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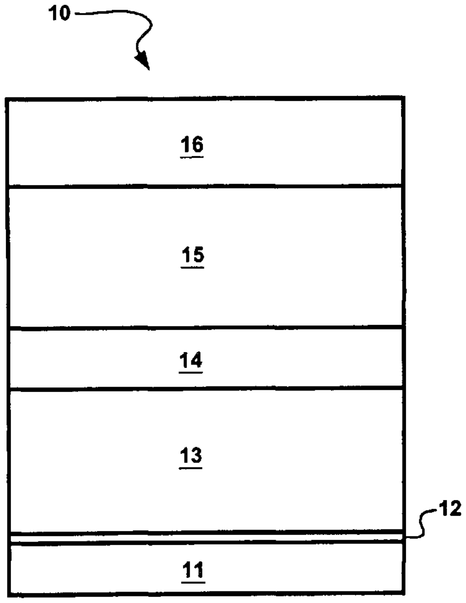
(54) **Title:** SEMICONDUCTOR DEVICES WITH SELECTIVELY DOPED III-V NITRIDE LAYERS



(57) **Abstract:** A semiconductor device is provided having n-type device layers of III-V nitride having donor dopants such as germanium (Ge), silicon (Si), tin (Sn), and/or oxygen (0) and/or p-type device layers of III-V nitride having acceptor dopants such as magnesium (Mg), beryllium (Be), zinc (Zn), and/or cadmium (Cd), either simultaneously or in a doping superlattice, to engineer strain, improve conductivity, and provide longer wavelength light emission.

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SEMICONDUCTOR DEVICES WITH SELECTIVELY DOPED III-V NITRIDE LAYERS

TECHNICAL FIELD

The present invention relates generally to semiconductor devices and more particularly to doping III-V nitride light-emitting devices.

BACKGROUND ART

Silicon (Si) is the donor of choice for doping n-type III-V nitrides due to its favorable properties. In particular, during metal-organic chemical vapor deposition (MOCVD), Si atoms can be delivered to the growing crystal by flowing silane (SiH4), which is available as a high purity grade gas. In addition, Si incorporates efficiently onto the gallium (Ga) sites in the gallium nitride (GAN) lattice where it acts as a donor. Further, Si in GaN (SiGa) is a shallow donor with an activation energy for ionization of ~20 meV.

However, with Si doping the achievable n-type conductivity of an III-V nitride layer is limited due to the fact that the incorporation of Si leads to the formation of cracks for heteroepitaxially-grown III-V nitride materials (particularly on sapphire substrates). For a given material thickness, the material cracks when the Si doping level exceeds a certain critical concentration. Likewise, for a given doping concentration, the material starts to crack when the material thickness exceeds a certain critical thickness.

Both a high doping concentration and a large material thickness are desirable to reduce the electrical resistivity of a semiconductor material. For example, for an .-.3.5 μm thick GaN material, as typically employed in a light-emitting diode (LED) structure, the doping concentration is limited to ~5el 8 cm-3. As a consequence of the a foregoing, the series resistance of an aluminum indium gallium nitride (AlInGaN) LED is dominated by the resistance of the Si-doped GaN layer. This is the case for growth on non-conductive substrates such as sapphire where the current passes laterally through the Si-doped GaN layer as well as growth on conductive substrates such as silicon carbide (SIC) and hydride vapor phase epitaxy (HVPE) grown GaN where the current passes vertically through the thick Si-doped GaN layer. Higher doping concentrations and/or thicker n-type GaN materials (for growth on non-conductive substrates) would be advantageous for the fabrication of III-V nitride based LEDs with low series resistance.

