CLAIMS

What is claimed is:

~~1. A method of forming inorganic nanorods on a transparent inorganic metal oxide substrate, the method comprising exposing the inorganic metal oxide substrate to an inductively coupled plasma at suitable conditions, wherein the plasma comprises one or more precursor materials suitable for forming the inorganic nanorods on the transparent inorganic metal oxide substrate at the given reaction conditions.~~

~~2. The method as claimed in claim 1, wherein the inorganic nanorods comprise a material selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5, WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.~~

~~3. The method as claimed in claim 1 or 2, wherein exposing the inorganic metal oxide substrate to the plasma is part of a process of chemical vapor deposition to form the inorganic nanorods on the inorganic metal oxide substrate.~~

~~4. The method as claimed in any one of claims 1 to 3, wherein the inorganic metal oxide substrate is selected from the group consisting of glass, quartz, crystal, ceramic and composite.~~

~~5. The method as claimed in any one of claims 1 to 4, wherein the inorganic metal oxide substrate is coated with at least one layer of coating material, wherein the coating material is selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5,WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.~~

6. The method as claimed in claim 5, wherein the at least one layer of coating material is configured to be a transparent conductive oxide electrode or a seeding layer or a protective layer or a combination thereof.

7. The method as claimed in any one of claims 1 to 6, wherein the inorganic metal oxide substrate is at a temperature of ≤ 400°C when exposing the inorganic metal oxide substrate to the plasma.

8. The method as claimed in any one of claims 1 to 7, wherein the plasma is generated at a power of ≥ 400 W.

9. The method as claimed in any one of claims 1 to 8, wherein the plasma further comprises gaseous argon and gaseous oxygen.

10. The method as claimed in claim 9, wherein the gaseous argon and the gaseous oxygen are provided at a combined flow rate of between about 1.67×10^{-7} m^3/s to about 1.67×10^{-5} m^3/s.

11. The method as claimed in claim 9 or 10, wherein the gaseous argon is provided at a flow rate of between about 0 to about 1.67×10^{-5} m^3/s.

12. The method as claimed in any one of claims 9 to 11, wherein the gaseous oxygen is provided at a flow rate of between about 1.67×10^{-9} m^3/s to about 1.67×10^{-5} m^3/s.

13. The method as claimed in any one of claims 10 to 12, wherein a ratio of the flow rate of the gaseous argon to the flow rate of the gaseous oxygen is between about 0 to about 50.

14. The method as claimed in any one of claims 1 to 13, wherein at least one portion of the inorganic metal oxide substrate is patterned.

~~15. The method as claimed in any one of claims 1 to 14, wherein the inorganic metal oxide substrate is conductive or semiconductive.~~

~~16. The method as claimed in any one of claims 1 to 15, wherein the inorganic metal oxide substrate comprises a metal oxide or a metalloid oxide.~~

~~17. A method of forming tin oxide nanorods on a transparent inorganic metal oxide substrate, the method comprising exposing the inorganic metal oxide substrate to an inductively coupled plasma at suitable conditions, wherein the plasma comprises one or more tin precursor materials suitable for forming the tin oxide nanorods on the transparent inorganic metal oxide substrate at the given reaction conditions.~~

~~18. The method as claimed in claim 17, wherein the one or more tin precursor materials are selected from the group consisting of dibutyltin diacetate, monobutyltin chloride, monobutyltin trichloride, monomethyltin trichloride, dimethyltin chloride, dimethyltin dichloride, trimethyltin chloride, tetramethyltin, tin tetrachloride, tin tert-butoxide, tin acetate, tin bis(acetylacetonate), tin 2-ethylhexanoate, tin oxalate, tin phthalocyanine and any combination thereof.~~

~~19. The method as claimed in claim 17 or 18, wherein exposing the inorganic metal oxide substrate to the plasma is part of a process of chemical vapor deposition to form the tin oxide nanorods on the inorganic metal oxide substrate.~~

~~20. The method as claimed in any one of claims 17 to 19, wherein the inorganic metal oxide substrate is selected from the group consisting of glass, quartz, crystal, ceramic and composite.~~

