CLAIMS:

1. A method for forming an ultra-smooth PECVD silicon film on a substrate in a plasma-enhanced chemical vapor deposition apparatus, the method comprising:

supplying a silicon-containing reactant to the plasma-enhanced chemical vapor deposition apparatus, wherein the silicon containing reactant comprises one or more reactants selected from the group consisting of silane, disilane, a halogen-substituted silane, and an alkyl-substituted silane;

supplying a one or more gases selected from the group consisting of helium, argon, and hydrogen to the plasma-enhanced chemical vapor deposition apparatus, under conditions configured for forming an ultra-smooth PECVD silicon film;

supplying a capacitively-coupled plasma to a process station of the plasma-enhanced chemical vapor deposition apparatus, the capacitively-coupled plasma including silicon radicals generated from the silicon-containing reactant; and

depositing the ultra-smooth silicon PECVD film, wherein the film has a roughness of less than about 4.5 Å.

2. The method of claim 1, wherein the ultra-smooth PECVD silicon film is amorphous silicon.

3. The method of claim 1, wherein the ultra-smooth PECVD silicon film is polycrystalline silicon.

4. The method of claim 1, wherein the ultra-smooth PECVD silicon film is doped and the dopant comprises at least one of boron, arsenic and phosphorus.

5. The method of claim 1, wherein the amount of one or more gases selected from the group consisting of helium, argon, and hydrogen is at least 150 of the amount of silicon-containing reactant.

6. A method for forming a silicon-containing film on a substrate in a plasma-enhanced chemical vapor deposition apparatus, the method comprising:

supplying a silicon-containing reactant to the plasma-enhanced chemical vapor deposition apparatus, wherein the silicon containing reactant comprises one or more reactants selected from the group consisting of silane, disilane, a halogen-substituted silane, and an alkyl-substituted silane;

supplying a co-reactant to the plasma-enhanced chemical vapor deposition apparatus;

supplying a capacitively-coupled plasma to a process station of the plasma-enhanced chemical vapor deposition apparatus, the plasma including silicon radicals

generated from the silicon-containing reactant and co-reactant radicals generated from the co-reactant; and

depositing the silicon-containing film on the substrate, the silicon-containing film having a refractive index of between 1.4 and 2.1, the silicon-containing film further having an absolute roughness of less than 4.5 Å as measured on a silicon substrate.

7. The method of claim 6, wherein the silicon-containing film is a silicon dioxide film and wherein the silicon dioxide film has an absolute roughness of less than 4.5 Å as measured on a silicon substrate over a thickness range of up to 3000 Å of the silicon dioxide film.

8. The method of claim 6, wherein the co-reactant includes one or more of NH_3, N_2O, CO, and CO_2.

~~9. The method of claim 6, wherein the silicon-containing reactant includes one or more of silane, disilane, a halogen-substituted silane, and an alkyl-substituted silane.~~

~~10.~~9. The method of claim 6, wherein the plasma has an ion density of less than 2 x 10^{10} ions/cm^3.

~~11.~~10. The method of claim 6, further comprising controlling an absolute roughness of the silicon-containing film by supplying a process gas mixture including the co-reactant in an amount at least 150 times an amount of the silicon-containing reactant.

~~12.~~11. The method of claim 6, wherein supplying a plasma to the substrate includes generating a high frequency plasma.

~~13.~~12. A method for forming a film stack including a first film and a second film on a substrate in-situ, the first film having a different material composition from the second film, the method comprising:

in a first film deposition phase,

supplying a first reactant gas mixture to a process station,

maintaining a first plasma using the first reactant gas mixture,

with the first plasma, depositing the first film on the substrate; and

in a second film deposition phase, and without an intervening vacuum break,

supplying a second reactant gas mixture to the process station,

maintaining a second plasma using the second reactant gas mixture,

with the second plasma, depositing the second film on the substrate,

and,

controlling a process parameter of the second film deposition phase so that the absolute roughness of the second film decreases with increasing thickness of the second film.

~~14.~~13. The method of claim ~~13~~12, wherein the first film is one of a polycrystalline silicon film and an amorphous silicon film and wherein the second film is a silicon-containing film having a refractive index of between 1.4 and 2.1, the silicon-containing film further having an absolute roughness of less than 4.5 Å as measured on a silicon substrate.