Further, in addition to Si, germanium (Ge) and tin (Sn) have been studied as potential donor impurities for III-V nitride materials. However, there are reports on Ge doping experiments where it was concluded that doping with Ge is problematic. In the S. Nakamura, T. Mukai, and M. Senoh, Si- and Ge- Doped GaN Materials Grown with GaN Buffer Layers, Jpn. J. Appl. Phys. 31, 2883, 1992, it is reported that the doping efficiency of Ge is about one order of magnitude lower than for Si. Furthermore, they concluded that the maximum carrier concentration for Ge-doped GaN is limited to ~lx1019 cm-3 because at this doping level the surface of the Ge-doped GaN materials becomes rough and shows pits. X. Zhang, P. Kung, A. Saxler, D. Walker, T.C. Wang, and M. Razeghi, Growth of AlxGaI-xN:Ge on sapphire and $i substrates, Appl. Phys. Lett. 67, 1745 (1995), concluded the Ge-doped aluminum gallium nitride (AlGaN) materials have low electron mobilities and that Ge doping is not useful for growing low resistivity materials.

For a long time, a solution has been sought to the problem of material cracking which occurs with Si doping levels exceeding certain concentrations at certain critical thicknesses. Further, Si doping is known to cause the III-V nitride materials to embrittle, which further enhances the tendency of the material to crack, and a solution to this problem has long been sought. It has also been shown that there is a large piezoelectric effect due to the lattice mismatch between GaN and its alloys. For example, an indium gallium nitride (InGaN) layer grown between two GaN layers will have a high piezoelectric sheet charge associated with each interface.

DISCLOSURE OF THE INVENTION

The present invention provides a semiconductor device having n-type device layers of III-V nitride having donor dopants such as germanium (Ge), silicon (Si), tin (Sn), and/or oxygen (O) and/or p-type device layers of III-V nitride having acceptor dopants such as magnesium (Mg), beryllium (Be), zinc (Zn), and/or cadmium (Cd), either simultaneously or in a doping superlattice, to engineer strain, improve conductivity, and provide longer wavelength light emission.

The present invention further provides a semiconductor device using Ge either singularly or in combination, as a co-dopant, with Si and Sn as donor dopants either simultaneously or in a doping superlattice to engineer strain. Unlike Si, the Ge doping concentration can range from ~1019 cm-3 to ~1020 cm-3 at layer thicknesses of 3 μm and higher without causing cracking problems.

The present invention further provides donor impurities which do not cause embrittlement of III-V nitride materials.

The present invention further provides multi-donor impurity doping for III-V nitride materials to control doping and strain engineering separately.

The present invention further provides highly conductive, n-type, Ge-doped, gallium nitride (GAN) materials for utilization in contact layers of III-V nitride devices.

The present invention further provides a light-emitting device with donor impurities which promote growth of high indium nitride (INN) containing indium gallium nitride (InGaN) light emission layers for light emission at long wavelengths (symbol 500 nm). This allows the InGaN active region to contain a higher InN composition with higher quality and thus a higher efficiency, longer wavelength light emission or the growth of an A1GaN layer on top of GaN without cracking.

The present invention further provides a light-emitting device co-doped using a combination of Si, Ge, Sn, oxygen (O), magnesium (Mg), beryllium (Be), zinc (Zn), or cadmium (Cd) to improve the conductivity of III-V nitride materials which stabilize the structural integrity of heteroepitaxially-grown III-V nitride materials on lattice mismatched substrates.

The present invention further provides a light-emitting device using different donor dopants for conductive and contact layers.

The present invention further provides a light-emitting device where a bottom layer is doped with Ge and a layer on top doped with a different species (e.g. Si, Sn, or a combination of Si, Ge, and Sn). This permits adjustment of the in-plane lattice constant of GaN closer to the in-plane lattice constant of a ternary compound (e.g., InGaN or aluminum gallium nitride (AlGaN)). This allows the InGaN active region to contain a higher InN composition with higher quality and thus a higher efficiency, longer wavelength light emission or the growth of an AlGaN layer on top of GaN without cracking.

The present invention further provides a method of controlling strain and, thus, the effects of piezoelectricity in III-V nitride layers. Strain engineering plays a major role in controlling piezoelectric interface charges.