~~21. The method as claimed in any one of claims 17 to 20, wherein the inorganic metal oxide substrate is coated with at least one layer of coating material, wherein the coating material is selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN,~~

~~Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5,WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.~~

~~22. The method as claimed in claim 21, wherein the at least one layer of coating material is configured to be a transparent conductive oxide electrode or a seeding layer or a protective layer or a combination thereof.~~

~~23. The method as claimed in any one of claims 17 to 22, wherein the inorganic metal oxide substrate is at a temperature of ≤ 400°C when exposing the inorganic metal oxide substrate to the plasma.~~

~~24. The method as claimed in any one of claims 17 to 23, wherein the plasma is generated at a power of ≥ 400 W.~~

~~25. The method as claimed in any one of claims 17 to 24, wherein the plasma further comprises gaseous argon and gaseous oxygen.~~

~~26. The method as claimed in claim 25, wherein the gaseous argon and the gaseous oxygen are provided at a combined flow rate of between about 1.67×10^{-7} m^3/s to about 1.67×10^{-5} m^3/s.~~

~~27. The method as claimed in claim 25 or 26, wherein the gaseous argon is provided at a flow rate of between about 0 to about 1.67×10^{-5} m^3/s.~~

~~28. The method as claimed in claim any one of claims 25 to 27, wherein the gaseous oxygen is provided at a flow rate of between about 1.67×10^{-9} m^3/s to about 1.67×10^{-5} m^3/s.~~

~~29. The method as claimed in any one of claims 26 to 28, wherein a ratio of the flow rate of the gaseous argon to the flow rate of the gaseous oxygen is between about 0 to about 50.~~

~~30. The method as claimed in any one of claims 17 to 29, wherein at least one portion of the inorganic metal oxide substrate is patterned.~~

~~31. The method as claimed in any one of claims 17 to 30, wherein the inorganic metal oxide substrate is conductive or semiconductive.~~

~~32. The method as claimed in any one of claims 17 to 31, wherein the inorganic metal oxide substrate comprises a metal oxide or a metalloid oxide.~~

~~33~~1. A photovoltaic device comprising:

a photoelectrode comprising inorganic nanorods on an inorganic metal oxide substrate; and

a mesoporous film configured to at least substantially contact the photoelectrode.

~~34~~2. The photovoltaic device as claimed in claim ~~33~~1, wherein the inorganic nanorods comprise a material selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5, WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.

~~35~~3. The photovoltaic device as claimed in claim ~~33~~-1 or ~~34~~2, wherein the inorganic metal oxide substrate is selected from the group consisting of glass, quartz, crystal and ceramic.

~~36~~4. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~35~~3, wherein the inorganic metal oxide substrate is coated with at least one layer of coating material,

wherein the coating material is selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5,WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.

~~37~~5. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~36~~4, wherein the mesoporous film comprises a material selected from the group consisting of TiO_2, ZnO, SnO_2, TiN, $SrTiO_3$ and Nb_2O_5.

~~38~~6. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~37~~5, wherein the mesoporous film comprises nanostructures comprising a material selected from the group consisting of TiO_2, ZnO, SnO_2, $SrTiO_3$, Nb_2O_5 and any combination thereof.

~~39~~7. The photovoltaic device as claimed in claim ~~38~~6, wherein the nanostructures are selected from a group consisting of nanoparticles, nanorods, nanowires, nanotubes, nanosheets, nanospheres and any combination thereof.

~~40~~8. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~39~~7, wherein at least one portion of the inorganic metal oxide substrate is patterned.

~~41~~9. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~40~~8, wherein the inorganic metal oxide substrate is transparent.

~~42~~10. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~41~~9, wherein the inorganic metal oxide substrate is conductive or semiconductive.

~~43~~11. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~42~~10, wherein the inorganic nanorods are at least substantially perpendicular to the inorganic metal oxide substrate.

4412. The photovoltaic device as claimed in any one of claims ~~33~~ 1 to ~~43~~11, wherein the inorganic nanorods are doped with a material selected from the group consisting of F, Sb, In, Zn and any combination thereof.

