CLAIMS

1. A patterning structure, comprising:

a radiation-sensitive imaging layer disposed over a substrate; and

an underlayer disposed between the substrate and the imaging layer, the underlayer is configured to:

increase adhesion between the substrate and the imaging layer and

reduce a radiation dose for effective photoresist exposure of the imaging layer.

2. The patterning structure of claim 1, wherein the imaging layer comprises an Extreme Ultraviolet (EUV)-sensitive inorganic photoresist layer, a chemical vapor deposited (CVD) film, a spin-on film, ~~or~~ a tin oxide film, or a tin oxide hydroxide film.

3. The patterning structure of claim 1, wherein the substrate is or comprises a hardmask, amorphous carbon film, amorphous carbon film doped with boron (B), amorphous carbon film doped with tungsten (W), amorphous hydrogenated carbon film, silicon oxide film, silicon nitride film, silicon oxynitride film, silicon carbide film, silicon boronitride film, amorphous silicon film, polysilicon film, or a combination thereof.

4. The patterning structure of ~~any of claims 1-3~~claim 1, wherein the underlayer has a thickness of no more than 25 nm or a thickness of about 2 to 20 nm.

5. The patterning structure of any one of claims 1-4 ~~or 4~~, wherein the underlayer comprises a hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination of two or more of any of these; and optionally wherein the hydronated carbon doped with iodine is configured to improve generation of secondary electrons upon exposure to radiation.

6. The patterning structure of any one of claims 1-4~~claim 5~~, wherein the underlayer comprises about 0-30 atomic % oxygen (O) and/or about 20-50 atomic % hydrogen (H); and/or wherein a surface of the underlayer comprises hydroxyl groups,

carboxyl groups, peroxy groups, sp^2 carbons, sp carbons, and/or unsaturated carbon-containing bonds.

7. The patterning structure of any one of claims 1-4~~1-6~~, wherein the underlayer comprises a density of about 0.7 to 2.9 g/cm^3; optionally wherein the underlayer further provides increased etch selectivity; and optionally wherein the underlayer further provides decreased line edge and line width roughness and/or decreased dose to size.

8. The patterning structure of any one of claims ~~1-7~~1-4, wherein the underlayer further comprises beta hydrogen atoms configured to be released upon exposure to radiation and/or oxygen atoms configured to form oxygen bonds to an atom in the imaging layer.

9. A patterning structure, comprising:

a substrate comprising a partially fabricated semiconductor device film stack;

a radiation-sensitive imaging layer disposed over the substrate; and

an underlayer disposed between the substrate and the imaging layer,

wherein the underlayer comprises a vapor deposited film of hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination of two or more of any of these, and

wherein the film has a thickness of no more than about 25 nm or a thickness of about 2 to 20 nm.

10. The patterning structure of claim 9, wherein the substrate further comprises an optionally doped amorphous carbon hardmask disposed thereon.

11. The patterning structure of claim ~~10~~ 9, wherein the underlayer comprises 0-30 atomic % oxygen (O) and/or about 20-50 atomic % hydrogen (H); and/or wherein a surface of the underlayer comprises hydroxyl groups, carboxyl groups, peroxy groups, sp^2 carbons, sp carbons, and/or unsaturated carbon-containing bonds.

12. The patterning structure of claim 9, wherein the hydronated carbon doped with iodine is configured to improve generation of secondary electrons upon exposure to radiation.

13. The patterning structure of claim 9, wherein the underlayer comprises a density of about 0.7 to 2.9 g/cm^3; optionally wherein the underlayer further provides increased etch selectivity; and optionally wherein the underlayer further provides decreased line edge and line width roughness and/or decreased dose to size.

14. The patterning structure of claim 9, wherein the underlayer further comprises beta hydrogen atoms configured to be released upon exposure to radiation and/or oxygen atoms configured to form oxygen bonds to an atom in the imaging layer.

15. The patterning structure of claim 9, wherein the imaging layer comprises an Extreme Ultraviolet (EUV)-sensitive inorganic photoresist layer, a chemical vapor deposited (CVD) film, a spin-on film, a tin oxide film, or a tin oxide hydroxide film.

16. The patterning structure of claim 9, wherein the imaging layer comprises a vapor deposited organometallic imaging layer.

17. The patterning structure of claim 16, wherein the vapor deposited organometallic imaging layer comprises tin or organotin.

