CLAIMS

1. A method for performing dry development, the method comprising:

performing, in a process chamber, a thermal dry development on a semiconductor substrate comprising an EUV-sensitive photoresist film using a halogen-containing gas in a plasma-free process to form a patterned photoresist mask; and

performing, in the process chamber after performing the thermal dry development, a plasma dry development on the semiconductor substrate by forming plasma with at least one reactive gas to descum.

2. The method of claim 1, wherein the at least one reactive gas comprises one or more halogen-containing gases, one or more hydrogen-containing gases, or a combination thereof.

3. The method of claim 1, wherein the at least one reactive gas comprises one or more hydrogen-containing gases, wherein the one or more hydrogen-containing gases comprise CH_4.

4. The method of claim 1, wherein the at least one reactive gas comprises multiple halogen-containing gases, each of the halogen-containing gases selected from the group consisting of: HBr, HCl, Cl_2, and BCl_3.

5. The method of claim 4, wherein the at least one reactive gas comprises HBr and Cl_2, HBr and HCl, HBr and BCl_3, or BCl_3 and Cl_2.

6. The method of claim 1, wherein the at least one reactive gas comprises a combination of one halogen-containing gas selected from HBr, HCl, Cl_2, and BCl_3, and one hydrogen-containing gas selected from H_2 and CH_4.

7. The method of claim 6, wherein the at least one reactive gas comprises HBr and H_2, BCl_3 and CH_4, Cl_2 and CH_4, HCl and CH_4, or HBr and CH_4.

8. The method of claim 1, wherein performing plasma dry development by forming plasma with at least one reactive gas comprises forming plasma with at least one reactive gas and at least one non-reactive gas, wherein the non-reactive gas is selected from the group consisting of: N_2, He, Ne, Ar, Kr, and Xe.

9. The method of claim 8, wherein the at least one reactive gas comprises HBr and the at least one non-reactive gas comprises N_2.

10. The method of claim 8, wherein the at least one reactive gas comprises Cl_2 and the at least one non-reactive gas comprises N_2.

11. The method of claim 1, wherein the halogen-containing gas comprises a hydrogen halide.

12. The method of claim 1, wherein performing the thermal dry development occurs at a first pressure in the process chamber, and wherein performing the plasma dry development occurs at a second pressure that is lower than the first pressure in the same process chamber, wherein transitioning in the process chamber from the first pressure to the second pressure occurs in ten seconds or less.

13. The method of claim 1, wherein performing the thermal dry development and performing the plasma dry development occur at a temperature between about -60°C and about 120°C.

14. The method of claim 1, wherein performing the thermal dry development and performing the plasma dry development are repeated alternatingly in the same process chamber.

15. A method for performing dry development and treatment, the method comprising:

thermally dry developing an EUV-sensitive metal-containing photoresist film on a semiconductor substrate using a process gas to form a patterned resist mask of the metal-containing photoresist film;

treating the patterned resist mask with a plasma of an inert gas; and

treating the patterned resist mask with a plasma of an oxidizing gas.

16. The method of claim 15, wherein the process gas comprises a halogen-containing gas.

17. The method of claim 16, wherein the halogen-containing gas comprises HBr, HCl, HF, HI, Br_2, Cl_2, F_2, I_2, BCl_3, or combinations thereof.

18. The method of claim 15, wherein treating the patterned resist mask with the plasma of the inert gas comprises hardening the patterned resist mask of the metal-containing photoresist film.

19. The method of claim 15, wherein treating the patterned resist mask with the plasma of the oxidizing gas comprises passivating the patterned resist mask of the metal-containing photoresist film.

20. The method of claim 15, wherein treating the patterned resist mask with the plasma of the oxidizing gas comprises an oxygen flash treatment for a duration between about 0.5 seconds and about 4 seconds.

21. The method of claim 15, wherein a plasma power during treating with the plasma of the inert gas is between about 50 W and about 300 W.

22. A method for performing dry development and treatment, the method comprising:

plasma dry developing an EUV-sensitive metal-containing photoresist film on a semiconductor substrate using a plasma of a process gas to form a patterned resist mask of the metal-containing photoresist film; and

treating the patterned resist mask with a plasma of an inert gas; and

treating the patterned resist mask with a plasma of an oxidizing gas.

23. The method of claim 22, wherein the process gas comprises a halogen-containing gas.

24. The method of claim 22, each of plasma dry developing, treating the patterned resist mask with the plasma of the inert gas, and treating the patterned resist mask with the plasma of the oxidizing gas occurs in the same plasma chamber.

25. The method of claim 22, wherein treating the patterned resist mask with the plasma of the oxidizing gas comprises an oxygen flash treatment for a duration between about 0.5 seconds and about 4 seconds.