The above and additional advantages of the present invention will become apparent to those skilled in the art from a reading of the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a light-emitting device incorporating the doped III-V nitride layer of the present invention;

FIG. 2 is a light-emitting device having the doped superlattice of the present invention; and

FIG. 3 is a light-emitting device incorporating the strain engineered doping of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1, therein is shown an electronic device such as a light-emitting device 10 which could be a light-emitting diode (LED) or laser diode (LD). The light-emitting device 10 includes an optional substrate 11 of sapphire, silicon carbide (SIC), silicon (Si), gallium arsenide (GaAs), or gallium nitride (GAN). It should be understood that the substrate 11 could be discarded in the formation of the light-emitting device 10 after deposition of the various layers which will hereinafter be described.

Due to difficulties in nucleation of the single crystalline III-V nitride layers on foreign substrates, a low temperature buffer layer 12 is often disposed on the substrate 11. The buffer layer 12 is of a material such as GaN or aluminum nitride (AlN) deposited on sapphire at low temperatures around 500°C.

A highly conductive, n-type, light-emitting, III-V nitride layer 13 is deposited on the buffer layer 12. The nitride layer 13 is made of a doped GaN, an indium gallium nitride (InGaN), an aluminum gallium nitride (A1GaN), an aluminum indium nitride (AlInN), or an aluminum gallium indium nitride (AlGaInN). These materials enable low driving voltages for the light-emitting device10 due to reduced resistance in the n-layer, excellent electron injection due to high electron concentration near the p-n junction, and the formation of electrodes to the layers with the ohmic electrical characteristics. In the preferred embodiment, the dopant is germanium (Ge) instead of silicon (Si) or combinations of Si, Ge, tin (Sn), and oxygen (O).

An active layer I4 is deposited on the nitride layer I3. The active layer 14 can have a single-quantum well (SQW), multiple-quantum well (MQW), or double-hetero (DH) structure. Generally, this layer is GaN, AlGaN, AlInN, InGaN, or AlInGaN.

A highly conductive p-type, III-V nitride layer 15 is deposited on the active layer 14. The p-type nitride layer 15 is similar to the n-type nitride layer 13 except with a p-type dopant being used.

Final device layers 16, such as cladding and/or contact layers, may be deposited on top of the p-type nitride layer 15.

The various layers may be grown using techniques such as metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), gas source MBE (GSPMBE), or hydride vapor phase epitaxy (HVPE). Also, the composition and/or doping of the various layers may change abruptly from one layer to another, may be smoothly graded over a finite thickness, may be graded over the entire thickness of a layer, or may be combined with undoped layers.

Referring now to FIG. 2, therein is shown an electronic device, such as a light-emitting device 20. The light-emitting device 20 includes an optional substrate 21 of sapphire, silicon carbide (SIC), silicon (Si), gallium arsenide (GaAs), or gallium nitride (GAN). Again, due to difficulties in nucleation of the single crystalline III-V nitride layers on foreign substrates, a low temperature buffer layer 22 is often disposed on the substrate 21. The buffer layer 22 is of a material such as GaN or AlN deposited on sapphire at low temperatures.

A highly conductive, n-type III-V nitride layer is deposited on the buffer layer 22. This nitride layer can be GaN with layers doped with different donors, GaN and InGaN layers doped with different donors, InGaN, AlGaN, and AlGaInN doped with different donors, or these layers with undoped layers in between. This layered structure may be termed a "superlattice", although the layers are thicker than those in a conventional superlattice structures since these layers should range from 10Å (angstroms) to 10µm (microns) in thickness. It has been determined that this greater thickness provides greater strain control.

The doped layers are designated as nitride layers 23 through 29, which have combinations of Si, Ge, Sn, and O as dopants. The combination of dopants is alternated such that the odd numbered doped nitride layers, designated as nitride layers 23, 25, 27, and 29, use one or more dopant(s) and the other nitride layers, the even numbered doped nitride layers, designated as nitride layers 24, 26, and 28, use another dopant or combination of dopants to achieve a desired state of strain. For example, the nitride layers 23, 25, 27, and 29 are Ge doped and the nitride layers 24, 26, and 28 are Si doped.

