CLAIMS

1. A method of preparing a substrate surface of a substrate to deposit a functionalization layer over a metallic barrier layer of a copper interconnect to assist deposition of a copper layer in the copper interconnect in an integrated system in order to improve electromigration performance of the copper interconnect, comprising:

depositing the metallic barrier layer to line the copper interconnect structure in the integrated system, wherein after depositing the metallic barrier layer, the substrate is transferred and processed in controlled environment to prevent the formation of metallic barrier oxide;

depositing the functionalization layer over the metallic layer in the integrated system; and

depositing the copper layer in the copper interconnect structure in the integrated system after the funcationalization layer is deposited over the metallic barrier layer.

2. The method of claim 1, further comprising:

cleaning an exposed surface of a underlying metal to the copper interconnect to remove a surface metal oxide of the exposed surface of the underlying metal in the integrated system before depositing the metallic barrier layer, wherein the underlying metal is part of an underlying interconnect electrically connected to the copper interconnect;

3. The method of claim 1, further comprising:

reducing a surface of the metallic barrier layer to make the surface of the metallic barrier layer metal-rich in the integrated system before depositing the functionalization layer.

4. The method of claim 1, wherein the material of the metallic barrier layer is selected from the group consisting of tantalum nitride (TaN), tantalum (Ta), Ruthenium (Ru), titanium (Ti), tungsten (W), zirconium (Zr), hafnium (Hf), molybdenum (Mo), niobium (Nb), vanadium (V), ruthenium (Ru) and chromium (Cr), and a hybrid combination of these matierals.

5. The method of claim 1, wherein the material used for the functionalization layer comprises a complexing group with at least two ends, one end of the complexing group forming a bond with the metallic barrier layer and another end of the complexing group forming a bond with copper.

6. The method of claim 4, wherein the complexing group is selected from the group consisting of decanethiol, octadecanethiol, tetraphenylporphines, diphenyl disulfide, aromatic thioacetate, ruthenium (II) tris(2, 2, prime-biphyridine) thiol, thiophenol, 4, 4 prime-dithiodipyridine, naphthalene disulfide, and bis(2-anthraquinyl) disulfide, 3-mercaptoprophyl trimethoxysilane, γ-methacryloxypropyl triethoxysilane, perfluoroctanoxylprophy-dimethyl silane, alkyltrichlorosilane, oxtadecylsiloxane, octanol, 22-mercapto-1-docosanoic acid, alkanephosphonic acids, octadecanoic acid, diaminododecane, n-phenylpyrrole, and 2,5-dithienylpyrrol triad.

7. The method of claim 3, wherein reducing the surface of the metallic barrier layer is performed by using a hydrogen-containing plasma.

8. The method of claim 1, wherein the copper interconnect include a metal line over a via and the underlying interconnect include a metal line.

9. The method of claim 1, wherein the copper interconnect include a metal line and the underlying interconnect include a contact.

10. The method of claim 2, wherein cleaning the exposed surface of the surface metal oxide is accomplished by using one of an Ar sputtering process or a plasma process using a fluorine-containing gas.

11. The method of claim 10, wherein the fluorine-containing gas is NF_3, CF_4, or a combination of both.

12. The method of claim 1, wherein depositing the metallic barrier layer further comprising:

depositing a first metallic barrier layer; and

depositing a second metallic barrier layer.

13. The method of claim 12, wherein the first metallic barrier layer is deposited by an atomic layer deposition (ALD) process and the second metallic barrier layer is deposited by a physical vapor deposition (PVD) process.

14. The method of claim 12, wherein the first metallic barrier layer is deposited by an ALD process and the second metallic barrier layer is deposited by an ALD process.

15. The method of claim 1, further comprising:

cleaning a surface of the functionalization layer in the integrated system before depositing the copper layer.

16. The method of clam 1, wherein selectively the thin copper seed layer is deposited by an electroless process.

17. The method of claim 1, wherein the gap-fill copper layer is deposited by an electrochemical plating (ECP) process.

18. The method of claim 1, wherein the copper layer replaces the functionalization layer and deposits directly on the metallic barrier layer.

