an outer conducting coating surrounding said shell which forms an electrode contact.

There is disclosed a composition of matter, in particular a photovoltaic cell, comprising:

at least one core semiconductor nanowire on a graphitic substrate, said at least one core 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 at least one group IV element;

a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound or at least one group II-VI compound or at least one group IV element such that said core nanowire and said shell form a n-type semiconductor and a p-type semiconductor respectively or vice versa; and

an outer contact and/or conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene.

According to a first aspect of the present invention, there is provided a composition of matter, in particular a photovoltaic cell, comprising:

at least one core semiconductor nanowire on a graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, said at least one core 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 at least one group IV element~~;

a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ such that said core nanowire and said shell form a n-type semiconductor and a p-type semiconductor respectively or vice versa; and optionally an outer conducting coating surrounding said shell which forms an electrode contact or a contact and/or conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene.

There is disclosed a process for preparing a cell as hereinbefore defined comprising:

(I) providing group II-VI elements or group III-V elements or at least

one group IV element to the surface of said graphitic substrate, preferably via a molecular beam;

(II) epitaxially growing at least one nanowire from the surface of the graphitic substrate to provide a nanowire core;

(III) coating said at least one nanowire core with a shell comprising at least one group III-V compound or at least one group II-VI compound or at least one group IV element such that said core nanowire and said shell form a n/p junction or a p/n junction respectively; and

(IV) coating said shell with an outer conducting coating surrounding said shell which forms an electrode contact, preferably a transparent electrode contact; or providing a conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene.

According to a second aspect of the present invention, there is provided a composition of matter, in particular a photovoltaic cell, comprising: at least one core semiconductor nanowire on a graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, said at least one nanowire having been grown epitaxially on said substrate wherein said nanowire comprises a bottom portion comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ which has been doped to form an n-type or p-type semiconductor; and an upper portion comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ which has been doped such that said upper portion forms a n-type semiconductor or p-type semiconductor opposite to that of the bottom portion.

According to a third aspect of the present invention, there is provided a composition of matter, in particular a tandem photovoltaic cell, comprising: at least one core semiconductor nanowire on a graphene layer, said at least one core nanowire having been grown epitaxially on said graphene layer wherein said nanowire comprises at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~; a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ such that said core nanowire and said shell form an n-type semiconductor and a p-type semiconductor respectively or vice versa; and an outer conducting coating surrounding said shell which forms an electrode contact; or an outer conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a

Claims

1. A composition of matter, in particular a photovoltaic cell, comprising:

at least one core semiconductor nanowire on a graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, said at least one core 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 at least one group IV element~~;

a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ such that said core nanowire and said shell form a n-type semiconductor and a p-type semiconductor respectively or vice versa; and optionally

an outer conducting coating surrounding said shell which forms an electrode contact or a contact and/or conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene.

2. A composition of matter as claimed in claim 1, in particular a photovoltaic cell, comprising:

at least one core semiconductor nanowire on a graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, said at least one core 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 at least one group IV element~~;

a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ such that said core nanowire and said shell form an n-type semiconductor and a p-type semiconductor respectively or vice versa; and

an outer conducting coating surrounding said shell which forms an electrode contact.

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

~~4. A composition as claimed in any preceding claim wherein said shell and core nanowire independently comprise a group III-V compound.~~

~~5~~4. A composition as claimed in any preceding claim in which the nanowires comprise AlAs, ZnO, GaSb, GaP, GaN, GaAs, InP, InN, InAs, InGaAs or AlGaAs.

~~6~~5. A composition as claimed in any preceding claim wherein the graphene, graphane or graphene oxide comprises 10 or fewer layers.

~~7~~6. A composition as claimed in any preceding claim wherein the substrate is CVD-grown graphene layers on metallic films or foils such as Ni, Cu, or Pt .

~~8~~7. A composition as claimed in any preceding claim wherein the substrate is flexible and transparent.

~~9~~8. A composition as claimed in any preceding claim wherein the substrate is doped with the same doping carriers as the contacted nanowires.

~~10~~9. A composition as claimed in any preceding claim wherein the substrate is doped by adsorption of organic or inorganic molecules such as metal-chlorides ($FeCl_3$, $AuCl_3$ or $GaCl_3$), NO_2, HNO_3, aromatic molecules or ammonia.