An active layer 30 is deposited on the nitride layer 29. The active layer 30 can have a SQW, MQW, or DH structure. Generally, this layer is an InN containing InGaN or AlInGaN. With a higher InN composition in the InGaN active region, a longer wavelength light emission can be obtained.

A highly conductive p-type, III-V nitride layer 31 is deposited on the active layer 30. The p-type nitride layer 31 is the same as the n-type nitride layer 23 except with a p-type dopant being used.

Final device layers 32, such as cladding and/or contact layers, may be deposited on top of the p-type nitride layer 31. The final device layers 32 are the other layers required by the light-emitting device 20.

Referring now to FIG. 3, therein is shown another electronic device, such as a light-emitting device 50. The light-emitting device 50 includes a substrate 51 of sapphire, SiC or GaN. Due to difficulties in nucleation of the single crystalline III-V nitride layers on foreign substrates, a low temperature buffer layer 52 is often deposited on the substrate 51. The buffer layer 52 is of a material such as GaN or AlN.

A highly conductive, n-type III-V nitride layer is deposited on the buffer layer 52. This nitride layer is made of doped GaN, InGaN, A1GaN, AlInN, or AlGaInN. Here, one dopant species is used in a nitride layer designated as nitride layer 53 and a second in a nitride layer designated as nitride layer 54. In the preferred embodiment, the dopants are combinations of Si, Ge, Sn, and O. Where the nitride layer 53 is doped with Si and the nitride layer 54 with Ge, the nitride layer 54 can be a contact layer.

An active layer 55 is deposited on the nitride layers 53 and 54. The active layer 55 can have a SQW or MQW structure. Generally, this layer is an InN containing InGaN or AlInGaN.

A highly conductive p-type, III-V nitride layer 56 is deposited on the active layer 55. The p-type nitride layer 56 is similar to the n-type nitride layers 53 and 54 except with a p-type dopant being used.

Final device layers 57, such as cladding and/or contact layers, may be deposited on top of the p-type nitride layer 56. The final device layers 57 are the other layers required by the light-emitting device 50.

In the past, Si has been the donor of choice for doping n-type, III-V nitride layers due to its favorable properties. However, with Si doping the achievable n-type conductivity of an III-V nitride layer is limited due to the fact that the incorporation of Si leads to the formation

of cracks in heteroepitaxially-grown GaN due to differences in lattice constants and in coefficients of thermal expansion with the substrate. It is possible that the cracking problem is a consequence of the small ionic radius of Si donors as compared to Ga host atoms. Si has an ionic radius of 0.413. while Ga has an ionic radius of 0.62Å. For example, it has been determined that for growth on c-plane sapphire, Si doping leads to more compressive strain in the c-axis direction for high Si doping concentrations. As a consequence, the basal plane of GaN is put into more tensile strain. Two potential donor impurities, Ge and Sn for III-V nitride materials possess larger ionic radii than Si and are much closer to the ionic radius of Ga. Ge has an ionic radius of 0.53 A and Sn has an ionic radius of 0.71Å.

Further, like Si, both Ge and Sn doping sources are readily available as gases, germanium hydride (Gert4) and tin hydride (SnH4), for use with conventional MOCVD processes. And, the donor ionization energies of Ge in GaN (GeGa) and Sn in GaN (SnGa) are expected to be similar to that of silicon in GaN (SiGa). This makes these ions ideal dopants.

With reference to the structure shown in FIG. 1, the nitride layer 13 can be doped with Si, Ge, Sn, or O alone or together in combination. In contrast to Si-doped GaN, heavily Ge-doped GaN will not crack when grown thicker than ~1 μm. Further, the nitride layer 13 with Ge doping levels in the range from ~1019 cm-3 to ~1020 cm-3 typically form ohmic contacts with various metals, and thus make good contact layers. Ge doping at such concentration has been deemed to be unobtainable in the literature, as indicated by Nakamura et al., supra.

