[0007] Thus, what is needed is a high SE-rate LED with high efficiency. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[0008] According to the Detailed Description, a light emitting diode device (LED) is provided. The LED includes a first-doped layer on a substrate, an active layer on the first-doped layer, a second-doped layer on the active layer, and a metal layer on the second-doped layer. The active layer is configured to emit electron-hole pairs. The second-doped layer is textured with a plurality of V-pits on a surface opposite to the active layer to define a surface plasmon thickness that is configured to allow the electron-hole pairs in the active layer to couple efficiently to a surface plasmon mode at an interface of the metal layer and the second-doped layer thereby increasing the spontaneous emission rate of the LED.

[0009] Light is emitted from a rear side of the LED when the metal layer has a thickness of approximately 30nm or thicker and the rearside includes a surface of the substrate opposite the first-doped layer.

[0010] In accordance with another aspect, a method for fabricating a light emitting diode (LED) is provided. The method includes depositing a first-doped GaN layer with first impurities on a substrate, forming one or more quantum well layers on

the first-doped layer, depositing a second-doped GaN layer with second impurities on the quantum well layer, and depositing a metal layer over the second-doped layer.

[0011] Depositing the second-doped layer includes texturing a plurality of sharp V-pits so that a first portion of the second-doped GaN layer has a first thickness and a second portion of the second-doped GaN layer has a second thickness, the first thickness defining a surface plasmon thickness that is configured to allow electron-hole

pairs in the one or more quantum well layers to couple efficiently to a surface plasmon mode at an interface of the metal layer and the second-doped layer for an increased spontaneous emission rate of the LED and the second thickness being determined to ensure formation of a p-n junction in the LED. Also, a thinnest portion of the second-doped layer and a thinnest portion of the metal layer over the thinnest portion of the second doped layer both are within the surface plasmon coupling thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with a present embodiment.

[0013] FIG. 1 depicts a perspective view of a light emitting diode (LED) in accordance with a present embodiment.

[0014] FIG. 2 depicts a flowchart of a method for fabricating the LED of FIG. 1 in accordance with a present embodiment.

[0015] FIG. 3, comprising FIGs. 3A, 3B and 3C, depicts the surface plasmon coupled LED of FIG. 1 in accordance with the present embodiment, wherein FIG. 3A comprises a perspective three-dimensional view, FIG. 3B comprises a cross sectional view, and FIG. 3C comprises a top planar view.

[0016] FIG. 4, comprising FIGs. 4A to 4E, depicts steps of a LED fabrication process in accordance with the present embodiment for an LED device with light emission from a polished sapphire substrate outer surface thereof.

[0017] FIG. 5, comprising FIGs. 5A to 5F, depicts steps of a LED fabrication process in accordance with the present embodiment for an LED device with light emission from a top surface opposite a substrate bottom surface thereof.

[0018] FIG. 6, comprising FIGs. 6A to 6D depicts graph of luminescence properties of the LED of FIG. 1 in accordance with the present embodiment, wherein FIG. 6A

CLAIMS

What is claimed is:

1. A light emitting diode device (LED) comprising:

a first-doped layer on a substrate;

an active layer on the first-doped layer, the active layer being configured to emit electron hole pairs;

a second-doped layer on the active layer; and

a metal layer on the second-doped layer,

wherein the second-doped layer is textured with a plurality of V-pits on a surface opposite to the active layer to define a surface plasmon thickness

that is configured to allow the electron-hole pairs in the active layer to couple efficiently to a surface plasmon mode at an interface of the metal layer and the second-doped layer thereby increasing the spontaneous emission rate of the LED, and

wherein light is emitted from a rear side of the LED when the metal layer has a thickness of approximately 30nm or thicker,

wherein the rear side comprises a surface of the substrate opposite the first-doped layer.

2. The LED of claim 1, wherein the active layer comprises one or more quantum well layers comprising material selected from semiconductor emitting material and organic molecules.

3. The LED of claim 1, wherein the substrate comprises a material selected from quartz, fused silica, silicon, sapphire and polymer.

