free metal-organic vapour phase epitaxy (MOVPE) and the surface morphology of the ZnO nanostructures was dependent on the growth temperature.

The present inventors have found that epitaxial nanowires of certain compounds/elements can be grown on graphitic substrates. Since graphitic substrates have no dangling bonds at the surface and very short atomic bond length compared with typical semiconductors like silicon and GaAs there is no reason to anticipate nucleation and epitaxial growth of nanowires thereon. As surprisingly noted below, there may beis a good lattice match with many semiconductors when using graphene depending on how the semiconductor atoms are placed on the surface of graphene.

In particular, the use of molecular beam epitaxy may offers excellent results in terms of nanowire growth. In particular the invention may enables the growth of group IV, II-VI or in particular group III-V semiconductor nanowires on graphitic substrates. Moreover, this is believed to be the first disclosure of any group III-V epitaxial nanowire grown on a graphitic substrate, and the first disclosure of any catalyst assisted epitaxial nanowire grown on a graphitic substrate.

Summary of Invention

Thus, viewed from one aspect the invention provides a composition of matter comprising at least one nanowire on a graphene, graphane or graphene oxidegraphitic substrate having a thickness of up to 20 nm, said at least one nanowire having been grown epitaxially on said substrate so that the atomic arrangement of the nanowire is based on the crystallographic structure of the substrate,

wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire consists ofcomprises at least one non carbon group IV elements only.

Viewed from another aspect the invention provides a process for preparing at least one nanowire grown epitaxially on a graphene, graphane or graphene oxide substrate having a thickness of up to 20 nmgraphitic substrate comprising the steps of:

(I) providing group II-VI elements or group III-V elements or at least one non carbon group IV element to the surface of said graphitic substrate, preferably via a molecular beam; and

(II) epitaxially growing at least one nanowire from the surface of the ~~graphitic~~ substrate so that the atomic arrangement of the nanowire is based on the crystallographic structure of the substrate.

The present disclosure also~~Viewed from another aspect the invention~~ provides a process for preparing at least one nanowire grown epitaxially on a graphitic substrate in the presence of a catalyst comprising the steps of:

(I) providing group II-VI elements or group III-V elements or at least one non carbon group IV element to the surface of said graphitic substrate, preferably via a molecular beam; and

(II) epitaxially growing at least one nanowire from the surface of the graphitic substrate.

Optionally, the surface of the graphitic substrate can be chemically/ physically modified to enhance the epitaxial growth of nanowires.

The present disclosure also~~Viewed from another aspect the invention~~ provides a nanowire made by a process as hereinbefore defined.

Embodiments of~~Viewed from another aspect~~ the invention provides a device, such as an electronic device, comprising a composition as hereinbefore defined, e.g. a solar cell.

Viewed from another aspect the invention provides the use of molecular beam epitaxy to grow ~~at least one~~ nanowire on a graphene, graphane or graphene oxide substrate having a thickness of up to 20 nm wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire comprises non carbon group IV elements only so that the atomic arrangement of the nanowire is based on the crystallographic structure of the~~as hereinbefore defined on a graphitic~~ substrate.

Definitions

By a group III-V compound is meant one comprising at least one ion from group III and at least one ion from group V. Similarly, a group II-VI compound is one comprising at least one group II ion and at least one group VI ion. There may be more than one ion present from each group, e.g. InGaAs and so on. Non carbon group IV nanowires are those that contain at least one non carbon group IV element only, for example a Si nanowire.

The term nanowire is used herein to describe a solid, wire like structure of nano 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

Claims

1. A composition of matter comprising at least one nanowire on a graphitic substrate, said at least one nanowire having been grown epitaxially on said substrate,

wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire consists of non carbon group IV elements only.

2. A composition as claimed in claim 1 wherein said nanowire grows in the [111] or [0001] direction.

3. A composition as claimed in any preceding claim wherein the nanowire comprises a group III-V compound.

4. A composition as claimed in any preceding claim in which the nanowires comprise GaSb, GaP, GaAs or InAs.

5. A composition as claimed in any preceding claim wherein the graphitic substrate comprises graphene, graphane or graphene oxide, preferably wherein said graphene, graphane or graphene oxide comprises 10 or fewer layers.

6. A composition as claimed in any preceding claim wherein the graphitic substrate is a laminated substrate exfoliated from a Kish graphite, a highly ordered pyrolytic graphite (HOPG), CVD-grown graphene layers on Ni films, or CVD-grown graphene layers on Cu foils.

7. A composition as claimed in any preceding claim wherein the graphitic substrate is flexible and transparent

8. A composition as claimed in any preceding claim wherein the surface of substrate is modified with a plasma treatment with a gas of oxygen, hydrogen, NO_2, and their combinations.

9. A composition as claimed in any preceding claim wherein the surface of substrate is modified by chemical doping using a solution of $FeCl_3$, $AuCl_3$ or $GaCl_3$.

10. A composition as claimed in any preceding claim wherein said nanowire is no more than 200 nm in diameter and has a length of up to 5 microns.

11. A composition as claimed in any preceding claim wherein said substrate comprises a plurality of nanowires wherein said nanowires are substantially parallel.