Also with reference to FIG. 1, the nitride layer 13 may be co-doped using a combination of the following donors: Si, Ge, Sn, and O. The different donor species are introduced simultaneously to stabilize the structural integrity of heteroepitaxially-grown III-V nitride on lattice mismatched substrates. For example, tensile strain can be reduced by using combinations of Si and Ge, Si and Sn, and Ge and Sn. In addition, the use of O is highly desirable as it will occupy the N-lattice site. Hence, there is no site competition with Si, Ge, or Sn which occupies the Ga lattice site, and higher doping levels may be achieved. With higher doping levels, it is possible to achieve much higher conductivity. Using co-dopants of Si/Ge, Si/Sn, and Ge/Sn, it is possible to stabilize the lattice and avoid cracking. The dopants and their percentages are chosen differently for the growth of GaN, InGaN, and A1GaN to adjust the strain state that is desirable for overgrowth of GaN, A1GaN, AlInN, InGaN, or AlInGaN.

With reference to FIG. 2, the light-emitting device 20 is a solution to the problem reported by Nakamura, et al., supra, that the doping efficiency for Ge is an order of magnitude lower than for Si. To circumvent this problem, Si layers could be sandwiched between Ge-doped layers so that the total thickness of the Si-doped layers does not exceed the critical thickness for cracking at the given doping level. Thus, the Si-doped layers 24, 26, and 28 would be relatively thin. The Ge-doped layers 23, 25, 27, and 29 can be doped to the same concentration, but can be made thick enough to provide the desired high conductivity..

Referring back to FIG. 1, the different dopants in the nitride layer 13 can be at a single dopant concentration or one which gradually changes from the buffer layer 12 to the nitride layer 13. It is also practical for the nitride layer 13 to start with one dopant at the buffer layer 12 and gradually decrease the concentration of the one dopant and gradually increase the concentration of the second dopant.

For example, a gradual adjustment of the strain for subsequent overgrowth of an InGaN or AlGaN active layer 14 will be possible by choosing a specific combination of dopants and grading their relative concentration. The in-plane lattice parameters for

InGaN and AlGaN are larger and smaller, respectively, than the lattice parameters for GaN.

As a consequence, co-doping of a GaN nitride layer 13 with two different donor species and increasing the concentration of the donor species that increases the in-plane lattice constant towards the interface with an InGaN active layer 14 will adjust the lattice for overgrowth of InGaN. For example, co-doping with Si and Ge, and increasing Si concentration towards the InGaN interface.

On the other hand, choosing an alternative pair of donor dopants for a GaN nitride layer 13 and increasing the concentration of the donor that decreases the in-plane lattice constant towards the interface with an AlGaN active layer 14 will be advantageous for overgrowth of thick AlGaN layers as required for growth of mirror stacks in surface emitting lasers, for example, co-doping with Si and Ge, and increasing Ge concentration towards the AlGaN interface.

With reference now to FIG. 3, similar results to those just described above can be achieved by the introduction of a separately doped layer. For example, the nitride layer 53 of GaN could be doped with Ge. This would allow for high doping and the layer could also be thick. On top of the Ge-doped GaN layer, a heavily doped nitride layer 54 is grown using a different donor species such as Si which increases the lattice parameter in the c-plane and therefore will allow InGaN with high InN compositions to grow. With a higher InN composition in the InGaN active region, a longer wavelength light emission can be obtained.

Also, higher tensile strain in the basal plane will reduce the piezoelectric sheet charge at the InGaN interface.

Alternately, the nitride layer 53 would contain GaN:Si and the nitride layer 54 of Ge-doped GaN would be grown on top with a Ge doping concentration of ~1020 cm-3. This high Ge-doped nitride layer 54 would be a contact layer which is thick enough so that it can be easily reached by etching even if the etch depth varies. The active layer 55 is then grown on top of this contact layer.