18. The patterning structure of claim 9, wherein the imaging layer comprises a spin-on organometallic imaging layer.

19. The patterning structure of claim 18, wherein the spin-on organometallic imaging layer comprises tin or organotin.

20. The patterning structure of claim 18, further comprising a hard mask between the substrate and the underlayer, and optionally wherein the hard mask is ashable.

~~12.~~21. A method of making a patterning structure, comprising:

providing a substrate;

depositing an underlayer on the substrate, wherein the underlayer is configured to increase adhesion between the substrate and the photoresist and/or reduce radiation dose for effective photoresist exposure; and

forming a radiation-sensitive imaging layer on the underlayer.

~~13.~~22. The method of claim ~~12~~ 21, wherein:

the substrate is a partially fabricated semiconductor device film stack;

the substrate further comprises or is a hardmask, amorphous carbon film, amorphous hydrogenated carbon film, silicon oxide film, silicon nitride film, silicon oxynitride film, silicon carbide film, silicon boronitride film, amorphous silicon film, polysilicon film, or a combination thereof;

the imaging layer comprises a tin oxide-based photoresist or a tin oxide hydroxide-based photoresist; and

the underlayer comprises a vapor deposited film of hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination of two or more of any of these, wherein the film has a thickness of no more than 25 nm.

~~14.~~23. The method of claim ~~13~~ 22, wherein the underlayer is vapor deposited on the substrate using a hydrocarbon precursor in the presence or absence of an oxocarbon precursor, thereby providing a carbon-containing film; and optionally wherein the oxocarbon precursor co-reacts with hydrogen (H_2) or a hydrocarbon and optionally further co-reacts with a silicon (Si) source dopant.

~~15.~~24. The method of claim ~~14~~ 23, wherein the hydrocarbon precursor comprises an alkane, an alkene, or an alkyne.

~~16.~~25. The method of claim ~~14~~ 23, wherein the underlayer is vapor deposited using the hydrocarbon precursor in the presence of a nitrogen-containing precursor, a tungsten-containing precursor, a boron-containing precursor, and/or an iodine-containing precursor, thereby providing a doped film.

~~17.~~26. The method of claim ~~16~~ 25, wherein the doped film comprises iodine; a combination of iodine and silicon; or a combination of iodine, silicon, and nitrogen.

~~18.~~27. The method of claim ~~13~~ 22, wherein the underlayer is vapor deposited on the substrate by using a silicon (Si)-containing precursor that co-reacts with an oxidizer and wherein the Si-containing precursor optionally further co-reacts with a carbon (C) source dopant.

28. The method of claim 21, wherein the hydronated carbon doped with iodine is configured to improve generation of secondary electrons upon exposure to radiation.

29. The method of claim 21, wherein the underlayer comprises about 0-30 atomic % oxygen (O) and/or about 20-50 atomic % hydrogen (H); and/or wherein a surface of the underlayer comprises hydroxyl groups, carboxyl groups, peroxy groups, sp^2 carbons, sp carbons, and/or unsaturated carbon-containing bonds.

30. The method of claim 21, wherein the underlayer comprises a density of about 0.7 to 2.9 g/cm^3; optionally wherein the underlayer further provides increased etch selectivity; and optionally wherein the underlayer further provides decreased line edge and line width roughness and/or decreased dose to size.

31. The method of claim 21, wherein the underlayer further comprises beta hydrogen atoms configured to be released upon exposure to radiation and/or oxygen atoms configured to form oxygen bonds to an atom in the imaging layer.

~~19.~~32. The method of any one of claims ~~12-18~~21-31, wherein said depositing further comprises applying a bias at a bias power of 0 W to about 1000 W and using a duty cycle of about 5% to 100%.

~~20.~~33. The method of claim ~~19~~ 32, wherein said applying the bias provides the underlayer having an increased density, as compared to an underlayer formed without applying the bias.

34. The method of claim 21, wherein said depositing comprises a plasma enhanced chemical vapor deposition (PECVD) process

~~21.~~35. The method of ~~any of~~ claim~~s~~ ~~12-19~~21, wherein the underlayer is vapor deposited on the substrate by PECVD as a termination operation of a vapor deposition on the substrate.

~~22.~~36. The method of ~~any of~~ claim~~s~~ ~~12-19~~21, wherein the underlayer is vapor deposited on the substrate by plasma enhanced chemical vapor deposition (PECVD) or atomic layer deposition (ALD).

