Claims

1. A method of producing a two-dimensional crystalline material, the method comprising:

providing a substrate having nucleation sites within a reaction chamber;

introducing at a precursor entry point a precursor into the reaction chamber, the precursor being in a gas phase and/or suspended in a gas;

heating the substrate to a temperature that is within a decomposition range of the precursor, and that allows two-dimensional crystalline material formation from a species released from the decomposed precursor; characterised in:

cooling the precursor entry point;

the reaction chamber being a close coupled reaction chamber;

providing a separation between the substrate surface upon which the two-dimensional crystalline material is formed and the point at which the precursor enters the reaction chamber that is sufficiently small, and a thermal gradient between the substrate surface and the point at which the precursor enters the chamber that is sufficiently steep, that the fraction of precursor that reacts in the gas phase within the reaction chamber is low enough to allow the formation of the two-dimensional crystalline material; and

wherein the distance between the surface of the substrate upon which the two-dimensional crystalline material is produced and the point at which precursor enters the chamber is less than 100mm; and

wherein the two-dimensional crystalline material is graphene and the species is carbon or wherein the two-dimensional crystalline material is silicene and the species is silicon.

2. The method according to claim 1 comprising sealing the close coupled reaction chamber after introducing the precursor to minimise or prevent flow of the precursor into or out of the close coupled reaction chamber.

3. The method according to claim 1 or 2 comprising passing a flow of precursor over the heated substrate within the close coupled reaction chamber.

4. The method according to claim 3 wherein the flow of precursor impinges on a boundary layer of the substrate from a direction that is perpendicular to the substrate surface.

5. The method according to any of claims 1-4 comprising providing uniform volumetric flow of precursor over an entire surface of the substrate.

6. The method according to any of claims 3, 4 or 5 comprising pulsing the flow of precursor over the heated substrate.

7. The method according to any of claims 1-6 comprising providing a first set of reactor conditions to promote initial adsorption of the constituent to the substrate, followed by providing a second set of reactor conditions to promote formation and coalescence of a two-dimensional crystalline material layer.

8. The method according to claim 7 wherein providing the second set of reactor conditions comprises changing the temperature of the substrate and/or changing the pressure within the reaction chamber and/or changing the flow rate of precursor over the substrate.

9. The method according to any of claims 1-8 wherein the distance between the surface of the substrate upon which the two-dimensional crystalline material is produced and the point at which precursor enters the chamber is less than or equal to 60mm.

10. The method according to any of claims 1-9 wherein the distance between the surface of the substrate upon which the two-dimensional crystalline material is produced and a ceiling of the close couple reaction chamber directly opposite the substrate is less than 100mm, and more preferably less than or equal to 60mm.

11. The method according to claim 9 or 10 wherein the distance is less than or equal to 20mm.

12. The method according to claim 11 wherein the distance is less than 10mm.

13. The method according to any of the previous claims wherein the substrate provides a crystalline surface upon which the two-dimensional crystalline material is produced.

14. The method according to any of the previous claims wherein the substrate provides a non-metallic surface upon which the two-dimensional crystalline material is produced.

15. The method according to any of claims 5-14 wherein a mixture of the precursor with a dilution gas is passed over the heated substrate.

16. The method according to claim 15 wherein the dilution gas includes one or more from the list of hydrogen, nitrogen, argon and helium.

17. The method according to claim 16 wherein the dilution gas includes hydrogen and/or nitrogen.

18. The method according to any of the previous claims comprising introducing a doping element into the close coupled reaction chamber and selecting a temperature of the substrate, a pressure of the close coupled reaction chamber, and a gas flow rate to produce a doped two-dimensional crystalline material.

19. The method according to claim 18 wherein the precursor includes the doping element.

20. The method according to claim 18 wherein a second precursor being in a gas phase and/or suspended in a gas and that comprises the doping element is passed over the heated substrate within the close coupled reaction chamber.

21. The method according to claim 20 wherein the flow of the second precursor over the heated substrate is pulsed.

22. The method according to claim 20 or 21 wherein the second precursor includes one or more compounds from one or more of the following groups: metalorganic, metallocene, halocarbon, hydride and halogen.

23. A method of producing multiple stacked two-dimensional crystalline material layers comprising using the method of any one of claims 1-22 to produce a first layer of two-dimensional crystalline material or doped two-dimensional crystalline material; followed by changing the temperature of the substrate and/or changing the pressure of the reaction chamber and/or changing the flow rate of precursor to form a further two-dimensional crystalline material layer or doped two-dimensional crystalline material layer on the first layer of two-dimensional crystalline material or doped two-dimensional crystalline material.

24. The method according to claim 23 comprises changing the precursor and/or introducing a second precursor being in a gas phase and/or suspended in a gas, to form the further two-dimensional crystalline material layer.

25. The method according to any of the previous claims wherein the precursor includes one or more compounds from any one or more of the groups: hydrocarbon, hydride, halocarbon, including haloalkane and halo amides, metallocene, metalorganic, amine including alkylamines, organic solvents and azo compounds, and optionally azides, imides, sulphides and phosphides.

26. The method according to claim 25 wherein the precursor includes one or more compounds from any one or more of the groups: halocarbon, hydrocarbon, azo, metallocene and optionally metalorganic.

27. The method according to claim 26 wherein the precursor includes bromomethane, methane, ethane, cyclopentadienylmagnesium, carbon tetra bromide, azomethane, azoethane and/or acetylene.

28. The method according to any of claims 1-27 wherein the temperature drop between then substrate and the precursor inlet is equal or greater than 1000°C per meter.

29. A two dimensional material produced using any method of claims 1-28.

30. A method of manufacturing a hetrostructure that includes a two-dimensional crystalline material having an interface with a second layer, the method comprising: using the method of any one of claims 1-27 with a first set of reactor conditions to produce a two-dimensional crystalline material on a substrate within a close coupled reaction chamber; and

introducing a second precursor under a second set of reactor conditions to form the second layer on the substrate.

31. The method according claim 30 wherein the second layer comprises a film.

32. The method according to claim 31 wherein the second layer is a semiconductor.

33. The method according to claim 32 wherein the second layer comprises at least one of the following: GaN, BN, AlN, AlGaN, SiN.

34. The method according to any of claims 30-33 wherein the second layer is a second two-dimensional crystalline material.

35. The method according to any of claim 30-34 wherein the separation between the substrate and a ceiling of the reactor chamber directly above the substrate is changed between forming the two-dimensional crystalline material layer and the second layer.