While the invention has been described in conjunction with a specific best mode, it is to be understood that many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the aforegoing description. For example, the structure is further applicable to highly doped p-layers in semiconductor devices where the dopants would be Mg, Be, Zn, or Cd. Accordingly, it is intended to embrace all such alternatives, modifications, and variations which fall within the spirit and scope of the included claims. All matters set forth herein or shown in the accompanying drawings are to be interpreted in an illustrative and non-limiting sense.

THE INVENTION CLAIMED IS:

1. A device comprising:
a substrate;
an III-V nitride layer positioned over said substrate;
an active layer positioned over said III-V nitride layer;
a second III-V nitride layer positioned over said active layer; and
said III-V nitride layer doped with an element dopant from a group consisting of germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof whereby stress is controlled and embrittlement of said III-V nitride layer is minimized.

2. A device as claimed in claim 1 wherein:
said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof.

3. The device as claimed in claim 1 wherein:
said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof, said second dopant changes concentration towards said active layer.

4. The device as claimed in claim 1 wherein:
said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof, said second dopant increases concentration towards said active layer; and
said dopant increases concentration away from said active layer.

5. The device as claimed in claim 1 wherein:
a portion of said III-V nitride layer is doped with a dopant from a group consisting of silicon, germanium, tin, oxygen, and a combination thereof; and

a second portion of said III-V nitride layer is doped with a dopant different from the dopant used in said first portion and selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof.

6. The device as claimed in claim I wherein:

a plurality of portions of said III-V nitride layer are doped with a dopant from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof;

a plurality of second portions of said III-V nitride layer are doped with a dopant different from the dopant used in said plurality of portions and selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof; and

said plurality of portions and said plurality of second portions are alternated whereby a superlattice structure is formed.

7. The device as claimed in claim 1 including:

an undoped layer in said III-V nitride layer.

8. The device as claimed in claim 1 wherein:

said III-V nitride layer includes a heavily doped portion using a different dopant than said dopant to increase the lattice parameter adjacent to said active layer.

9. The device as claimed in claim 1 wherein:

said III-V nitride layer is heavily doped to render it highly conductive to be a contact layer for the device.

10. The device as claimed in claim 1 wherein:

said III-V nitride layer contains a plurality of dopants to selectively vary the composition and properties of said III-V nitride layer from said structure to said active layer.

11. The device as claimed in claim 1 wherein: said III-V nitride layer and the second III-V nitride layer range from 10A to 10pm in thickness.

12. A light-emitting device comprising:

a substrate containing an element from a group consisting of aluminum, carbon, gallium, indium, nitrogen, oxygen, silicon, and a combination thereof;

a III-V nitride layer positioned over said substrate and containing an element selected from a group consisting of aluminum, gallium, indium, nitrogen, and a combination thereof;

an active layer positioned over said III-V nitride layer and containing an element selected from a group consisting of aluminum, gallium, indium, nitrogen, and a combination thereof;

a second III-V nitride layer positioned over said active layer and containing an element selected from a group consisting of aluminum, gallium, indium, nitrogen, and a combination thereof; and

said III-V nitride layer doped with an element dopant from a group consisting of germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof whereby compression or tension cracking and embrittlement of said III-V nitride layer is minimized.

13. The light-emitting device as claimed in claim 12 wherein:

said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof.

14. The light-emitting device as claimed in claim 12 wherein:

said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof, said second dopant changes concentration towards said active layer whereby the lattice constant of said III-V nitride layer changes towards the lattice constant of said active layer.

15. The light-emitting device as claimed in claim 12 wherein:

said III-V nitride layer contains a second dopant selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof, said second dopant increases concentration towards said active layer; and said dopant increases concentration away from said active layer whereby high conductivity and long wavelength emissions from the active layer are achieved.