4. The LED of claim 1, wherein the first-doped layer is an n-doped layer and the second-doped layer is a p-doped layer.

5. The LED of claim 1, wherein the first-doped layer comprises a material selected from the group comprising Si, Ge, SiC, GaAs, InGaP, InGaAs, InGaN, GaN, AlGaN, ZnSe, ZnCdSe, AlGaAs, InP and a molecule doped polymer or

wherein the second-doped layer comprises a material selected from the group comprising Si, Ge, SiC, GaAs, InGaP, InGaAs, InGaN, GaN, AlGaN, ZnSe, ZnCdSe, AlGaAs, InP and a molecule doped polymer.

6. The LED of claim 1, wherein the active layer comprises a material selected from the group comprising Si, Ge, SiC, GaAs, InGaP, InGaAs, InGaN, GaN, AlGaN, ZnSe, ZnCdSe, CdS, AlGaAs and InP.

7. The LED of claim 1, wherein the metal layer comprises a metal selected from the group consisting of Au, Ag, Al, Cu, Ti, Ni, Cr, Zn, and an alloy formed from one or more of Au, Ag, Al, Cu, Ti, Ni, Cr, and Zn.

8. The LED of claim 1, wherein the metal layer is formed on a first portion of the second-doped layer but not on a second portion of the second-doped layer, or

the metal layer is formed on the first and second portions of the second-doped layer.

9. The LED of claim 1, wherein the metal layer comprises a random array of metal nanoparticles formed through annealing or spincoating of metallic nanoparticles; or wherein the metal layer comprises patterned metallic nanostructures fabricated using lithography and deposition processes.

10. The LED of claim 1, wherein the second-doped layer is patterned with any one of the following: plasmonic nanostructures, metamaterial nanostructures, a structure of sub-wavelength grating, a structure of nanoantennas, and a structure of nanoapertures.

11. The LED of claim 1, further comprising a first electrode in contact with the first-doped layer and an electrode layer forming a second electrode in contact with the second-doped layer, or

comprising a phosphors layer on a surface of the LED.

12. A method for fabricating a light emitting diode (LED), the method comprising:

depositing a first-doped GaN layer with first impurities on a substrate;

forming one or more quantum well layers on the first-doped layer;

depositing a second-doped GaN layer with second impurities on the quantum well layer;

depositing a metal layer over the second-doped layer,

wherein depositing the second-doped GaN layer comprises texturing a plurality of sharp V-pits so that a first portion of the second-doped GaN layer has a first thickness and a second portion of the second-doped GaN layer has a second thickness, the first thickness defining a surface plasmon thickness that is configured to allow electron-hole pairs in the one or more quantum well layers to couple efficiently to a surface plasmon mode at an interface of the metal layer and the second-doped layer for an increased spontaneous emission rate of the LED and the second thickness being determined to ensure formation of a p-n junction in the LED, and wherein a thinnest portion of the second-doped layer and a thinnest portion of the metal layer over the thinnest portion of the second doped layer both are within the surface plasmon coupling thickness.

13. The method of claim 12, further comprises forming an electrode pad being a first electrode in contact with the first-doped GaN layer and the electrode layer forming a second electrode in contact with the second-doped GaN layer.

14. The method of claim 12 wherein depositing the metal layer over the second-doped layer comprises at least one of depositing the metal layer over an electrode layer, annealing or spincoating of metallic nanoparticles.

15. A method for fabricating a light emitting diode (LED), the method comprising:

depositing a first-doped GaN layer with first impurities on a substrate;

forming one or more quantum well layers on the first-doped layer;

depositing a second-doped GaN layer with second impurities on the quantum well layer;

depositing a metal layer over the second-doped layer; and avoiding the second-doped layer where an electrode layer is formed when depositing the metal layer over the second-doped layer, or avoiding a second portion of the second-doped layer when depositing the metal layer over the second-doped layer,

wherein depositing the second-doped GaN layer comprises texturing a plurality of sharp V-pits so that a first portion of the second doped GaN layer has a first thickness and the second portion of the second doped GaN layer has a second thickness, the first thickness defining a surface plasmon thickness that is configured to allow electron-hole pairs in the one or more quantum well layers to couple efficiently to a surface plasmon mode at an interface of the metal layer and the second-doped layer for an increased spontaneous emission rate of the LED and the second thickness being determined to ensure formation of a p-n junction in the LED.

16. The LED of claim 1, wherein the second-doped layer is textured with the plurality of V-pits on the surface opposite to the active layer to further define a second portion that is configured to form a p-n junction in the LED.