19. An integrated system for processing a substrate in controlled environment to enable deposition of a functionalization layer over a metallic barrier layer of a copper interconnect to improve electromigration performance of the copper interconnect, comprising:

a lab-ambient transfer chamber capable of transferring the substrate from a substrate cassette coupled to the lab-ambient transfer chamber into the integrated system;

a vacuum transfer chamber operated under vacuum at a pressure less than 1 Torr;

a vacuum process module for depositing the metallic barrier layer, wherein the vacuum process module for depositing the metallic barrier layer is coupled to the vacuum transfer chamber, and is operated under vacuum at a pressure less than 1 Torr;

a controlled-ambient transfer chamber filled with an inert gas selected from a group of inert gases; and

a deposition process module used to deposit the functionalization layer on the surface of the metallic barrier layer, wherein the deposition process module used to deposit the functionalization layer is coupled to the controlled-ambient transfer chamber.

20. The integrated system of claim 19, further comprising:

an electroless copper deposition process module used to deposit a thin layer of copper seed layer in the copper interconnect after the functionalization layer is deposited on the surface of the metallic barrier layer, wherein the electroless copper deposition process module is coupled to the controlled-ambient transfer chamber.

21. The integrated system of claim 19, further comprising:

a vacuum process module for cleaning an exposed surface of a metal oxide of a underlying metal, wherein the underlying metal is part of a underlying interconnect, the copper interconnect is electrically connected to the underlying interconnect, and the vacuum process module for cleaning is coupled to the vacuum transfer chamber, and is operated under vacuum at a pressure less than 1 Torr.

22. The integrated system of claim 19, further comprising:

a hydrogen-containing reduction process module used to reduce metal oxide or metal nitride on a surface of the metallic barrier to make the surface metal-rich before the functionalization layer is deposited on the surface of the metallic barrier layer, wherein the hydrogen-containing reduction process module is coupled to the vacuum transfer chamber, the hydrogen-containing reduction process module is operated under vacuum at a pressure less than 1 Torr.

23. The integrated system of claim 20, wherein the electroless copper deposition process module is also used to deposit a gap-fill copper layer over the thin copper seed layer.

24. The integrated system of claim 20, further comprising:

an electroless copper deposition process module to deposit a gap-fill copper layer over the thin copper seed layer.

25. The integrated system of claim 19, further comprising:

a substrate cleaning process module used to clean the substrate surface after depositing the functionalization layer over the metallic barrier layer, wherein the substrate cleaning process module is coupled to the controlled-ambient transfer module.

26. The integrated system of claim 19, further comprising:

a first loadlock coupled to the vacuum transfer chamber and the controlled-ambient transfer chamber, wherein the first loadlock assists the substrate to be transferred between the vacuum transfer chamber and the controlled-ambient transfer chamber, the first loadlock being configured to be operated under vacuum at pressure less than 1 Torr or to be filled with an inert gas selected from a group of inert gases; and

a second loadlock coupled to the vacuum transfer chamber and the lab-ambient transfer chamber, wherein the second loadlock assists the substrate to be transferred between the vacuum transfer chamber and the lab-ambient transfer chamber, the second loadlock being configured to be operated under vacuum at pressure less than 1 Torr or at lab ambient or to be filled with an inert gas selected from a group of inert gases.

27. The integrated system of claim 19, wherein the vacuum transfer chamber and the at least one vacuum process module coupled to the vacuum transfer chamber are operated at a pressure less than 1 Torr to control the exposure of the substrate to oxygen.

28. The integrated system of claim 19, wherein the controlled-ambient transfer chamber and each one the at least one process module coupled to the controlled-ambient transfer chamber are filled with one or more inert gases selected from the group of inert gases to control the exposure of the substrate to oxygen.

29. The integrated system of claim 19, wherein substrate is transferred and processed in the integrated system to limit a duration the substrate is exposed to oxygen.

30. The method of claim 29, wherein limiting the exposure of the substrate surface to oxygen enables the functionalization layer being deposited on the surface of the metallic barrier layer.

31. The integrated system of claim 19, wherein the at least one process module coupled to the controlled-ambient transfer module enables a dry-in/dry-out processing of the substrate, wherein the substrate goes in and comes out the at least one process module in a dry state.