16. The light-emitting device as claimed in claim 12 wherein:
a first portion of said III-V nitride layer is doped with a dopant from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof; and
a second portion of said III-V nitride layer is thicker than said first portion and is doped with a dopant different from the dopant used in said first portion and selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof.

17. The light-emitting device as claimed in claim 12 wherein:
a plurality of first portions of said III-V nitride layer are doped with a dopant from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof;
a plurality of second portions of said III-V nitride layer are doped with a dopant different from the dopant used in said plurality of first portions and selected from a group consisting of silicon, germanium, tin, oxygen, magnesium, beryllium, zinc, cadmium, and a combination thereof; and
each of said plurality of first portions and each of said plurality of second portions are alternated whereby the conductivity and the stress in the device are controlled.

18. The light-emitting device as claimed in claim 12 including: a plurality of undoped layers in said III-V nitride layer and in said second III-V nitride layer.

19. The light-emitting device as claimed in claim 12 wherein:
said III-V nitride layer includes a heavily doped portion using a different dopant than said dopant to increase the lattice parameter adjacent to said active layer.

20. The light-emitting device as claimed in claim 12 wherein:
said III-V nitride layer has at least a portion heavily doped to render it a contact layer.

21. The light-emitting device as claimed in claim 12 wherein:

said III-V nitride layer contains a plurality of dopants to selectively vary the composition and properties of said III-V nitride layer from said substrate to said active layer.

22. The light-emitting device as claimed in claim 12 wherein:
said III-V nitride layer and the second III-V nitride layer range from 10Å to 10μm in thickness.

