei die Vorrichtungsschichten durch MOCVD gezüchtet werden unter Bildung einer grünes Licht emittierenden Diode, und der planare, einkristalline, halbpolare GaN-Film {101;¯1}-GaN ist.

8. Verfahren gemäß Anspruch 1, wobei der Ammoniakstrom ein Standardliter pro Minute und der Chlorwasserstoffstrom 75 Standardkubikzentimeter pro Minute beträgt.

Revendications

1. Procédé permettant de faire croître un film plan de nitrure de gallium GaN monocristallin et semi-polaire, lequel procédé comporte les étapes suivantes :

a) placer un substrat dans un réacteur, dans lequel on fait le vide pour en évacuer l’oxygène et que l’on remplit ensuite à nouveau avec de l’azote ;
b) élever la température dans le réacteur ;
c) faire passer sur le substrat un courant gazeux d’azote, d’hydrogène ou d’ammoniac, sous la pression atmosphérique ;
d) abaisser la pression dans le réacteur quand le four atteint une température de croissance, étant entendu que c’est à partir de la pression atmosphérique que la pression dans le réacteur est abaissée quand le four atteint la température de croissance ;
e) faire croître du nitrure de gallium GaN sur une surface du substrat, par épitaxie en phase vapeur d’hydrure dans le réacteur, en faisant passer de l’ammoniac et en commençant à faire passer un courant de chlorure d’hydrogène HCl sur du gallium Ga pour faire démarrer la croissance du nitrure de gallium, étant entendu :

que la température de croissance se situe entre 900 et 1200 °C, et que la pression dans le réacteur se situe entre 10 et 1000 torrs ;

f) et faire refroidir le réacteur après la croissance du nitrure de gallium, en arrêtant le courant de chlorure d'hydrogène, mais en continuant à faire passer de l'ammoniac pendant que le réacteur refroidit, pour préserver le nitrure de gallium ;
g) et dans lequel procédé la surface de croissance du film plan de nitrure de gallium monocristallin et semi-polaire est parallèle à la surface du substrat, et l'aire de la surface de croissance du film de nitrure de gallium semi-polaire vaut au moins 10 mm sur 10 mm ;

et dans lequel procédé

A) soit le substrat est en saphir et la surface est une surface {1100} du saphir,

i) et l'on ne fait passer que de l'hydrogène et de l'azote pendant l'élévation de température, et le substrat est ensuite soumis à une nitruration à haute température, réalisée avec un courant d'ammoniac à la température de croissance, ce qui donne un film plan de nitrure de gallium semi-polaire qui est du GaN $\{10\bar{1}3\}$,
ii) ou l'on fait passer de l'ammoniac pendant que la température du four s'élève jusqu'à la température de croissance, de sorte que la nitruration a lieu à température relativement basse, ce qui donne un film plan de nitrure de gallium semi-polaire et monocristallin qui est du GaN $\{11\bar{2}2\}$;

B) soit le substrat est un substrat spinelle et la surface est une surface {110} du spinelle, et l'élévation de la température est opérée dans des conditions qui favorisent la nitruration de la surface du spinelle, ce qui donne un film plan de nitrure de gallium semi-polaire et monocristallin qui est du GaN $\{10\bar{1}3\}$;
C) soit le substrat est un substrat spinelle et la surface est une surface {100} du spinelle, désorientée avec miscut dans la direction <011>, et l'élévation de la température est opérée dans des conditions qui favorisent la nitruration de la surface du spinelle, ce qui donne un film plan de nitrure de gallium semi-polaire et monocristallin qui est du GaN $\{10\bar{1}1\}$,

2. Procédé conforme à la revendication 1, dans lequel la surface du film plan de nitrure de gallium semi-polaire et monocristallin a au moins 50 mm (2 pouces) de diamètre et est parallèle à la surface du substrat.

3. Procédé conforme à la revendication 1, dans lequel on réalise le miscut du substrat avant de placer celui-ci dans le réacteur.

4. Procédé conforme à la revendication 1, dans lequel il y a croissance d'un film plan de GaN $\{11\bar{2}2\}$ semi-polaire et monocristallin sur une surface $\{1\bar{1}00\}$ de saphir, et l'on fait passer de l'ammoniac pendant que la température du réacteur s'élève jusqu'à la température de croissance, de sorte que la nitruration a lieu à température relativement basse.