Claims

1. A method of preparing a substrate surface of a substrate to deposit a functionalization layer over a metallic barrier layer of a copper interconnect to assist deposition of a copper layer in the copper interconnect in an integrated system configured to operate a mixture of dry and wet processes in order to improve electromigration performance of the copper interconnect, comprising:

depositing the metallic barrier layer to line the copper interconnect structure by a dry process in the integrated system configured to operate a mixture of dry and wet processes, wherein after depositing the metallic barrier layer, the substrate is transferred and processed in a controlled environment in the integrated system to prevent the formation of metallic barrier oxide, the controlled environment defined by a vacuum transfer module coupled to one or more dry process chambers and a controlled-ambient transfer module coupled to one or more wet process chambers, the vacuum transfer module and the controlled-ambient transfer module being coupled to each other by a single load lock so as to form a common path for the substrate to directly travel between the vacuum transfer module and the controlled-ambient transfer module;

transporting the substrate from the vacuum transfer module to the controlled-ambient transfer module;

depositing the functionalization layer over the metallic barrier layer by a wet process in the integrated system; and

depositing the copper layer over the functionalization layer in the copper interconnect structure by a wet process in the integrated system after the functionalization layer is deposited over the metallic barrier layer, wherein the material used for the functionalization layer comprises a complexing group with at least two ends, one end of the complexing group forming a bond with the metallic barrier layer and another end of the complexing group forming a bond with the copper layer, wherein the functionalization layer between the metallic barrier layer and the copper layer enables the deposition of the copper layer and improves adhesion between the metallic barrier layer and the copper layer;

wherein the transfer modules transfer the substrate in a dry state from one process chamber to a next process chamber, wherein ambient conditions are controlled during the transfers in the transfer modules.

2. The method of claim 1, further comprising:

cleaning an exposed surface of a underlying metal to the copper interconnect to remove a surface metal oxide of the exposed surface of a underlying metal in the integrated system before depositing the metallic barrier layer, wherein the underlying metal is part of an underlying interconnect electrically connected to the copper interconnect.

3. The method of claim 1, further comprising:

reducing a surface of the metallic barrier layer to make the surface of the metallic barrier layer metal-rich in the integrated system before depositing the functionalization layer.

4. The method of claim 1, wherein the material of the metallic barrier layer is selected from the group consisting of tantalum nitride (TaN), tantalum (Ta), Ruthenium (Ru), titanium (Ti), tungsten (W), zirconium (Zr), hafnium (Hf), molybdenum (Mo), niobium (Nb), vanadium (V), ruthenium (Ru) and chromium (Cr), and a hybrid combination of these materials.

5. The method of claim 1, wherein the complexing group is selected from the group consisting of decanethiol, octadecanethiol, tetraphenylporphines, diphenyl disulfide, aromatic thioacetate, ruthenium (II) tris(2, 2, prime-biphyridine) thiol, thiophenol, 4, 4 prime-dithiodipyridine, naphthalene disulfide, and bis(2-anthraquinyl) disulfide, 3-mercaptoprophyl trimethoxysilane, γ-methacryloxypropyl triethoxysilane, perfluoroctanoxylprophy-dimethyl silane, alkyltrichlorosilane, oxtadecylsiloxane, octanol, 22-mercapto-1-docosanoic acid, alkanephosphonic acids, octadecanoic acid, diaminododecane, n-phenylpyrrole, and 2,5-dithienylpyrrol triad.

6. The method of claim 3, wherein reducing the surface of the metallic barrier layer is performed by using a hydrogen-containing plasma.

7. The method of claim 1, wherein the copper interconnect is over an underlying interconnect which includes a metal line.

8. The method of claim 1, wherein the copper interconnect is over an underlying interconnect which includes a contact.

9. The method of claim 2, wherein cleaning the exposed surface of the surface metal oxide is accomplished by using one of an Ar sputtering process or a plasma process using a fluorine-containing gas.

10. The method of claim 9, wherein the fluorine-containing gas is NF_3, CF_4, or a combination of both.

11. The method of claim 1, wherein depositing the metallic barrier layer further comprising:

depositing a first metallic barrier layer; and

depositing a second metallic barrier layer.

12. The method of claim 11, wherein the first metallic barrier layer is deposited by an atomic layer deposition (ALD) process and the second metallic barrier layer is deposited by a physical vapor deposition (PVD) process.

13. The method of claim 11, wherein the first metallic barrier layer is deposited by an ALD process and the second metallic barrier layer is deposited by an ALD process.

14. The method of claim 1, further comprising:

cleaning a surface of the functionalization layer in the integrated system before depositing the copper layer.

15. The method of clam 1, wherein the copper layer is a thin copper seed layer selectively deposited by an electroless process.

16. The method of claim 15, wherein a gap-fill copper layer is deposited following the deposition of the thin copper seed layer by an electrochemical plating (ECP) process.