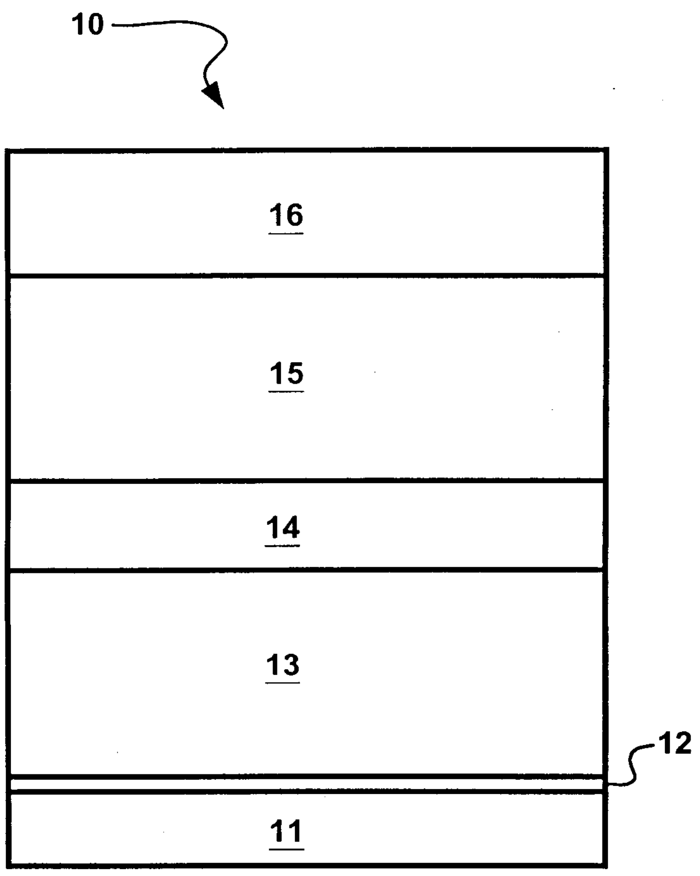

FIG. 1

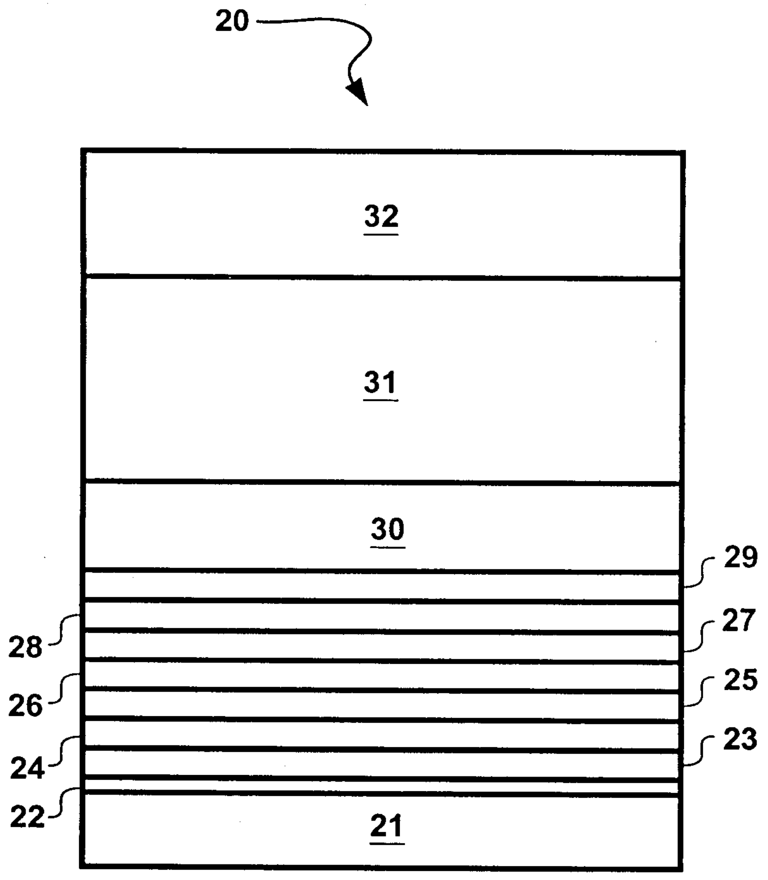

FIG. 2

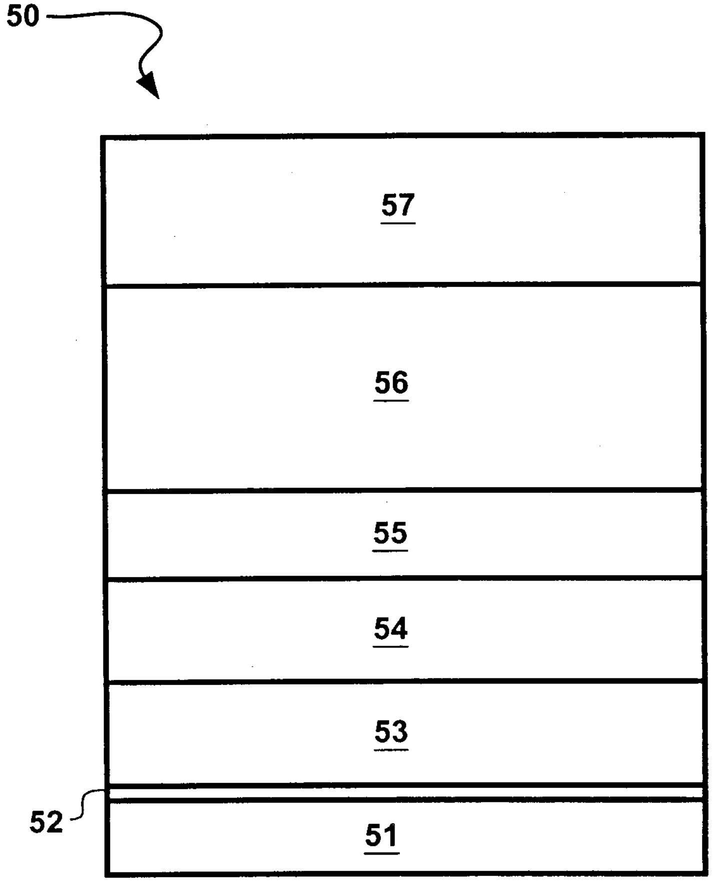

FIG. 3