An ionized physical vapor deposition (I-PVD) process is provided. A plasma reaction chamber is provided. The plasma reaction chamber comprises a metal target and a wafer pedestal set up on the top and bottom section inside the chamber, an ionization unit set up between the target and the wafer pedestal and a conductive mesh set up between the ionization unit and the wafer pedestal. A wafer is put on the wafer pedestal. Thereafter, a negative bias voltage is applied to the metal target and a smaller negative bias voltage is applied to the conductive mesh to deposit a thin film over the wafer. The ionized metallic atoms inside the chamber accelerate towards the conductive mesh but decelerate after passing though the mesh so that step coverage of the deposited thin film is improved without damaging the wafer through ion bombardments.
FIG. 4A

FIG. 4B
CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of Taiwan application serial no. 92118826, filed on Jul. 10, 2003.

BACKGROUND OF INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a semiconductor fabrication process and associated apparatus. More particularly, the present invention relates to an ionized physical vapor deposition (I-PVD) process and apparatus thereof.

[0004] 2. Description of the Related Art

[0005] In the process of fabricating semiconductor devices, metallic films are formed by performing a physical vapor deposition (PVD) process or a chemical vapor deposition (CVD) process. In general, the PVD process is more frequently used. However, the step coverage of a PVD process is normally inferior to a CVD process.

[0006] To improve the step coverage of a PVD process, an ionized physical vapor deposition (I-PVD) process has been introduced. Through an ionization unit having a magnetic induction coil or a magnetic pole design, a portion of the neutral metallic atoms is ionized. The ionized metallic atoms are accelerated by an electric field (the electric field between a target and a wafer) towards the wafer. Hence, the ionized metallic atoms will shoot into the wafer surface perpendicularly and increase the step coverage of a deposited film.

[0007] In the aforementioned technique, a negative bias voltage is applied to the target and another smaller radio frequency (RF) negative bias voltage is applied to wafer.

[0008] Hence, the positive metallic ions will be attracted by and accelerate towards the negatively bias wafer. Yet, the bombardment of accelerated ions on the surface of a wafer often results in some damages especially around the contact areas, which may lead to an increase in contact resistance.

SUMMARY OF INVENTION

[0009] Accordingly, one object of the present invention is to provide an ionized physical vapor deposition (I-PVD) process and apparatus thereof that can improve step coverage and reduce damage to the surface of a wafer.

[0010] To achieve these and other advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, the invention provides an ionized physical vapor deposition (I-PVD) apparatus. The I-PVD apparatus comprises a reaction chamber, a wafer pedestal, an ionization unit, a target and a conductive mesh. The wafer pedestal is set up on the bottom section of the reaction chamber for supporting a wafer. The target is set up over the wafer pedestal on the top cover of the reaction chamber. The top cover of the reaction chamber serves as an electrode. Obviously, another electrode plate inside the reaction chamber may be used as an electrode instead of the top cover electrode. The ionization unit is set up between the target and the wafer pedestal for ionizing the metallic atoms let loose from the target due to bombardment. The conductive mesh is set up between the ionization unit and the wafer pedestal serving as another electrode. The conductive mesh is positioned such that the distance from the wafer pedestal is much smaller than the distance to the target. The conductive mesh is separated from the wafer pedestal by a distance between 1 to 2 cm, for example.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

[0015] FIG. 1 is a diagram showing the component layout of an ionized physical vapor deposition apparatus according to one preferred embodiment of this invention.

[0016] FIG. 2 is a top view of the conductive mesh in FIG. 1.

[0017] FIG. 3 is a schematic cross-sectional view showing a thin film with a good step coverage over a wafer formed according to one preferred embodiment of this invention.

[0018] FIGS. 4A and 4B are schematic cross-sectional views showing a thin film with a good step coverage over a wafer formed according to another preferred embodiment of this invention.