12. A composition as claimed in any preceding claim wherein said nanowires are grown in the presence of a catalyst.

13. A process for preparing at least one nanowire grown epitaxially on a graphitic substrate comprising the steps of:

(I) providing group II-VI elements or group III-V elements or at least one non carbon group IV element to the surface of said graphitic substrate, preferably via a molecular beam; and

(II) epitaxially growing at least one nanowire from the surface of the graphitic substrate.

14. A process as claimed in claim 13 in which a catalyst is deposited on the substrate.

15. A process as claimed in claim 14 wherein said catalyst is Au or the metal of the nanowire to be grown, e.g. Ga.

16. A process as claimed in claim 14 to 15 where the substrate is coated with a hole-patterned mask, said catalyst being introduced on to the graphitic substrate surface exposed via the hole pattern.

17. A process as claimed in claim 16 where the hole-patterned mask comprises SiO_2 or Si_3N_4, e.g. deposited by e-beam evaporation, CVD, PE-CVD, or sputtering.

18. A process as claimed in claim 16 to 17 where the surface of the graphitic substrate exposed through the hole pattern is modified with a plasma treatment with a gas of oxygen, hydrogen, NO_2, and their combinations.

19. A device comprising a composition as claimed in any one of claims 1 to 12, e.g. an optical or electronic device, e.g. a solar cell.

20. Use of molecular beam epitaxy to grow a nanowire on a graphitic substrate, wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire comprises non carbon group IV elements only.

The claims defining the invention are as follows:

1. A composition of matter comprising at least one nanowire on a graphene, graphane or graphene oxide substrate having a thickness of up to 20 nm, said at least one nanowire having been grown epitaxially on said substrate so that the atomic arrangement of the nanowire is based on the crystallographic structure of the substrate,

wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire consists of non carbon group IV elements only.

2. A composition as claimed in claim 1 wherein said nanowire grows in the [111] or [0001] direction.

3. A composition as claimed in claim 1 or 2 wherein the nanowire comprises a group III-V compound.

4. A composition as claimed in any one of the preceding claims in which the nanowires comprise GaSb, GaP, GaAs or InAs.

5. A composition as claimed in any one of the preceding claims wherein the substrate comprises graphene, graphane or graphene oxide, wherein said graphene, graphane or graphene oxide comprises 10 or fewer layers.

6. A composition as claimed in any one of the preceding claims wherein the substrate is a laminated substrate exfoliated from a Kish graphite, a highly ordered pyrolytic graphite (HOPG), CVD-grown graphene layers on Ni films, or CVD-grown graphene layers on Cu foils.

7. A composition as claimed in any one of the preceding claims wherein the substrate is flexible and transparent.

8. A composition as claimed in any one of the preceding claims wherein the surface of substrate is modified with a plasma treatment with a gas of oxygen, hydrogen, NO_2, and their combinations.

9. A composition as claimed in any one of the preceding claims wherein the surface of substrate is modified by chemical doping using a solution of $FeCl_3$, $AuCl_3$ or $GaCl_3$.

10. A composition as claimed in any one of the preceding claims wherein said nanowire is no more than 200 nm in diameter and has a length of up to 5 microns.

11. A composition as claimed in any one of the preceding claims wherein said substrate comprises a plurality of nanowires wherein said nanowires are substantially parallel.

12. A composition as claimed in any one of the preceding claims wherein said nanowires are grown in the presence of a catalyst.

13. A process for preparing at least one nanowire grown epitaxially on a graphene, graphane or graphene oxide substrate having a thickness of up to 20 nm comprising the steps of:

(I) providing group II-VI elements or group III-V elements or at least one non carbon group IV element to the surface of said substrate, preferably via a molecular beam; and

(II) epitaxially growing at least one nanowire from the surface of the substrate so that the atomic arrangement of the nanowire is based on the crystallographic structure of the substrate.

14. A process as claimed in claim 13 in which a catalyst is deposited on the substrate.

15. A process as claimed in claim 13 to 14 wherein said catalyst is Au or the metal of the nanowire to be grown, e.g. Ga.

16. A process as claimed in any one of claims 13 to 15 where the substrate is coated with a hole-patterned mask, said catalyst being introduced on to the substrate surface exposed via the hole pattern.

17. A process as claimed in claim 16 where the hole-patterned mask comprises SiO_2 or Si_3N_4, e.g. deposited by e-beam evaporation, CVD, PE-CVD, or sputtering.

18. A process as claimed in claim 16 to 17 where the surface of the substrate exposed through the hole pattern is modified with a plasma treatment with a gas of oxygen, hydrogen, NO_2, and their combinations.

19. A device comprising a composition as claimed in claims 1 to 12, e.g. an optical or electronic device, e.g. a solar cell.

20. Use of molecular beam epitaxy to grow a nanowire on a graphene, graphane or graphene oxide substrate having a thickness of up to 20 nm wherein said nanowire comprises at least one group III-V compound or at least one group II-VI compound or wherein said nanowire comprises non carbon group IV elements only so that the atomic arrangement of the nanowire is based on the crystallographic structure of the substrate.