5. Procédé conforme à la revendication 1, dans lequel il y a croissance d'un film plan de GaN $\{10\bar{1}3\}$ semi-polaire et monocristallin sur une surface $\{1\bar{1}00\}$ du substrat de saphir, et le substrat est ensuite soumis à une nitruration à haute température, réalisée avec un courant d'ammoniac à la température de croissance, et l'on ne fait passer que de l'hydrogène et de l'azote pendant l'étape d'élévation de température.

6. Procédé conforme à la revendication 1, qui comporte en outre le fait de faire croître des couches de dispositif sur le substrat, selon une technique de dépôt chimique en phase vapeur avec précurseurs métallo-organiques (MOCVD) ou d'épitaxie par faisceaux moléculaires (MBE).

7. Procédé conforme à la revendication 6, dans lequel on fait croître les couches de dispositif selon une technique MOCVD, pour fabriquer une diode émettant une lumière verte,
et le film plan de nitrure de gallium semi-polaire et monocristallin est du GaN $\{10\bar{1}1\}$,

8. Procédé conforme à la revendication 1, dans lequel le débit du courant d'ammoniac vaut 1 litre standard par minute et le débit du courant de chlorure d'hydrogène vaut 75 centimètres cubes standard par minute.

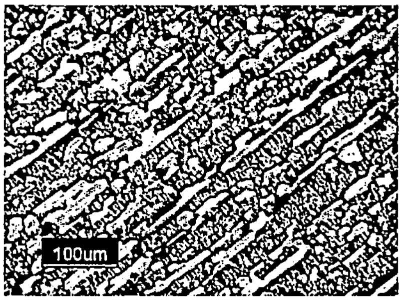

FIG. 1A

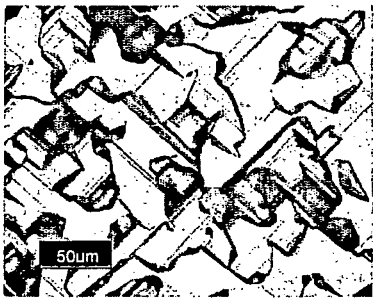

FIG. 1B

FIG. 1C

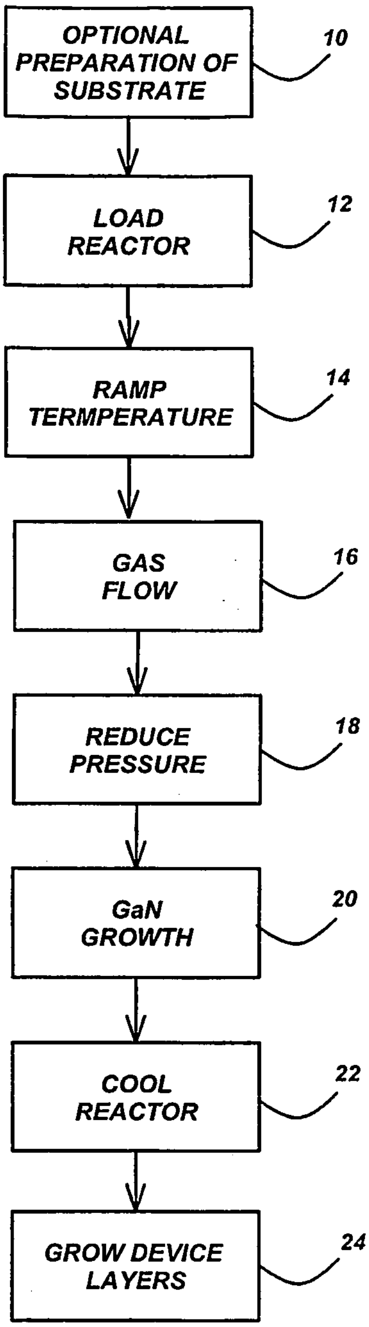
OPTIONAL PREPARATION OF SUBSTRATE
10
LOAD REACTOR
12
RAMP TERMPERATURE
14
GAS FLOW
16
REDUCE PRESSURE
18
GaN GROWTH
20
COOL REACTOR
22
GROW DEVICE LAYERS
24

FIG. 2

FIG. 3

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