DETAILED DESCRIPTION

[0019] Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever
possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

[0020] FIG. 1 is a diagram showing the component layout of an ionized physical vapor deposition apparatus according to one preferred embodiment of this invention. The ionized physical vapor deposition (I-PVD) apparatus comprises a reaction chamber 100, a wafer pedestal 104, a target 106, an ionization unit 108 and a conductive mesh 110.

[0021] The wafer pedestal 104 is set up on the bottom section of the reaction chamber 100 for supporting a wafer 112. The target 106 is fixed to a top section inside the reaction chamber 100. In one embodiment of this invention, the top cover 102 of the reaction chamber 100 is a conductive plate that may serve as an electrode. Furthermore, the top cover 102 is connected to a power supply 120 including, for example, a direct current (DC) power supply. Hence, the target 106 is fastened to the surface of the top cover 102 over the wafer pedestal 104. In another embodiment of this invention, an additional electrode plate 102 is set up at the top section inside the reaction chamber 100 such that the electrode plate 102 is electrically connected to the DC power supply 120. The target 106 is attached to the surface of the electrode plate 102 over the wafer pedestal 104. The target 106 is fabricated from a metallic material including, for example, titanium, cobalt, nickel, tantalum, tungsten, aluminum or copper.

[0022] The ionization unit 108 is set up inside the reaction chamber 100 between the target 106 and the wafer pedestal 104 for ionizing metallic atoms let loose through bombardment. The ionization unit 108 can be a magnetic induction coil or magnetic pole piece, for example. Thus, the ionized physical vapor deposition (I-PVD) apparatus can be an ionized metal plasma (IMP) physical vapor deposition apparatus, a self-ionized plasma (SIP) physical vapor deposition apparatus, a hollow cathode magnetron sputtering (HCM) apparatus according to the type of ionization unit used. If a hollow cathode magnetron sputtering apparatus is used, the electrode plate 102 in FIG. 1 will integrate with a magnetic pole design to form a hollow structure.

[0023] The conductive mesh 110 is set up between the wafer pedestal 104 and the ionization unit 108. The conductive mesh 110 is positioned at a smaller distance away from the wafer pedestal 104 than the target 106. The conductive mesh 110 is separated from the wafer pedestal 104 by a distance between 1 to 2 cm, for example. In addition, the conductive mesh 110 is preferably fabricated using a material identical to the target 106 to prevent unwanted contamination during the deposition process.

[0024] The conductive mesh 110 has a metal net structure having a top view as shown in FIG. 2. Since the conductive mesh 110 is fabricated using a metallic material, the mesh 110 is electrically conductive and can serve as an electrode.

[0025] Furthermore, the conductive mesh 110 is connected to a power supply 118 such as a radio frequency (RF) power supplier.

[0026] In addition, the ionized physical vapor deposition (I-PVD) apparatus further comprises a gas supply device 116 for delivering an inert gas such as argon while the physical vapor deposition process for forming a metallic film is carried out. Furthermore, reactive gases may pass into the reaction chamber 100 selectively through a special channel so that the reactive gases can participate in the vapor deposition to form a thin film the metallic compound. For example, if the target 106 is fabricated using titanium, the gas supply device 116 may deliver argon and nitrogen into the reaction chamber 100 for producing a titanium nitride thin film on the surface of the wafer 112.

[0027] An ionized physical vapor deposition (I-PVD) process for forming a thin film over a wafer can be carried using the I-PVD apparatus as shown in FIG. 1. First, a wafer 112 is put on the wafer pedestal 104 inside the reaction chamber 100 ready for receiving a layer of deposited thin film. A cross-sectional view of the wafer 112 is shown in FIG. 3. The wafer 112 comprises a silicon substrate 200 and a dielectric layer 202 over the substrate 200. The dielectric layer 202 has an opening 204. Thereafter, the power supply 118 and 120 is initialized such that a negative bias voltage is applied to the target 106 and another smaller negative bias voltage is applied to the conductive mesh 110. The plasma thus produced bombarded the target 106 to produces free metallic atoms 113. Meanwhile, the ionization unit 108 is switched on so that the loose metallic atoms 113 are ionized into positively charged metallic ions 114.