~~23.~~37. The method of ~~any of~~ claim~~s~~ ~~12-22~~21, further comprising, after said depositing, modifying the underlayer to provide a roughened surface and optionally exposing the underlayer or the roughened surface to an oxygen-containing plasma to provide an oxygen-containing surface.

38. The method of claim 21, wherein the imaging layer comprises an Extreme Ultraviolet (EUV)-sensitive inorganic photoresist layer, a chemical vapor deposited (CVD) film, a spin-on film, a tin oxide film, or a tin oxide hydroxide film.

39. The method of claim 21, wherein said forming comprises vapor depositing an imaging layer on the underlayer.

40. The method of claim 39, wherein the imaging layer comprises a vapor deposited organometallic imaging layer.

41. The method of claim 40, wherein the vapor deposited organometallic imaging layer comprises tin or organotin.

42. The method of claim 21, wherein said forming comprises spin-coating an imaging layer on the underlayer.

43. The method of claim 42, wherein the imaging layer comprises a spin-on organometallic imaging layer.

44. The method of claim 43, wherein the organometallic imaging layer comprises tin or organotin.

45. The method of claims 38-44, further comprising, after said forming: exposing the organometallic imaging layer to Extreme Ultraviolet (EUV) radiation.

46. The method of claim 45, further comprising, after said exposing: developing the organometallic imaging layer using wet development.

47. The method of claim 45, further comprising, after said exposing: developing the organometallic imaging layer using wet development.

48. The method of claim 47, wherein the wet development is performed using an alkaline developer, an ammonium-based ionic liquid, a glycol ether, an organic acid, a ketone, or an alcohol.

49. The method of claim 47, wherein the wet development is performed using tetramethylammonium hydroxide (TMAH).

50. The method of claim 47, wherein the wet development is performed using propylene glycol methyl ether (PGME) or propylene glycol methyl ether acetate (PGMEA).

51. The method of claim 47, wherein the wet development is performed using an organic acid.

52. The method of claim 47, wherein the wet development is performed using 2-heptanone.

53. The method of claim 47, wherein the wet development is performed using ethanol.

54. The method of claim 42, further comprising, after said spin-coating: performing a post-application bake at a temperature below 200°C.

55. The method of claim 45, further comprising, after said exposing: performing a post-exposure bake at a temperature below 200°C.

56. The method of claim 47, further comprising, after said developing: performing a post-development bake at a temperature below 200°C.

57. The method of claim 21, further comprising: providing a hard mask between the substrate and the underlayer, and optionally wherein the hard mask is an ashable hard mask.

~~24.~~58. A method of depositing an underlayer, the method comprising:

providing a substrate in a process chamber; and

depositing by a plasma enhanced chemical vapor deposition (PECVD) process a hydronated carbon film on a surface of the substrate, wherein the hydronated carbon film is a low density film.

~~25.~~59. The method of claim ~~24~~ 58, wherein the PECVD process comprises introducing a carbon-containing precursor selected from methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4), propylene (C_3H_6), propyne (C_3H_4), allene (C_3H_4), cyclopropene (C_3H_4), butane (C_4H_{10}), cyclohexane (C_6H_{12}), benzene (C_6H_6), and toluene (C_7H_8).

~~26.~~60. The method of claim ~~25~~ 59, wherein the PECVD process further comprises introducing a nitrogen-containing precursor, a tungsten-containing precursor, a boron-containing precursor, and/or an iodine-containing precursor, thereby providing a doped film.

~~27.~~61. The method of claim ~~24~~ 58, wherein the PECVD process comprises a transformer coupled plasma (TCP) or an inductively coupled plasma (ICP).

~~28.~~62. The method of claim ~~27~~ 61, wherein a TCP power is about 100-1000 W with no bias.

~~29.~~63. The method of claim ~~27~~ 61, wherein the PECVD process further comprises a pressure of about 10-1000 mTorr and/or a temperature of about 0-100°C.

~~30.~~64. The method of claim ~~27~~ 61, wherein the PECVD process further comprises an applied pulsed bias comprising a power of about 10-1000 W or an applied continuous wave bias comprising a power of about 10-500 W.

~~31.~~65. The method of claim ~~30~~ 64, wherein the applied pulsed bias comprises a duty cycle of about 1-99% and a pulsing frequency of about 10-2000 Hz.

~~32.~~66. The method of any one of claims ~~24-31~~58-65, further comprising, after said depositing, modifying the hydronated carbon film to provide a roughened surface and optionally exposing the roughened surface to an oxygen-containing plasma to provide an oxygen-containing surface.

