

CLAIMS

1. A method of encapsulating graphene in a semiconductor substrate, the method comprising:

providing a semiconductor substrate, wherein the semiconductor substrate includes a metal layer formed in a dielectric layer;

selectively depositing graphene on the metal layer relative to exposed non-metal surfaces of the semiconductor substrate, wherein the semiconductor substrate is maintained at a deposition temperature less than a semiconductor processing temperature limit during selective deposition of graphene;

depositing a metal oxide over at least the graphene by a thermal-based deposition technique; and

depositing a hermetic barrier over the metal oxide.

2. The method of claim 1, further comprising:

treating a surface of the graphene prior to depositing the metal oxide by exposure to plasma.

3. The method of claim 2, wherein the plasma includes an H₂ and O₂ plasma, H₂O and O₂ plasma, or N₂ and O₂ plasma.

4. The method of claim 3, wherein a concentration of an oxidant species in the plasma is equal to or less than a concentration of a co-flowed reactant in the plasma.

5. The method of claim 2, wherein exposure to plasma occurs at a temperature between about 10°C and about 100°C, at a pressure between about 0.5 Torr and about 5 Torr, and for a duration between about 1 second and about 10 seconds.

6. The method of claim 1, wherein the metal oxide comprises aluminum oxide, hafnium oxide, zirconium oxide, yttrium oxide, or combinations thereof.

7. The method of claim 6, wherein the metal oxide comprises aluminum oxide.

8. The method of claim 7, wherein depositing the metal oxide over at least graphene comprises:

introducing a dose of an aluminum-containing precursor to the semiconductor substrate; and

exposing the semiconductor substrate to an oxidant to react with the aluminum-containing precursor and form aluminum oxide over graphene.

9. The method of claim 8, wherein the aluminum-containing precursor is trimethyl aluminum (TMA) and the oxidant is a water-free oxidant.

10. The method of claim 8, wherein a D peak of a Raman spectrum characterizing graphene is decreased after forming aluminum oxide over graphene.

11. The method of any one of claims 1-10, wherein the hermetic barrier comprises a nitrogen-doped silicon carbide, oxygen-doped silicon carbide, or silicon nitride.

12. The method of any one of claims 1-10, wherein selectively depositing graphene on the metal layer comprises:

flowing one or more hydrocarbon precursors into a reaction chamber and towards the semiconductor substrate;

generating, from a hydrogen source gas, radicals of hydrogen in a remote plasma source; and

introducing the radicals of hydrogen into the reaction chamber and towards the semiconductor substrate, wherein the radicals of hydrogen react with the one or more hydrocarbon precursors to deposit graphene on the metal layer.

13. The method of any one of claims 1-10, wherein the metal layer includes copper, ruthenium, aluminum, nickel, cobalt, tungsten, molybdenum, or combinations thereof.

14. A method of encapsulating graphene in a semiconductor substrate, the method comprising:

providing a semiconductor substrate, wherein the semiconductor substrate includes a metal layer formed in a dielectric layer;

selectively depositing graphene on the metal layer relative to exposed non-metal surfaces of the semiconductor substrate, wherein the semiconductor substrate is maintained at a deposition temperature less than a semiconductor processing temperature limit during selective deposition of graphene; and

depositing a hermetic barrier over the graphene by a non-direct plasma deposition technique.

15. The method of claim 14, further comprising:

treating a surface of the graphene prior to depositing the hermetic barrier by exposure to plasma.

16. The method of claim 15, wherein the plasma includes an H₂ and O₂ plasma, H₂O and O₂ plasma, or N₂ and O₂ plasma.

17. The method of claim 14, wherein depositing the hermetic barrier comprises: flowing a silicon-containing precursor to the semiconductor substrate in a reaction chamber;

generating, from a source gas, radicals in a remote plasma source that are generated upstream of the silicon-containing precursor; and

introducing the radicals into the reaction chamber and to the semiconductor substrate, wherein the radicals react with the silicon-containing precursor to form the hermetic barrier over the graphene.

18. The method of any one of claims 14-17, wherein the hermetic barrier includes nitrogen-doped silicon carbide, oxygen-doped silicon carbide, or silicon nitride.

19. The method of any one of claims 14-17, further comprising:

depositing an etch stop by a thermal-based deposition technique over the graphene prior to depositing the hermetic barrier.

20. The method of any one of claims 14-17, wherein selectively depositing

graphene on the metal layer comprises:

flowing one or more hydrocarbon precursors into a reaction chamber and towards the semiconductor substrate;

generating, from a hydrogen source gas, radicals of hydrogen in a remote plasma source; and

introducing the radicals of hydrogen into the reaction chamber and towards the semiconductor substrate, wherein the radicals of hydrogen react with the one or more hydrocarbon precursors to deposit graphene on the metal layer.