[0028] The electric field between the ionized metallic atoms 114 and the conductive mesh 110 accelerates the ionized metallic atoms 114 to shoot at the conductive mesh 110. With the acceleration, the ionized metallic atoms 114 will bombard the wafer 112 perpendicularly and improve the step coverage of the deposited thin film. However, as the ionized metallic atoms 114 pass through the conductive mesh 110, the positively charged metallic atoms 114 will be subjected to the backward attraction of the negatively biased conductive mesh 110. Hence, the ionized metallic atoms 114 will decelerate a little before reaching the wafer 112. In other words, the average energy of the metallic atoms 114 bombarding the wafer 112 is greatly reduced. As shown in FIG. 3, the thin film 206 on the surface dielectric layer 202 and a portion of the substrate 200 has good step coverage. Furthermore, damages to the surface of the dielectric layer 202 and the substrate 200 resulting from bombarding the wafer 112 with accelerated ionized metallic atoms 114 are minimized.

[0029] An example that illustrates the deployment of an I-PVD apparatus to carry out an I-PVD process includes depositing titanium using an ionized metal plasma (IMP) PVC apparatus. In this particular case, the negative bias voltage that applies to the target is a direct current (DC) source with power set to a level between 1000 to 3000 Watts and the negative bias voltage that applies to the conductive mesh is a radio frequency source with power set to a level between 50 to 200 Watts.

[0030] In another embodiment of this invention, a film layer is deposited over the dielectric layer 202 and the substrate 200 before the thin film 206. FIGS. 4A and 4B are schematic cross-sectional views showing a thin film with a good step coverage over a wafer formed according to another preferred embodiment of this invention. As shown in FIGS. 1 and 4A, a wafer 112 is put on the wafer pedestal 104 inside the reaction chamber 100. Thereafter, the power supply 120 is turned on to apply a negative bias voltage to the target 106 but no bias voltage is applied to the conductive mesh 110 yet. In the meantime, the ionization unit 108
is turned on to ionize the metallic atoms 113 bombarded out of the target 106 into positively charged metallic ions 114. Since the conductive mesh 110 is not voltage biased, the metallic ions 114 pass through the conductive mesh 110 with and travel towards the wafer 112 with moderate acceleration. Ultimately, a film layer 210 is formed over the dielectric layer 202 and the substrate 200. The film layer 210 has an overall thickness roughly 20% to 30% (40 Å to 50Å, for example) of the final thickness of the thin film 206. Because the deposition process is carried out without applying any bias voltage to the conductive mesh 110, the film layer 210 has poor step coverage. Yet, the ultimate step coverage of the thin film is relatively unaffected because overall thickness of the thin film 210 is small.

[0031] As shown in FIGS. 1 and 4B, a negative bias voltage is again applied to the target 106 and another smaller negative bias voltage is applied to the conductive mesh 110. Similarly, the ionization unit 108 is turned on to ionize the metallic atoms 113 bombarded out of the target 106 into positively charged metallic ions 114. The electric field between the target 106 and the conductive mesh 110 accelerates the ionized metallic atoms 114 towards the wafer 112. Hence, the ionized metallic atoms 114 will shoot perpendicularly into the wafer 112 and improve the step coverage of the thin film. However, the positively charged ions 114 will be attracted by the negatively biased conductive mesh 110 after passing through the mesh 110. Thus, the conductive mesh 100 is able to decelerate the ions 114 on its way to the wafer 112. The thin film 206 over the film layer 210 has a thickness of about 200 Å or more and has good step coverage. With the film layer 210 covering both the dielectric layer 202 and the substrate 200, the amount of damages to the wafer 112 resulting from the bombardment of metallic ions 114 is greatly reduced.

[0032] In the aforementioned embodiment, if the thin film to be deposited on the wafer is a metallic compound, an additional reaction gas is also passed into the reaction chamber 100 all through the reaction process.