~~11~~10. A composition as claimed in any preceding claim wherein said surface of the substrate is doped by a substitutional doping method during its growth with incorporation of dopants such as B, N, S, or Si.

~~12~~11. A composition as claimed in any preceding claim wherein said surface of the substrate is provided with nanostructures, such as nanowires or nanoparticles, with high conductivity (> 10^3 S/cm) dispersed thereon.

~~13~~12. A composition as claimed in any preceding claim wherein said nanowire is no more than 500 nm in diameter and has a length of up to 8 microns, such as up to 5 microns.

~~14~~13. A composition as claimed in any preceding claim wherein said substrate comprises a plurality of nanowires wherein said nanowires are substantially parallel.

~~15~~14. A composition as claimed in any preceding claim wherein said nanowires are grown in the presence of a catalyst.

~~16~~15. A composition as claimed in any preceding claim wherein said outer coating is a mixed metal oxide with high conductivity and transparency such as AlZnO (AZO) and InSnO (ITO) or/and a further graphitic layer.

~~17~~16. A composition as claimed in any preceding claim wherein said core is p- type semiconductor and said shell is an n-type semiconductor.

~~18~~17. A composition as claimed in any preceding claim wherein an undoped (intrinsic) layer is present between said core and shell layers.

~~19~~18. A process for preparing a cell as claimed in claims 1 to ~~18~~ 17 comprising:

(I) providing ~~group II-VI elements or~~ group III-V elements ~~or group IV elements~~ to the surface of said graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, preferably via a molecular beam;

(II) epitaxially growing at least one nanowire from the surface of the graphitic substrate to provide a nanowire core;

(III) coating said at least one nanowire core with a shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one~~

~~group IV element~~ such that said core nanowire and said shell form a n/p junction or a p/n junction respectively; and

(IV) coating said shell with an outer conducting coating surrounding said shell which forms an electrode contact, preferably a transparent electrode contact; or providing a conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene.

~~20~~19. A solar cell, comprising a cell as claimed in claim 1 to ~~18~~17.

~~21~~20. A solar cell comprising a plurality of photovoltaic cells as claimed in claim 1 to ~~18~~17 preferably stacked vertically on top of each other.

~~22~~21. A solar cell comprising a plurality of photovoltaic cells as claimed in claim 1 to ~~18~~17 wherein at least two of said photovoltaic cells have different band gaps.

~~23~~22. A process as claimed in claim ~~19~~18 in which a catalyst is deposited on the substrate in step (I) prior to supply of the reactants thereto.

~~24~~23. A process as claimed in claim ~~19~~18 or ~~23~~22 where the substrate is coated with a hole-patterned mask in step (I) prior to supply of the reactants thereto.

~~25~~24. A composition of matter, in particular a photovoltaic cell, comprising:

at least one core semiconductor nanowire on a graphene, graphane or graphene oxide substrate having a thickness of 20 nm or less, said at least one nanowire having been grown epitaxially on said substrate wherein said nanowire comprises a bottom portion comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ which has been doped to form an n-type or p-type semiconductor; and

an upper portion comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ which has been doped such that said upper portion forms a n-type semiconductor or p-type semiconductor opposite to that of the bottom portion.

~~26~~25. A composition as claimed in claim 1 to ~~18~~17 or ~~25~~24 where graphitic layers are used as the top contact for the formed nanowires.

~~27~~26. A composition of matter, in particular a tandem photovoltaic cell, comprising:

(A) at least one core semiconductor nanowire on a graphene layer, said at least one core nanowire having been grown epitaxially on said graphene layer wherein said nanowire comprises at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~;

a semiconductor shell surrounding said core nanowire, said shell comprising at least one group III-V compound ~~or at least one group II-VI compound or at least one group IV element~~ such that said core nanowire and said shell form an n-type semiconductor and a p-type semiconductor respectively or vice versa; and

an outer conducting coating surrounding said shell which forms an electrode contact; or

an outer conducting layer which contacts the top of the semiconductor shell on said nanowire and which forms an electrode, e.g. a transparent graphitic layer such as graphene; and

(B) a thin-film p-n junction cell having a bottom electrode and a top electrode;

where said graphene layer serves as the top electrode for the thin-film p-n junction cell.

~~28~~27. A composition of matter as claimed in claim ~~27~~26 further comprising a photovoltaic cell as claimed in claim stacked thereon, preferably separated from the electrode contact via a dielectric layer or air gap.