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, 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 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.

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 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;

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

each of the nanowires or nanopyramids protrudes from the substrate and each nanowire or nanopyramid comprises a p-n or p-i-n-junction;

the top part of at least a portion of said nanowires or nanopyramids is covered with a light-reflective or transparent contact layer to form at least one contact to group of nanowires or nanopyramids;

an electrode is in electrical contact with said graphitic substrate;

the light-reflective or transparent contact layer is in electrical contact with the first electrode via said nanowires or nanopyramids.

There is also disclosed the use of an LED device as hereinbefore defined as a LED, in particular in the UV region of the spectrum.

In a second embodiment, the invention relates to a photodetector. Rather than emitting light, the device of the invention can be adapted to absorb light and subsequently generate a photocurrent and hence detect light.

Thus, viewed from another aspect the invention provides 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.

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

each of the plurality of nanowires or nanopyramids protrudes from the substrate and each nanowire or nanopyramid comprises a p-n- or p-i-n-junction;

a top portion of each nanowire or nanopyramid or at least one group of nanowires or nanopyramids from the plurality of nanowires or nanopyramids is covered with a transparent contact layer to form at least one contact to group of nanowires or nanopyramids;

an electrode is in electrical contact with said graphitic substrate;

the transparent contact layer is in electrical contact with the first electrode via the p-n or p-i-n-junction in said nanowires or nanopyramids.

There is also disclosed the use of a photodetector device as hereinbefore defined as a photodetector, in particular in the UV region of the spectrum.

In another aspect, the invention provides 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.

Definitions

By a group III-V compound semiconductor is meant one comprising at least one element from group III and at least one element from group V. There may be more than one element present from each group, e.g. AlGaN (i.e. a ternary compound), AlInGaN (i.e. a quaternary compound), and so on. The designation Al(In)GaN implies either AlGaN or AlInGaN, i.e. that the presence of In is optional. Any element indicated in brackets may or may not be present.

The term nanowire is used herein to describe a solid, wire-like structure of nanometer dimensions. Nanowires preferably have an even diameter throughout the majority of the nanowire, e.g. at least 75% of its length. The term nanowire is intended to cover the use of nanorods, nanopillars, nanocolumns or nanowhiskers some of which may have tapered end structures. The nanowires can be said to be in essentially in one-dimensional form with nanometer dimensions in their width or diameter and their length typically in the range of a few 100 nm to a few μm. Ideally the nanowire diameter is between 50 and 500 nm, however, the diameter can exceed few microns (called microwires).

Ideally, the diameter at the base of the nanowire and at the top of the nanowire should remain about the same (e.g. within 20% of each other).

The term nanopyramid refers to a solid pyramidal type structure. The term pyramidal is used herein to define a structure with a base whose sides taper to a single point generally above the centre of the base. It will be appreciated that the single vertex point may appear chamferred. The nanopyramids may have multiple faces, such as 3 to 8 faces, or 4 to 7 faces. Thus, the base of the nanopyramids might be a square, pentagonal, hexagonal, heptagonal, octagonal and so on. The pyramid is formed as the faces taper from the base to a central point (forming