~~15.~~14. The method of claim ~~14~~13, wherein the first film includes one of a boron dopant, an arsenic dopant, and a phosphorous dopant.

~~16.~~15. The method of claim ~~13~~12, wherein the first film is a silicon nitride film and wherein the second film is a silicon-containing film having a refractive index of between 1.4 and 2.1, the silicon-containing film further having an absolute roughness of less than 4.5 Å as measured on a silicon substrate.

~~17.~~16. The method of claim ~~13~~12, wherein increasing a thickness of the second film decreases an absolute roughness of a third film relative to an absolute roughness of the first film, the third film being deposited in a third film deposition phase in-situ with the first film deposition phase and the second film deposition phase.

~~18.~~17. The method of claim ~~13~~12, wherein controlling the process parameter of the second film deposition phase includes supplying an amount of a silicon-containing reactant in the second reactant gas mixture at a ratio equal to or less than 1:150 of a total amount of the second reactant gas mixture.

~~19.~~18. The method of claim ~~13~~12, wherein controlling the process parameter of the second film deposition phase includes generating the second plasma with a capacitively-coupled plasma source.

~~20.~~19. The method of claim ~~14~~13, wherein controlling the process parameter of the second film deposition phase includes generating the second plasma at a process station pressure of 8 torr or less.

~~21.~~20. The method of claim ~~14~~13, wherein controlling the process parameter of the second film deposition phase includes maintaining an ion density of less than 2×10^{10} ions/cm^3 in the second plasma.

~~22.~~21. The method of claim ~~14~~13, controlling the process parameter of the second film deposition phase includes supplying an inert gas to the second plasma.

~~23.~~22. The method of claim ~~14~~13, further comprising:

applying photoresist to the substrate;

exposing the photoresist to light;

patterning the resist with a pattern and transferring the pattern to the substrate; and

selectively removing the photoresist from the substrate.

~~24.~~23. A plasma-enhanced chemical vapor deposition apparatus configured to deposit a silicon-containing film on a substrate, the apparatus comprising:

a process station;

a first reactant feed for supplying a silicon-containing reactant to the process station;

a second reactant feed for supplying a co-reactant to the process station;

a capacitively-coupled plasma source; and

a controller configured to control the capacitively-coupled plasma source to maintain a plasma and to control one or more process parameters of the process station to effect the deposition of a silicon-containing film having a refractive index of between 1.4 and 2.1and an absolute roughness of less than 4.5 Å as measured on a silicon substrate.

~~25.~~24. A system, comprising the apparatus of claim ~~24~~23 and a stepper tool.

~~26.~~25. The apparatus of claim ~~24~~23, further comprising a showerhead disposed within the process station, the showerhead configured to distribute process gases to the substrate, the showerhead fluidly coupled to one or more of an NH_3 source, an N_2O source, a CO source, a CO_2 source, a silane source, a disilane source, a nitrogen source, a hydrazine source, a halogen-substituted silane source, and an alkyl-substituted silane source.

~~27.~~26. A method for forming an ultra-smooth PECVD film on a substrate in a plasma-enhanced chemical vapor deposition apparatus, the method comprising:

supplying a silicon-containing reactant to the plasma-enhanced chemical vapor deposition apparatus;

supplying a co-reactant to the plasma-enhanced chemical vapor deposition apparatus, the co-reactant supplying a suitable reducing environment;

supplying a capacitively-coupled plasma to a process station of the plasma-enhanced chemical vapor deposition apparatus, the capacitively-coupled plasma including silicon radicals generated from the silicon-

containing reactant and co-reactant radicals generated from the co-reactant; and

depositing the ultra-smooth PECVD film on the substrate.

~~28.~~27. The method of claim ~~27~~26, wherein the co-reactant comprises hydrogen.

~~29.~~28. The method of claim ~~27~~26, wherein the ultra-smooth PECVD film is amorphous.

~~30.~~29. The method of claim ~~27~~26, wherein the ultra-smooth PECVD film is polycrystalline.

~~31.~~30. The method of claim ~~30~~29, wherein the ultra-smooth PECVD film includes a dopant.

