CLAIMS

1. A method of forming a boron-based ceramic film comprising a dopant on a substrate, the method comprising:

(a) receiving the substrate in a reaction chamber;

(b) providing a first reactant and a second reactant to the reaction chamber, the first reactant comprising a boron halide; and

(c) generating an inductively coupled plasma in the reaction chamber and reacting the first reactant with the second reactant in a plasma enhanced chemical vapor deposition reaction at a temperature of 600°C or less to form the boron-based ceramic film comprising the dopant on the substrate.

2. The method of claim 1, wherein the boron-based ceramic film has a hydrogen content of 15% (atomic) or less.

3. The method of claim 2, wherein the boron-based ceramic film has a halide content of 1% (atomic) or less.

4. The method of claim 3, wherein the boron-based ceramic film has a Young's modulus of 175 GPa or greater.

5. The method of claim 4, wherein the boron-based ceramic film has an oxygen content of 1% (atomic) or less.

6. The method of claim 1, wherein the second reactant comprises a saturated or unsaturated hydrocarbon, and wherein the saturated or unsaturated hydrocarbon is the only hydrogen-bearing precursor provided to the reaction chamber.

7. The method of claim 1, wherein the first reactant comprises BF_3 and the second reactant comprises CH_4, and wherein the boron-based ceramic film comprises boron carbide having a composition of B_xC_y, where $2 < x < 4.5$, and $y = 1$.

8. The method of claim 1, wherein the boron-based ceramic film further comprises tungsten

and/or silicon.

9. The method of claim 1, wherein a Young's modulus of the boron-based ceramic film is between 250-300 GPa.

10. The method of claim 1, wherein a hardness of the boron-based ceramic film is 20 GPa or greater.

11. The method of claim 1, wherein a hydrogen content of the boron-based ceramic film is 13% (atomic) or less.

12. The method of claim 1, wherein a halide content of the boron-based ceramic film is 0.75% (atomic) or less.

13. The method of claim 1, wherein a density of the boron-based ceramic film is 2 g/cc or greater.

14. The method of claim 1, wherein the boron-based ceramic film has a boron content of 50% (atomic) or greater.

15. The method of claim 1, wherein the first reactant comprises BF_3 and/or BCl_3.

16. The method of claim 1, wherein the first reactant comprises BBr_3 and/or BI_3.

17. The method of claim 1, wherein the second reactant comprises a reactant selected from the group consisting of: methane (CH_4), ethane (C_2H_6), propane (C_3H_8), ethene (C_2H_4), and propene (C_3H_6).

18. The method of claim 1, wherein the boron-based ceramic film is amorphous.

19. The method of claim 1, wherein the dopant comprises phosphorus.

20. The method of claim 1, wherein the dopant comprises nitrogen.

21. An apparatus for processing substrates, the apparatus comprising:

(a) a reaction chamber;

(b) a substrate support configured to support a substrate in the reaction chamber;

(c) one or more inlet for introducing reactants to the reaction chamber;

(d) one or more outlet for removing material from the reaction chamber; and

(e) a controller having at least one processor and a memory, wherein the at least one processor and the memory are communicatively connected with one another, and the memory stores computer-executable instructions for controlling the at least one processor to cause:

(i) exposing the substrate to an inductively coupled plasma to drive a plasma enhanced chemical vapor deposition reaction between a boron halide and an additional reactant to form a doped boron-based ceramic film on the substrate at a temperature of 600°C or less.

22. An apparatus for forming a doped boron-based ceramic film on a substrate, the apparatus comprising:

(a) a reaction chamber;

(b) a substrate support configured to support the substrate in the reaction chamber;

(c) one or more inlet for introducing reactants to the reaction chamber;

(d) one or more outlet for removing material from the reaction chamber;

(e) a plasma generator configured to generate a plasma in the reaction chamber, the plasma being an inductively coupled plasma; and

(f) a controller having at least one processor and a memory, wherein the at least one processor and the memory are communicatively connected with one another, and the memory stores computer-executable instructions for controlling the at least one processor to cause:

(i) receiving the substrate in the reaction chamber,

(ii) flowing a first reactant and a second reactant into the reaction chamber, and

(iii) generating the plasma in the reaction chamber and reacting the first reactant with the second reactant at a temperature of 600°C or less to form the doped boron-based ceramic film on the substrate, wherein the boron-based ceramic film has:

(1) a Young's modulus of 175 GPa or greater,

(2) a hydrogen content of 15% (atomic) or less, and

(3) a halide content of 1% (atomic) or less.

23. The apparatus of any one of claims 21 or 22, wherein the doped boron-based ceramic film comprises a dopant selected from the group consisting of phosphorus and nitogen.