67. The method of claim 58, further comprising, after said depositing: vapor depositing an organometallic imaging layer on the hydronated carbon film.

68. The method of claim 58, further comprising, after said depositing: spin-coating an organometallic imaging layer on the hydronated carbon film.

69. The method of claim 67 or 68, wherein the organometallic imaging layer comprises tin or organotin.

70. The method of claim 67 or 68, further comprising, after said spin-coating: exposing the organometallic imaging layer to Extreme Ultraviolet (EUV) radiation.

71. The method of claim 70, further comprising, after said exposing: developing the organometallic imaging layer using dry development.

72. The method of claim 70, further comprising, after said exposing: developing the organometallic imaging layer using wet development.

73. The method of claim 72, wherein the wet development is performed using an alkaline developer, an ammonium-based ionic liquid, a glycol ether, an organic acid, a ketone, or an alcohol.

74. The method of claim 72, wherein the wet development is performed using tetramethylammonium hydroxide (TMAH).

75. The method of claim 72, wherein the wet development is performed using propylene glycol methyl ether (PGME) or propylene glycol methyl ether acetate (PGMEA).

76. The method of claim 72, wherein the wet development is performed using an organic acid.

77. The method of claim 72, wherein the wet development is performed using 2-heptanone.

78. The method of claim 72, wherein the wet development is performed using ethanol.

79. The method of claim 68, further comprising, after said spin-coating: performing a post-application bake at a temperature below 200°C.

80. The method of claim 70, further comprising, after said exposing: performing a post-exposure bake at a temperature below 200°C.

81. The method of claim 72, further comprising, after said developing: performing a post-development bake at a temperature below 200°C.

82. The method of claim 58, further comprising: providing a hard mask between the substrate and hydronated carbon film, and optionally wherein the hard mask is an ashable hard mask.

83. A method, comprising:

spin-coating an organometallic imaging layer on an underlayer on a substrate;

wherein the underlayer is configured to increase adhesion between the substrate and the imaging layer and reduce a radiation dose for effective photoresist exposure of the imaging layer.

84. The method of claim 83, further comprising: exposing the organometallic imaging layer to EUV radiation.

85. The method of claim 84, further comprising: developing, after the radiation exposure, the organometallic imaging layer using wet development.

86. The method of claim 85, wherein the wet development is performed using an alkaline developer, an ammonium-based ionic liquid, a glycol ether, an organic acid, a ketone, or an alcohol.

87. The method of claim 85, wherein the wet development is performed using tetramethylammonium hydroxide (TMAH).

88. The method of claim 85, wherein the wet development is performed using propylene glycol methyl ether (PGME) or propylene glycol methyl ether acetate (PGMEA).

89. The method of claim 85, wherein the wet development is performed using an organic acid.

90. The method of claim 85, wherein the wet development is performed using 2-heptanone.

91. The method of claim 85, wherein the wet development is performed using ethanol.

92. The method of claim 83, further comprising, after said spin-coating: performing a post-application bake at a temperature below 200°C.

93. The method of claim 84, further comprising, after said exposing: performing, after the EUV exposure, a post-exposure bake at a temperature below 200°C.

94. The method of claim 85, further comprising, after said developing: performing a post-development bake at a temperature below 200°C.

95. The method of claim 83, wherein the underlayer is provided by PECVD.

96. The method of claim 83, wherein the organometallic imaging layer comprises tin or organotin.

97. The method of claim 83, further comprising: providing a hard mask between the substrate and the underlayer, and optionally wherein the hard mask is an ashable hard mask.

98. The method of claim 83, wherein the underlayer comprises hydronated carbon.

99. The method of claim 83, wherein the underlayer comprises hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination of two or more of any of these; and optionally wherein the hydronated carbon doped with iodine is configured to improve generation of secondary electrons upon exposure to radiation.

100. The method of claim 83, wherein the underlayer comprises about 0-30 atomic % oxygen (O) and/or about 20-50 atomic % hydrogen (H); and/or wherein a surface of the underlayer comprises hydroxyl groups, carboxyl groups, peroxy groups, sp^2 carbons, sp carbons, and/or unsaturated carbon-containing bonds.

101. The method of claim 83, wherein the underlayer comprises a density of about 0.7 to 2.9 g/cm^3; optionally wherein the underlayer further provides increased etch selectivity; and optionally wherein the underlayer further provides decreased line edge and line width roughness and/or decreased dose to size.