~~32.~~31. The method of claim ~~31~~30, wherein the dopant comprises at least one of boron, arsenic and phosphorous.

~~33.~~32. The method of claim ~~27~~26, further comprising adding a DC bias to promote surface rearrangement of the ultra-smooth PECVD film.

~~34.~~33. The method of claim ~~27~~26, further comprising applying ion bombardment to the surface of the ultra-smooth PECVD film to promote surface rearrangement of the ultra-smooth PECVD film.

~~35.~~34. The method of claim ~~27~~26, wherein the ultra-smooth PECVD film comprises an absolute roughness of less than about 4.5 Å as measured on the substrate.

35. A method for forming a stack of films for a three-dimensional memory device, the method comprising depositing a plurality of films, wherein the plurality of films comprises films having a first composition and films having a second composition, different from the first composition, wherein the films having the first and second composition alternate within the stack, and wherein at least one film in the deposited stack is a silicon-containing film deposited on a substrate in a plasma-enhanced chemical vapor deposition apparatus, by a method comprising:

supplying a silicon-containing reactant to the plasma-enhanced chemical vapor deposition apparatus, wherein the silicon-containing reactant comprises one or more reactants selected from the group consisting of silane, disilane, a halogen-substituted silane, and an alkyl-substituted silane;

supplying a co-reactant to the plasma-enhanced chemical vapor deposition apparatus, wherein the co-reactant comprises one or more co-reactants selected from the group consisting of NH_3, N_2O, CO, and CO_2;

supplying a capacitively-coupled plasma to a process station of the plasma-enhanced chemical vapor deposition apparatus, the plasma including silicon radicals generated from the silicon-containing reactant and co-reactant radicals generated from the co-reactant; and

depositing the silicon-containing film on the substrate at a deposition rate of less than 10 Å/second, the silicon-containing film being deposited under process conditions that produce a film having a refractive index of between 1.4 and 2.1, and an absolute roughness of less than 4.5 Å as measured on a silicon substrate for up to 3000 Å of deposited film, wherein the absolute roughness does not substantially increase with increasing deposited thickness for up to 3000 Å of deposited film, wherein said process conditions comprise:

supplying the co-reactant in an amount that is at least 150 times the amount of the silicon-containing reactant;

forming plasma that comprises high frequency (HF) plasma generated with a power density of at least 0.35 W/square inch, wherein the formed plasma has an ion density of less than 2×10^{10} ions/cm^3;

depositing the silicon-containing film at a pressure of about 8 torr or less and at a temperature of between 300 – 600 °C.

36. A method for forming a stack of films for a three-dimensional memory device, the method comprising depositing a plurality of films, wherein the plurality of films comprises films having a first composition and films having a second composition, different from the first composition, wherein the films having the first and second composition alternate within the stack, and wherein at least one film in the deposited stack is an ultra-smooth silicon PECVD film deposited on a substrate in a plasma-enhanced chemical vapor deposition apparatus, by a method comprising:

supplying silane to the plasma-enhanced chemical vapor deposition apparatus;

supplying a co-reactant to the plasma-enhanced chemical vapor deposition apparatus, the co-reactant supplying a suitable reducing environment;

supplying a capacitively-coupled plasma to a process station of the plasma-enhanced chemical vapor deposition apparatus, the capacitively-coupled plasma including silicon radicals generated from the silane and co-reactant radicals generated from the co-reactant; and

depositing the ultra-smooth silicon PECVD film on the substrate at a deposition rate of less than 10 Å/second, the silicon PECVD film being deposited

under process conditions that produce a film having absolute roughness of less than 4.5 Å as measured on a silicon substrate for up to 3000 Å of deposited film, wherein the absolute roughness does not substantially increase with increasing deposited thickness for up to 3000 Å of deposited film, and wherein said process conditions comprise:

supplying the silane and other gas or gases, wherein the other gas or gases are selected from the group consisting of hydrogen, helium, argon, and combinations thereof, and are supplied in an amount that is at least 150 times the amount of silane;

forming plasma that comprises high frequency (HF) plasma generated with a power density of at least 0.35 W/square inch, wherein the formed plasma has an ion density of less than 2×10^{10} ions/cm^3;

depositing the silicon film at a pressure of about 8 torr or less and at a temperature of between 300 – 650 °C.