[0033] In this invention, a conductive mesh is set up close to the wafer and a negative bias voltage is applied to the conductive mesh. Hence, ionized metallic atoms will accelerate towards the mesh and improve the step coverage of a deposited film. The negative voltage biased mesh also decelerates the ionized metallic atoms before reaching the wafer so that damage to the wafer resulting from the bombardment by the metallic ions is greatly reduced.

[0034] In addition, a film layer may be deposited over the wafer without applying a negative bias voltage to the conductive mesh prior to forming the thin film. The film layer protects the wafer against direct bombardment by ionized metallic atoms during a subsequent thin film deposition process.

[0035] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

1. An ionized physical vapor deposition (I-PVD) apparatus, comprising:
   - a reaction chamber;
   - a target fixed on a top section inside the reaction chamber;
   - a wafer pedestal set up on a bottom section inside the reaction chamber;
   - an ionization unit set up between the target and the wafer pedestal; and
   - a conductive mesh set up between the ionization unit and the wafer pedestal.

2. The I-PVD apparatus of claim 1, wherein the conductive mesh and the target are fabricated using an identical material.

3. The I-PVD apparatus of claim 1, wherein the conductive mesh is set up at a smaller distance away from the wafer pedestal than the target.

4. The I-PVD apparatus of claim 3, wherein the conductive mesh is separated from the wafer pedestal by a distance between 1 to 2 cm.

5. The I-PVD apparatus of claim 1, wherein the top section of the reaction chamber serves as a first electrode and the conductive mesh serves as a second electrode.

6. The I-PVD apparatus of claim 1, wherein the apparatus further comprises a first electrode fixed on the top section inside the reaction chamber and the target is fixed on the first electrode such that the conductive mesh serves as a second electrode.

7. An ionized physical vapor deposition (I-PVD) process, comprising the steps of:
   - providing a plasma reaction chamber having a target and a wafer pedestal set up within the chamber, wherein an ionization unit is set up between the target and the wafer pedestal and a conductive mesh set up between the ionization unit and the wafer pedestal;
   - placing a wafer on the wafer pedestal; and
   - applying a negative bias voltage to the target and a smaller negative bias voltage to the conductive mesh for depositing a thin film over the wafer.

8. The I-PVD process of claim 7, wherein before the step of depositing a thin film over the wafer, further comprises applying a negative bias voltage to the target without applying any bias voltage to the conductive mesh to form a film layer over the wafer and then applying a negative bias voltage to the target and a smaller negative bias voltage to the conductive mesh to form a thin film over the film layer.

9. The I-PVD process of claim 8, wherein the film layer has a thickness between 20% to 30% of the ultimate thickness of the thin film.

10. The I-PVD process of claim 7, wherein the process of depositing the thin film further comprises passing a reactive gas into the reaction chamber.

11. An ionized physical vapor deposition (I-PVD) process, comprising the steps of:
   - producing ionized metallic atoms inside a reaction chamber and accelerating the ionized metallic atoms at a first acceleration rate towards a wafer; and
   - passing the ionized metallic atoms through a conductive mesh before reaching the wafer such that the ionized metallic atoms are able to decelerate and form a metallic thin film on the wafer.
12. The I-PVD process of claim 11, wherein before the step of forming a metallic thin film over the wafer, further comprising:

producing ionized metallic atoms inside the reaction chamber such that the ionized metallic atoms accelerate at a second acceleration rate through the conductive mesh to reach the wafer and form a film layer over the wafer, wherein the second acceleration rate is smaller than the first acceleration rate; and

accelerating the ionized metallic atoms towards the wafer at the first acceleration rate such that the ionized metallic atoms decelerate after passing through the conductive mesh to form the metallic thin film over the film layer.

13. The I-PVD process of claim 11, wherein the step of producing ionized metallic atoms further comprises passing a reactive gas into the reaction chamber.

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