

CLAIMS

What is claimed is:

1. A method of forming a boron-based ceramic film on a substrate, the method comprising:
 - (a) receiving the substrate in a reaction chamber;
 - 5 (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 about 600°C or less to form the boron-based ceramic film on the substrate.
- 10 2. The method of claim 1, wherein the boron-based ceramic film has a hydrogen content of about 15% (atomic) or less.
3. The method of claim 2, wherein the boron-based ceramic film has a halide content of about 1% (atomic) or less.
- 15 4. The method of claim 3, wherein the boron-based ceramic film has a Young's modulus of about 175 GPa or greater.
5. The method of claim 4, wherein the boron-based ceramic film has an oxygen content of about 1% (atomic) or less.
- 20 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 $y = 1$.
- 25 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 about 250-300 GPa.
10. The method of claim 1, wherein a hardness of the boron-based ceramic film is about 20 GPa or greater.
- 5 11. The method of claim 1, wherein a hydrogen content of the boron-based ceramic film is about 13% (atomic) or less.
12. The method of claim 1, wherein a halide content of the boron-based ceramic film is about 0.75% (atomic) or less.
- 10 13. The method of claim 1, wherein a density of the boron-based ceramic film is about 2 g/cc or greater.
14. The method of claim 1, wherein the boron-based ceramic film has a boron content of about 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 .
- 15 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. An apparatus for processing substrates, the apparatus comprising:
- 20 (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:

- 5 (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 boron-based ceramic film on the substrate at a temperature of about 600°C or less..

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

- 10 (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;
- 15 (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:
- 20 (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 about 600°C or less to form the boron-based ceramic film on the substrate, wherein the boron-based ceramic film has:
- 25 (1) a Young's modulus of about 175 GPa or greater,
- (2) a hydrogen content of about 15% (atomic) or less, and
- (3) a halide content of about 1% (atomic) or less.