CLAIMS

1. A method for nitriding a substrate, comprising:

positioning the substrate on a substrate support in a processing volume of a processing chamber;

flowing a nitrogen-containing source and a carrier gas into a plasma processing source coupled to the processing chamber such that a flow rate of the nitrogen-containing source is from 3% to 20% of a flow rate of the carrier gas;

generating an inductively-coupled plasma in the plasma processing source by operating an inductively-coupled plasma source at a power of 2,000 W to 10,000 W, the inductively-coupled plasma comprising a radical species formed from the nitrogen-containing source, the carrier gas, or both; and

nitriding the substrate within the processing chamber, comprising:

operating a heat source within the processing chamber at a temperature of 150 °C to 650 °C to heat the substrate;

maintaining a pressure of the processing chamber of 50 mTorr to 2 Torr;

introducing the inductively-coupled plasma to the processing chamber; and

adjusting a nitrogen content, a number of nitrogen atoms per unit area, a nitride thickness, or combinations thereof, of the substrate by exposing the substrate to the radical species,

wherein the plasma processing source comprises:

a gas injection channel defined between a gas injection insert and a sidewall of the plasma processing source; and

an induction coil positioned proximate the sidewall and horizontally overlapping the gas injection channel.

2. The method of claim 1, wherein H_2 is co-flowed with the nitrogen-containing source, and the inductively-coupled plasma further comprises a radical species formed from the H_2.

3. The method of claim 1, wherein flowing the nitrogen-containing source and the carrier gas into the plasma processing source comprises flowing the nitrogen-containing source and the carrier gas into the gas injection channel.

4. The method of claim 1, wherein the nitrogen-containing source comprises NH_3, N_2, hydrazine (N_2H_4), or combinations thereof.

5. The method of claim 1, wherein the carrier gas comprises Ar, He, Ne, Kr, Xe, or combinations thereof.

6. The method of claim 1, wherein the heat source comprises a lamp positioned above the substrate, a lamp positioned below the substrate, a heater embedded within the substrate support, or combinations thereof.

7. The method of claim 1, wherein the heat source has a plasma source output with a diameter of 5 cm to 38 cm.

8. The method of claim 1, wherein the substrate comprises crystalline silicon, amorphous silicon, polycrystalline silicon, crystalline SiGe, amorphous SiGe, polycrystalline SiGe, silicon oxide, silicon nitride, hafnium oxide, hafnium zirconium oxide, or combinations thereof.

9. The method of claim 1, further comprising:

performing an oxygen radical treatment before or after nitriding the substrate;

performing a hydrogen radical treatment before or after nitriding the substrate; or

a combination thereof.

10. The method of claim 9, wherein the oxygen radical treatment, the hydrogen radical treatment, or both, are performed in the same processing chamber as nitriding the substrate.

11. A method for nitriding a substrate, comprising:

positioning the substrate on a substrate support in a processing volume of a processing chamber;

generating an inductively-coupled plasma in a plasma processing source coupled to the processing chamber, wherein generating the inductively-coupled plasma comprises:

operating an inductively-coupled plasma source at a power of 2,000 W to 10,000 W;

flowing hydrazine and a carrier gas into the plasma processing source such that a flow rate of the hydrazine is from 3% to 100% of a flow rate of the carrier gas, the carrier gas comprising Ar, He, Ne, Kr, Xe, or combinations thereof; and

forming the inductively-coupled plasma, the inductively-coupled plasma comprising a radical species comprising N, NH, or a combination thereof; and

nitriding the substrate within the processing chamber, wherein nitriding the substrate comprises:

operating a heat source within the processing chamber at a temperature of 150 °C to 650 °C to heat the substrate;

maintaining a pressure of the processing chamber of 50 mTorr to 2 Torr;

introducing the inductively-coupled plasma to the processing chamber; and

adjusting a nitrogen content, a number of nitrogen atoms per unit area, a nitride thickness, or combinations thereof, of the substrate by exposing the substrate to the inductively-coupled plasma comprising the radical species,

wherein the plasma processing source comprises:

a gas injection channel defined between a gas injection insert and a sidewall of the plasma processing source; and

an induction coil positioned proximate the sidewall and horizontally overlapping the gas injection channel.

12. The method of claim 11, wherein the flow rate of the hydrazine is from 5% to 15% of the flow rate of the carrier gas.

13. The method of claim 11, wherein:

the pressure is from 200 mTorr to 1 Torr;

the temperature is from 500 °C to 650 °C;

nitriding the substrate is performed for 5 minutes or less; or

combinations thereof.

14. The method of claim 11, wherein the heat source has a plasma source output with a diameter of 10 cm to 38 cm.

15. The method of claim 11, wherein:

H_2 is co-flowed with the hydrazine and the inductively-coupled plasma further comprises a radical species formed from the H_2;

NH_3, N_2, or a combination thereof is co-flowed with the hydrazine and the inductively-coupled plasma further comprises a radical species formed from the NH_3, N_2, or a combination thereof; or

a combination thereof.

16. A method for nitriding a substrate, comprising:

positioning the substrate on a substrate support in a processing volume of a processing chamber, the substrate comprising silicon;

generating an inductively-coupled plasma in a plasma processing source coupled to the processing chamber, wherein generating the inductively-coupled plasma comprises:

operating an inductively-coupled plasma source at a power of 2,000 W to 10,000 W;

flowing a nitrogen-containing source and a carrier gas into the plasma processing source such that a flow rate of the nitrogen-containing source is from 3% to 100% of a flow rate of the carrier gas, the carrier gas comprising Ar, He, Ne, Kr, Xe, or combinations thereof; and

forming the inductively-coupled plasma, the inductively-coupled plasma comprising a radical species comprising N, NH, or a combination thereof; and

nitriding the substrate within the processing chamber, wherein nitriding the substrate comprises:

operating a heat source within the processing chamber at a temperature of 150 °C to 650 °C to heat the substrate;

maintaining a pressure of the processing chamber of 50 mTorr to 2 Torr;

introducing the inductively-coupled plasma to the processing chamber; and

adjusting a nitrogen content, a number of nitrogen atoms per unit area, a nitride thickness, or combinations thereof, of the substrate by exposing the substrate to the inductively-coupled plasma comprising the radical species,

wherein the plasma processing source comprises:

a gas injection channel defined between a gas injection insert and a sidewall of the plasma processing source; and

an induction coil positioned proximate the sidewall and horizontally overlapping the gas injection channel.

17. The method of claim 16, wherein the substrate comprises silicon germanium (SiGe).

18. The method of claim 16, wherein:

the flow rate of the nitrogen-containing source is from 5% to 15% of the flow rate of the carrier gas;

the pressure is from 200 mTorr to 1 Torr;

the temperature is from 500 °C to 650 °C;

nitriding the substrate is performed for 10 minutes or less; or

combinations thereof.

19. The method of claim 16, wherein:

H_2 is co-flowed with the nitrogen-containing source and the inductively-coupled plasma further comprises a radical species formed from the H_2;

the plasma processing source is integrated within the processing chamber; or

a combination thereof.