102. The method of claim 83, wherein the underlayer further comprises beta hydrogen atoms configured to be released upon exposure to radiation and/or oxygen atoms configured to form oxygen bonds to an atom in the imaging layer.

103. A method, comprising:

providing an underlayer on a substrate, the underlayer comprises a vapor deposited film of hydronated carbon;

spin-coating an organotin imaging layer on the underlayer;

exposing the organotin imaging layer to Extreme Ultraviolet (EUV) radiation; and

developing the organotin imaging layer using wet development.

104. The method of claim 103, wherein the wet development is performed using an alkaline developer, an ammonium-based ionic liquid, a glycol ether, an organic acid, a ketone, or an alcohol.

105. The method of claim 103, wherein the wet development is performed using tetramethylammonium hydroxide (TMAH).

106. The method of claim 103, wherein the wet development is performed using propylene glycol methyl ether (PGME) or propylene glycol methyl ether acetate (PGMEA).

107. The method of claim 103, wherein the wet development is performed using an organic acid.

108. The method of claim 103, wherein the wet development is performed using 2-heptanone.

109. The method of claim 103, wherein the wet development is performed using ethanol.

110. The method of claim 103, further comprising, after said spin-coating: performing a post-application bake at a temperature below 200°C.

111. The method of claim 103, further comprising, after said exposing: performing a post-exposure bake at a temperature below 200°C.

112. The method of claim 103, further comprising, after said developing: performing a post-development bake at a temperature below 200°C.

113. The method of claim 103, wherein the underlayer is provided by plasma enhanced chemical vapor deposition (PECVD).

114. The method of claim 103, further comprising, after said spin-coating: providing an ashable hard mask between the substrate and the underlayer.

115. A patterning structure, comprising:

a substrate;

an underlayer on the substrate; and

a spin-on organometallic imaging layer on the underlayer;

wherein the underlayer is configured to increase adhesion between the substrate and the imaging layer and reduce a radiation dose for effective photoresist exposure of the imaging layer.

116. The patterning structure of claim 115, wherein the underlayer comprises hydronated carbon.

117. The patterning structure of claim 116, wherein the underlayer comprises hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination of two or more of any of these; and optionally wherein the hydronated carbon doped with iodine is configured to improve generation of secondary electrons upon exposure to radiation.

118. The patterning structure of claim 117, wherein the underlayer comprises about 0-30 atomic % oxygen (O) and/or about 20-50 atomic % hydrogen (H); and/or wherein a surface of the underlayer comprises hydroxyl groups, carboxyl groups, peroxy groups, sp^2 carbons, sp carbons, and/or unsaturated carbon-containing bonds.

119. The patterning structure of claim 115, wherein the underlayer comprises a density of about 0.7 to 2.9 g/cm^3; optionally wherein the underlayer further provides increased etch selectivity; and optionally wherein the underlayer further provides decreased line edge and line width roughness and/or decreased dose to size.

120. The patterning structure of claim 115, wherein the underlayer further comprises beta hydrogen atoms configured to be released upon exposure to radiation and/or oxygen atoms configured to form oxygen bonds to an atom in the imaging layer.

121. The patterning structure of claim 115, further comprising a hard mask between the substrate and the underlayer, and optionally wherein the hard mask is ashable.

122. The patterning structure of claim 115, wherein the organometallic imaging layer comprises tin or organotin.

123. A patterning structure, comprising:

a substrate;

a hard mask on the substrate;

an underlayer on the hard mask; and

a spin-on organometallic imaging layer on the underlayer;

wherein the underlayer comprises a vapor deposited film of hydronated carbon doped with oxygen (O), silicon (Si), nitrogen (N), tungsten (W), boron (B), iodine (I), chlorine (Cl), or a combination thereof.

124. The patterning structure of claim 123, wherein the hard mask is ashable.

125. The patterning structure of claim 123, wherein the organometallic imaging layer comprises tin or organotin.

~~33.~~126.An apparatus for processing a substrate, the apparatus comprising:

a process chamber comprising a substrate support;

a process gas source connected with the process chamber and associated flow-control hardware;

substrate handling hardware connected with the process chamber; and

a controller having a processor and a memory, wherein the ~~processer~~processor and the memory are communicatively connected with one another, the processor is at least operatively connected with the flow-control and substrate handling hardware, and the memory stores computer-executable instructions for conducting the operations recited in the methods of any one of claims ~~12-32~~21, 58, 83, or 103.