17. A method of preparing a substrate surface of a substrate to deposit a functionalization layer over a metallic barrier layer of a copper interconnect to assist deposition of a copper layer in the copper interconnect in an integrated system configured to operate a mixture of dry and wet processes in order to improve electromigration performance of the copper interconnect, comprising:

cleaning an exposed surface of a underlying metal to the copper interconnect to remove a surface metal oxide of the exposed surface of a underlying metal in the integrated system configured to operate a mixture of dry and wet processes before depositing the metallic barrier layer, wherein the underlying metal is part of an underlying interconnect electrically connected to the copper interconnect;

depositing the metallic barrier layer to line the copper interconnect structure by a dry process in the integrated system, wherein after depositing the metallic barrier layer, the substrate is transferred and processed in a controlled environment in the integrated system to prevent the formation of metallic barrier oxide, the controlled environment defined by a vacuum transfer module coupled to one or more dry process chambers and a controlled-ambient transfer module coupled to one or more wet process chambers, the vacuum transfer module and the controlled-ambient transfer module being coupled to each other by a single load lock so as to form a common path for the substrate to travel between the vacuum transfer module and the controlled-ambient transfer module;

reducing a surface of the metallic barrier layer to make the surface of the metallic barrier layer metal-rich in the integrated system before depositing the functionalization layer;

transporting the substrate from the vacuum transfer module to the controlled-ambient transfer module;

depositing the functionalization layer over the metallic barrier layer by a wet process in the integrated system; and

depositing the copper layer over the functionalization layer in the copper interconnect structure by a wet process in the integrated system after the functionalization layer is deposited over the metallic barrier layer, wherein the material used for the functionalization layer comprises a complexing group with at least two ends, one end of the complexing group forming a bond with the metallic barrier layer and another end of the complexing group forming a bond with copper, wherein the functionalization layer

between the metallic barrier layer ad the copper layer enables the deposition of the copper layer and improves adhesion between the metallic barrier layer and the copper layer;

wherein the transfer modules transfer the substrate in a dry state from one process chamber to a next process chamber so as to limit exposure to oxygen.

18. The method of claim 17, wherein the material of the metallic barrier layer is selected from the group consisting of tantalum nitride (TaN), tantalum (Ta), Ruthenium (Ru), titanium (Ti), tungsten (W), zirconium (Zr), hafnium (Hf), molybdenum (Mo), niobium (Nb), vanadium (V), ruthenium (Ru) and chromium (Cr), and a hybrid combination of these materials.

19. The method of claim 17, wherein the complexing group is selected from the group consisting of decanethiol, octadecanethiol, tetraphenylporphines, diphenyl disulfide, aromatic thioacetate, ruthenium (II) tris(2, 2, prime-biphyridine) thiol, thiophenol, 4, 4 prime-dithiodipyridine, naphthalene disulfide, and bis(2-anthraquinyl) disulfide, 3-mercaptoprophyl trimethoxysilane, γ-methacryloxypropyl triethoxysilane, perfluoroctanoxylprophy-dimethyl silane, alkyltrichlorosilane, oxtadecylsiloxane, octanol, 22-mercapto-1-docosanoic acid, alkanephosphonic acids, octadecanoic acid, diaminododecane, n-phenylpyrrole, and 2,5-dithienylpyrrol triad.

20. The method of claim 17, wherein reducing the surface of the metallic barrier layer is performed by using a hydrogen-containing plasma.

21. The method of claim 17, wherein the copper interconnect is over an underlying interconnect which includes a metal line.

22. The method of claim 17, wherein the copper interconnect is over an underlying interconnect which includes a contact.

23. The method of claim 17, wherein cleaning the exposed surface of the surface metal oxide is accomplished by using one of an Ar sputtering process or a plasma process using a fluorine-containing gas.

24. The method of claim 23, wherein the fluorine-containing gas is NF_3, CF_4, or a combination of both.

25. The method of claim 17, wherein depositing the metallic barrier layer further comprising:

depositing a first metallic barrier layer; and

depositing a second metallic barrier layer.

26. The method of claim 25, wherein the first metallic barrier layer is deposited by an atomic layer deposition (ALD) process and the second metallic barrier layer is deposited by a physical vapor deposition (PVD) process.

27. The method of claim 25, wherein the first metallic barrier layer is deposited by an ALD process and the second metallic barrier layer is deposited by an ALD process.

28. The method of claim 17, further comprising:

cleaning a surface of the functionalization layer in the integrated system before depositing the copper layer.

29. The method of clam 17, wherein the copper layer is a thin copper seed layer selectively deposited by an electroless process.

30. The method of claim 29, wherein a gap-fill copper layer is deposited following the deposition of the thin copper seed layer by an electrochemical plating (ECP) process.