4513. The photovoltaic device as claimed in any one of claims ~~33~~ 1 to 4412, wherein the inorganic nanorods further comprise a layer of coating on a surface of the inorganic nanorods to form core-sheath nanorods.

4614. The photovoltaic device as claimed in claim ~~45~~13, wherein the layer of coating comprises a material selected from the group consisting of titanium dioxide, zinc oxide, magnesium oxide, aluminium oxide, niobium oxide and strontium titanate.

4715. The photovoltaic device as claimed in any one of claims ~~33~~ 1 to 4614, wherein the photoelectrode further comprises a nanoparticle, or a nanorod, or a nanowire, or a nanotube, or a nanoflower, or a nanobrush, or a nanocrystal, or a nanocrystalline film, or any combination thereof.

4816. The photovoltaic device as claimed in any one of claims ~~33~~ 1 to ~~47~~15, wherein the photoelectrode further comprises a sensitizer.

4917. The photovoltaic device as claimed in claim ~~48~~16, wherein the sensitizer comprises a dye, or a quantum dot, or a nanocrystal, or a nanocrystalline film, or a photonic crystal, or any combination thereof.

~~50~~18. The photovoltaic device as claimed in claim ~~49~~17, wherein the dye is selected from a group consisting of N719, N749, Z907 and N3.

~~51~~19. The photovoltaic device as claimed in claim ~~49~~17, wherein the sensitizer selected from a group consisting of the quantum dot, the nanocrystal, the nanocrystalline film and the photonic crystal comprises a compound selected from the group consisting of ZnS, ZnSe, CdS, CdSe, CdTe, PbS, PbSe, InAs, InP, NiO, SnS, SnS_2, Cu_2O, Si, Se, In_2S3,

AgS_2, Sb_2S_3, CuS_2, $CuInS_2$, $CuIn(S,Se)_2$, $Cu(In,Ga)Se_2$, $Cu(In,Ga)(S,Se)_2$, Cu_2ZnSnS_4, $Cu_2ZnSnSe_4$ and $Cu_2CdSnSe_4$.

~~52~~20. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~51~~19, further comprising an electrolyte.

~~53~~21. The photovoltaic device as claimed in claim ~~52~~20, wherein the electrolyte comprises a solid, or a semisolid, or a gel, or a liquid.

~~54~~22. The photovoltaic device as claimed in claim ~~52~~-20 or ~~53~~21, wherein the electrolyte comprises iodine, or iodide, or copper iodide, or copper thiocyanate or any combination thereof.

~~55~~23. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~54~~22, further comprising a counter electrode.

~~56~~24. The photovoltaic device as claimed in any one of claims ~~33~~-1 to ~~55~~23, wherein the photovoltaic device is a solar cell.

CLAIMS

What is claimed is:

1. A photovoltaic device comprising:

a photoelectrode comprising inorganic nanorods on an inorganic metal oxide substrate; and

a mesoporous film configured to at least substantially contact the photoelectrode.

2. The photovoltaic device as claimed in claim 1, wherein the inorganic nanorods comprise a material selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5, WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.

3. The photovoltaic device as claimed in claim 1 or 2, wherein the inorganic metal oxide substrate is selected from the group consisting of glass, quartz, crystal and ceramic.

4. The photovoltaic device as claimed in any one of claims 1 to 3, wherein the inorganic metal oxide substrate is coated with at least one layer of coating material, wherein the coating material is selected from the group consisting of SnO_2, SnO, In_2O_3, ZnO, TiO_2, TiN, Fe_2O_3, CuO, Cu_2O, VO_2, V_2O_5, Nb_2O_5,WO_3, CdO, F-doped SnO_2, Sb-doped SnO_2, Sn-doped In_2O_3, F-doped In_2O_3, ZnO-doped In_2O_3 (ZIO), Al-doped ZnO (AZO), F-doped ZnO, Ga-doped ZnO (GZO), Nb-doped TiO_2, Nb-doped $SrTiO_3$, (La, Sr)CoO_3, (La, Sr)MnO_3, $SrRuO_3$, $CuAlO_2$, $CuInO_2$ and any combination thereof.

