The growth of nanowires on graphene is not new. In WO2012/080252, there is a discussion of the growth of semiconductor nanowires on graphene substrates using molecular beam epitaxy (MBE). WO2013/104723 concerns improvements on the '252 disclosure in which a graphene top contact is employed on NWs grown on graphene. These previous documents are not, however, concerned with UV LED flip chips. More recently, the inventors have described core shell nanowires grown on graphene (WO2013/190128).

US 2011/0254034 describes nanostructured LEDs emitting in the visible region. The device comprises a nanostructured LED with a group of nanowires protruding from a substrate. The nanowires have a p-i-n junction and a top portion of each nanowire is covered with a light-reflective contact layer which may also act as an electrode. When a voltage is applied between the electrode and the light-reflective contact layer, light is generated within the nanowire.

No one before, however, has considered an LED flip chip based on nanowires (NWs) or nanopyramids (NPs) grown on graphene.

Summary of Invention

Thus, embodiments of the invention provide a light emitting diode device comprising:

a plurality of nanowires or nanopyramids grown on a graphitic substrate, said nanowires or nanopyramids having a p-n or p-i-n junction,

a first electrode in electrical contact with said graphitic substrate;

a second electrode in contact with the top of at least a portion of said nanowires or nanopyramids optionally in the form of a light reflective layer;

wherein said nanowires or nanopyramids comprise at least one group III-V compound semiconductor. In use, light is preferably emitted in a direction substantially parallel to but opposite from the growth direction of the nanowires.

Thus, viewed from one aspect, the invention provides a light emitting diode device comprising:

a plurality of nanowires or nanopyramids grown on a graphitic substrate, said nanowires or nanopyramids having a p-n or p-i-n junction,

a first electrode in electrical contact with said graphitic substrate;

a light reflective layer in contact with the top of at least a portion of said nanowires or nanopyramids or in contact with a second electrode in electrical contact with the top of at least a portion of said nanowires or nanopyramids, said light reflective layer optionally acting as the second electrode;

optionally a second electrode in electrical contact with the top of at least a portion of said nanowires or nanopyramids, said second electrode being essential where said light reflective layer does not act as an electrode;

wherein said nanowires or nanopyramids comprise at least one group III-V compound semiconductor; and wherein in use light is emitted from said device in a direction substantially opposite to said light reflective layer.

There is also disclosed a light emitting diode device comprising:

a plurality of nanowires or nanopyramids grown on a graphitic substrate, preferably through the holes of an optional hole-patterned mask on said graphitic substrate, said nanowires or nanopyramids having a p-n or p-i-n junction,

a first electrode in electrical contact with said graphitic substrate;

a light reflective layer in contact with the top of at least a portion of said nanowires or nanopyramids, said light reflective layer optionally acting as the second electrode;

a second electrode in electrical contact with the top of at least a portion of said nanowires or nanopyramids, said second electrode being essential where said light reflective layer does not act as an electrode;

wherein said nanowires or nanopyramids comprise at least one group III-V compound semiconductor; and wherein in use light is emitted from said device in a direction substantially opposite to said light reflective layer.

There is also disclosed a nanostructured LED comprising a plurality of group III-V compound semiconductor nanowires or nanopyramids grown epitaxially on a graphitic substrate; wherein

Claims

1. A light emitting diode device comprising:

a plurality of nanowires or nanopyramids grown on a graphitic substrate, said nanowires or nanopyramids having a p-n or p-i-n junction,

a first electrode in electrical contact with said graphitic substrate;

a light reflective layer in contact with the top of at least a portion of said nanowires or nanopyramids or in contact with a second electrode in electrical contact with the top of at least a portion of said nanowires or nanopyramids, said light reflective layer optionally acting as the second electrode;

optionally a second electrode in electrical contact with the top of at least a portion of said nanowires or nanopyramids, said second electrode being essential where said light reflective layer does not act as an electrode;

wherein said nanowires or nanopyramids comprise at least one group III-V compound semiconductor; and wherein in use light is emitted from said device in a direction substantially opposite to said light reflective layer.

2. A photodetector device comprising:

a plurality of nanowires or nanopyramids grown on a graphitic substrate, said nanowires or nanopyramids having a p-n or p-i-n junction,

a first electrode in electrical contact with said graphitic substrate;

a second electrode in contact with the top of at least a portion of said nanowires or nanopyramids optionally in the form of a light reflective layer;

wherein said nanowires or nanopyramids comprise at least one group III-V compound semiconductor; and wherein in use light is absorbed in said device.

3. A device as claimed in any preceding claim wherein said nanowires or nanopyramids are grown through the holes of a hole-patterned mask on said graphitic substrate.

4. A device as claimed in any preceding claim wherein said nanowires or nanopyramids are grown epitaxially.

5. A device as claimed in any preceding claim wherein the substrate is graphene.

6. A device as claimed in any preceding claim wherein the substrate is up to 20 nm in thickness.

7. A device as claimed in any preceding claim wherein the substrate is graphene having up to 10 atomic layers.

8. A device as claimed in any preceding claim wherein the device further comprises a support adjacent the graphitic substrate, opposite to the grown nanowires or nanopyramids.

9. A device as claimed in claim 8 wherein said support is fused silica or quartz.

10. A device as claimed in any preceding claim wherein said device further comprises an intermediate layer adjacent the graphitic substrate, opposite to the grown nanowires or nanopyramids.

11. A device as claimed in claim 10 wherein said intermediate layer is hBN, metal grid or Ag nanowire network.

12. A device as claimed in any preceding claim wherein the nanowires or nanopyramids comprise GaN, AlGaN, InGaN or AlInGaN.

13. A device as claimed in any preceding claim wherein the nanowires or nanopyramids comprise a multiple quantum well, such as an Al(In)GaN MQWs.

14. A device as claimed in any preceding claim wherein the nanowires or nanopyramids contain electron blocking layer, which could be either single barrier or multiquantum barrier.

15. A device as claimed in any preceding claim which emits or absorbs in the UV spectrum.

16. A device as claimed in any preceding claim wherein the p-n or p-i-n junction within a nanowire is axial.

17. A device as claimed in any preceding claim wherein the nanowires or nanopyramids comprise a tunnel junction such as Al or highly doped InGaN layer.

18. A device as claimed in any preceding claim wherein the nanowires or nanopyramids comprise an (Al)GaN/Al(Ga)N superlattice.

19. A device as claimed in any preceding claim wherein the nanowires or nanopyramids comprise AlGaN with an increasing or decreasing concentration of Al along a direction, such as axially, in the nanowire or nanopyramid.

20. A device as claimed in any preceding claim wherein the nanowires or nanopyramids are doped using Mg or Be.

21. A light emitting diode device as claimed in claim 1 or 3 to 20 wherein the space between the nanowires or nanopyramids is filled by a supporting and electrically isolating filler material transparent to the light emitted from the said device.

22. A photodetector device as claimed in claims 2 to 20 wherein the space between the nanowires or nanopyramids is filled by a supporting and electrically isolating filler material transparent to visible and/or UV light entering into the said device.

23. A composition of matter comprising a plurality of group III-V nanowires or nanopyramids grown epitaxially on a graphitic substrate, said nanowires or nanopyramids comprising:

an n-type doped region and a p-type doped region separated by an intrinsic region which acts as a multiple quantum well, said p-type doped region comprising an electron blocking layer.