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 order to improve electromigration performance of the copper interconnect in an integrated system, comprising:

depositing the metallic barrier layer to line the copper interconnect structure in the integrated system,

oxidizing a surface of the metallic barrier layer;

depositing the functionalization layer over the oxidized surface of the metallic barrier layer; and

depositing the copper layer in the copper interconnect structure after the functionalization layer is deposited over the metallic barrier layer.

2. 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), and chromium (Cr), and a hybrid combination of these materials.

3. 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 oxidized surface of the metallic barrier layer and another end of the complexing group forming a bond with copper.

4. The method of claim 3, wherein the end of the complexing group that forming a bond with oxidized surface of the metallic barrier layer is selected from the group consisting of phosphate (PO_4-), silicon, silane (-$Si(OR)_3$, and acid or acetate (-O-CO-R), R being H or C_xH_y.

5. The method of claim 3, wherein the end of the complexing group forming a bond with copper is metallic or organometallic and is selected from the group consisting of Ru-pyridine, Pd-amine (palladium-amine), Pd-pyridine, Cu-pyridine, Cu-amine, Ru-amine, Ru-acetate, Cu-acetate and Pd-acetate.

6. The method of claim 3, wherein the end of the complexing group forming a bond with copper a thiol-containing ligand, gold nanoparticles being deposited to form catalytic sites for the subsequent copper deposition step.

7. The method of claim 1, wherein oxidizing the surface of the metallic barrier layer is performed by an oxidizing ambient.

8. 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 before depositing the metallic barrier layer, wherein the underlying metal is part of an underlying interconnect electrically connected to the copper interconnect.

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

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

11. The method of claim 1, wherein the copper interconnect includes a through-hole via in a 3 dimensional (3D) packaging or personal computer board (PCB).

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 the copper layer is deposited by an electroless process.

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

18. The method of claim 1, wherein depositing the metallic barrier layer, oxidizing the surface of the metallic barrier layer, depositing the functionalization layer, and depositing the copper layer are performed in an integrated system.

19. 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 order to improve electromigration performance of the copper interconnect in an integrated system, comprising:

depositing the metallic barrier layer to line the copper interconnect structure in the integrated system,

depositing the functionalization layer over the oxidized surface of the metallic barrier layer; and

depositing the copper layer in the copper interconnect structure after the functionalization layer is deposited over the metallic barrier layer.

20. 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 is coupled to the controlled-ambient transfer chamber.

21. The integrated system of claim 20, 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.

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

an oxidation process module used to oxidize a surface of the metallic barrier layer before the functionalization layer is deposited on the surface of the metallic barrier layer, wherein the oxidation process module is coupled to the vacuum transfer chamber and is operated under vacuum at a pressure less than 1 Torr.

23. The integrated system of claim 21, 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 21, 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 20, 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 20, wherein the deposition process module used to deposit the functionalization layer is a wet process module and is coupled to the controlled-ambient transfer module.

27. The integrated system of claim 20, wherein the deposition process module used to deposit the functionalization layer is a dry process module and is coupled to vacuum transfer module.

28. The integrated system of claim 20, 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.

29. The integrated system of claim 20, wherein the vacuum transfer chamber and the 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.

30. The integrated system of claim 20, wherein the controlled-ambient transfer chamber and the deposition 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.

31. The integrated system of claim 20, 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.

32. The integrated system of claim 20, wherein the oxidation process module prepares the surface of the metallic barrier layer to be deposited with the functionalization layer.

What is claimed is:

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 order to improve electromigration performance of the copper interconnect in an integrated system, comprising:

depositing the metallic barrier layer to line the copper interconnect structure in the integrated system,

oxidizing a surface of the metallic barrier layer;

depositing the functionalization layer over the oxidized surface of the metallic barrier layer; and

depositing the copper layer in the copper interconnect structure after the functionalization layer is deposited over the metallic barrier layer, and

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 oxidized surface of the metallic barrier layer and another end of the complexing group forming a bond with copper.

2. 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), and chromium (Cr), and a hybrid combination of these materials.

3. The method of claim 1, wherein the end of the complexing group that forming a bond with oxidized surface of the metallic barrier layer is selected from the group consisting of phosphate (PO_4-), silicon, silane (--$Si(OR)_3$, and acid or acetate (--O--CO--R), R being H or C_xH_y.

4. The method of claim 1, wherein the end of the complexing group forming a bond with copper is metallic or organometallic and is selected from the group consisting of Ru-pyridine, Pd-amine (palladium-amine), Pd-pyridine, Cu-pyridine, Cu-amine, Ru-amine, Ru-acetate, Cu-acetate and Pd-acetate.

5. The method of claim 1, wherein the end of the complexing group forming a

bond with copper is a thiol-containing ligand, gold nanoparticles being deposited to form catalytic sites for the subsequent copper deposition step.

6. The method of claim 1, wherein oxidizing the surface of the metallic barrier layer is performed by an oxidizing ambient.

7. 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 before depositing the metallic barrier layer, wherein the underlying metal is part of an underlying interconnect electrically connected to the copper interconnect.

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

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

10. The method of claim 1, wherein the copper interconnect includes a through-hole via in a 3 dimensional (3D) packaging or personal computer board (PCB).

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 deposited by an electroless process.

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

17. The method of claim 1, wherein depositing the metallic barrier layer, oxidizing the surface of the metallic barrier layer, depositing the functionalization layer, and depositing the copper layer are performed in an integrated system.

18. 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;

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

an oxidation process module used to oxidize a surface of the metallic barrier layer before the functionalization layer is deposited on the surface of the metallic barrier layer, wherein the oxidation process module is coupled to the vacuum transfer chamber and is operated under vacuum at a pressure less than 1 Torr;

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.

19. The integrated system of claim 18, wherein the electroless copper deposition process module is also used to deposit a gap-fill copper layer over the thin copper seed layer.

20. The integrated system of claim 18, further comprising:

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

21. The integrated system of claim 18, 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.

22. The integrated system of claim 18, wherein the deposition process module used to deposit the functionalization layer is a wet process module and is coupled to the controlled-ambient transfer module.

23. The integrated system of claim 18, wherein the deposition process module used to deposit the functionalization layer is a dry process module and is coupled to vacuum transfer module.

24. The integrated system of claim 18, 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.

25. The integrated system of claim 18, wherein the vacuum transfer chamber and the 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.

26. The integrated system of claim 18, wherein the controlled-ambient transfer chamber and the deposition 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.

27. The integrated system of claim 18, 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.

28. The integrated system of claim 18, wherein the oxidation process module prepares the surface of the metallic barrier layer to be deposited with the functionalization layer.