5. The photovoltaic device as claimed in any one of claims 1 to 4, wherein the mesoporous film comprises a material selected from the group consisting of TiO_2, ZnO, SnO_2, TiN, $SrTiO_3$ and Nb_2O_5.

6. The photovoltaic device as claimed in any one of claims 1 to 5, wherein the mesoporous film comprises nanostructures comprising a material selected from the group consisting of TiO_2, ZnO, SnO_2, $SrTiO_3$, Nb_2O_5 and any combination thereof.

7. The photovoltaic device as claimed in claim 6, wherein the nanostructures are selected from a group consisting of nanoparticles, nanorods, nanowires, nanotubes, nanosheets, nanospheres and any combination thereof.

8. The photovoltaic device as claimed in any one of claims 1 to 7, wherein at least one portion of the inorganic metal oxide substrate is patterned.

9. The photovoltaic device as claimed in any one of claims 1 to 8, wherein the inorganic metal oxide substrate is transparent.

10. The photovoltaic device as claimed in any one of claims 1 to 9, wherein the inorganic metal oxide substrate is conductive or semiconductive.

11. The photovoltaic device as claimed in any one of claims 1 to 10, wherein the inorganic nanorods are at least substantially perpendicular to the inorganic metal oxide substrate.

12. The photovoltaic device as claimed in any one of claims 1 to 11, wherein the inorganic nanorods are doped with a material selected from the group consisting of F, Sb, In, Zn and any combination thereof.

13. The photovoltaic device as claimed in any one of claims 1 to 12, wherein the inorganic nanorods further comprise a layer of coating on a surface of the inorganic nanorods to form core-sheath nanorods.

14. The photovoltaic device as claimed in claim 13, wherein the layer of coating comprises a material selected from the group consisting of titanium dioxide, zinc oxide, magnesium oxide, aluminium oxide, niobium oxide and strontium titanate.

15. The photovoltaic device as claimed in any one of claims 1 to 14, wherein the photoelectrode further comprises a nanoparticle, or a nanorod, or a nanowire, or a nanotube, or a nanoflower, or a nanobrush, or a nanocrystal, or a nanocrystalline film, or any combination thereof.

16. The photovoltaic device as claimed in any one of claims 1 to 15, wherein the photoelectrode further comprises a sensitizer.

17. The photovoltaic device as claimed in claim 16, wherein the sensitizer comprises a dye, or a quantum dot, or a nanocrystal, or a nanocrystalline film, or a photonic crystal, or any combination thereof.

18. The photovoltaic device as claimed in claim 17, wherein the dye is selected from a group consisting of N719, N749, Z907 and N3.

19. The photovoltaic device as claimed in claim 17, wherein the sensitizer selected from a group consisting of the quantum dot, the nanocrystal, the nanocrystalline film and the photonic crystal comprises a compound selected from the group consisting of ZnS, ZnSe, CdS, CdSe, CdTe, PbS, PbSe, InAs, InP, NiO, SnS, SnS_2, Cu_2O, Si, Se, In_2S3, AgS_2, Sb_2S_3, CuS_2, $CuInS_2$, $CuIn(S,Se)_2$, $Cu(In,Ga)Se_2$, $Cu(In,Ga)(S,Se)_2$, Cu_2ZnSnS_4, $Cu_2ZnSnSe_4$ and $Cu_2CdSnSe_4$.

20. The photovoltaic device as claimed in any one of claims 1 to 19, further comprising an electrolyte.

21. The photovoltaic device as claimed in claim 20, wherein the electrolyte comprises a solid, or a semisolid, or a gel, or a liquid.

22. The photovoltaic device as claimed in claim 20 or 21, wherein the electrolyte comprises iodine, or iodide, or copper iodide, or copper thiocyanate or any combination thereof.

23. The photovoltaic device as claimed in any one of claims 1 to 22, further comprising a counter electrode.

24. The photovoltaic device as claimed in any one of claims 1 to 23, wherein the photovoltaic device is a solar cell.