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[54] **METHOD AND APPARATUS FOR INCREASING THE METAL ION FRACTION IN IONIZED PHYSICAL VAPOR DEPOSITION**

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[51] **Int. Cl.**^{7} **D06F 29/00**

[52] **U.S. Cl.** **204/192.12**; 204/298.06; 204/298.08; 204/298.11

[58] **Field of Search** 204/298.08, 298.11, 204/298.06, 192.12

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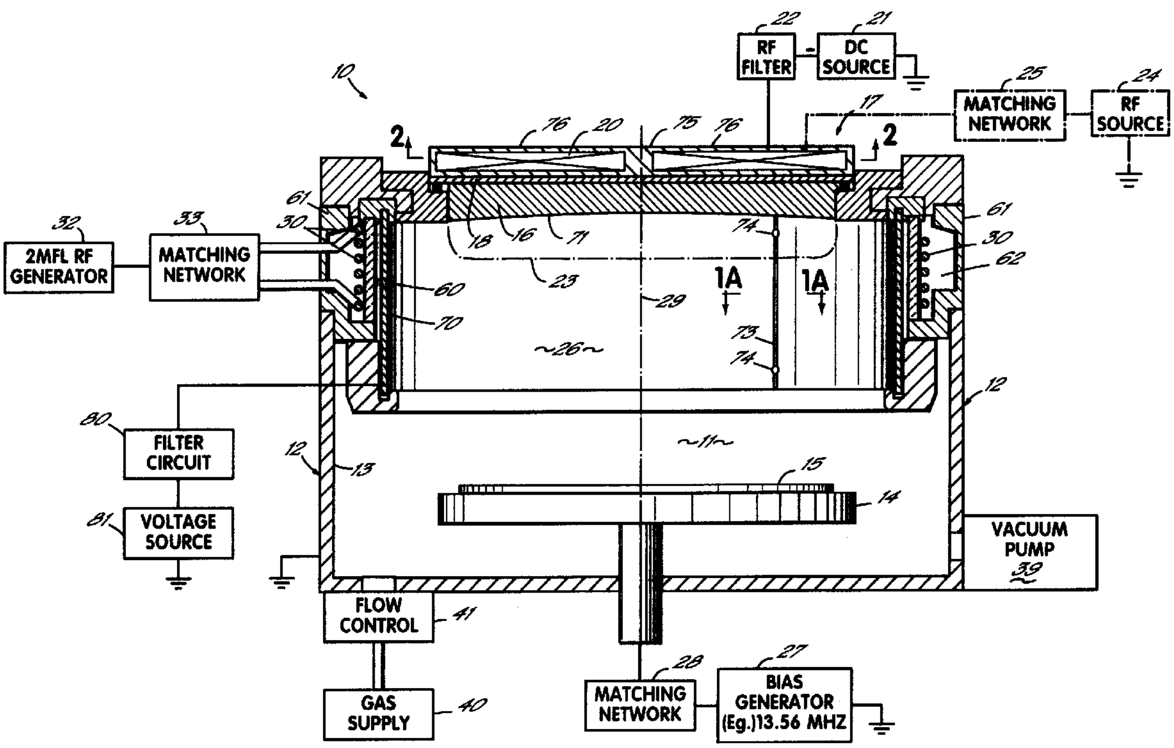
[57] **ABSTRACT**

An ionized physical vapor deposition method and apparatus are provided which employs a magnetron magnetic field produced by cathode magnet structure behind a sputtering target to produce a main sputtering plasma, and an RF inductively coupled field produced by an RF coil outside of and surrounding the vacuum of the chamber to produce a secondary plasma in the chamber between the target and a substrate to ionize sputtered material passing from the target to the substrate so that the sputtered material can be electrically or magnetically steered to arrive at the substrate at right angles. A circumferentially interrupted shield or shield structure in the chamber protects the window from material deposits. A low pass LC filter circuit allows the shield to float relative to the RF voltage but to dissipate DC potential on the shield. Advantages provided are that loss of electrons and ions from the secondary plasma is prevented, preserving plasma density and providing high ionization fraction of the sputtered material arriving at the substrate.

14 Claims, 2 Drawing Sheets



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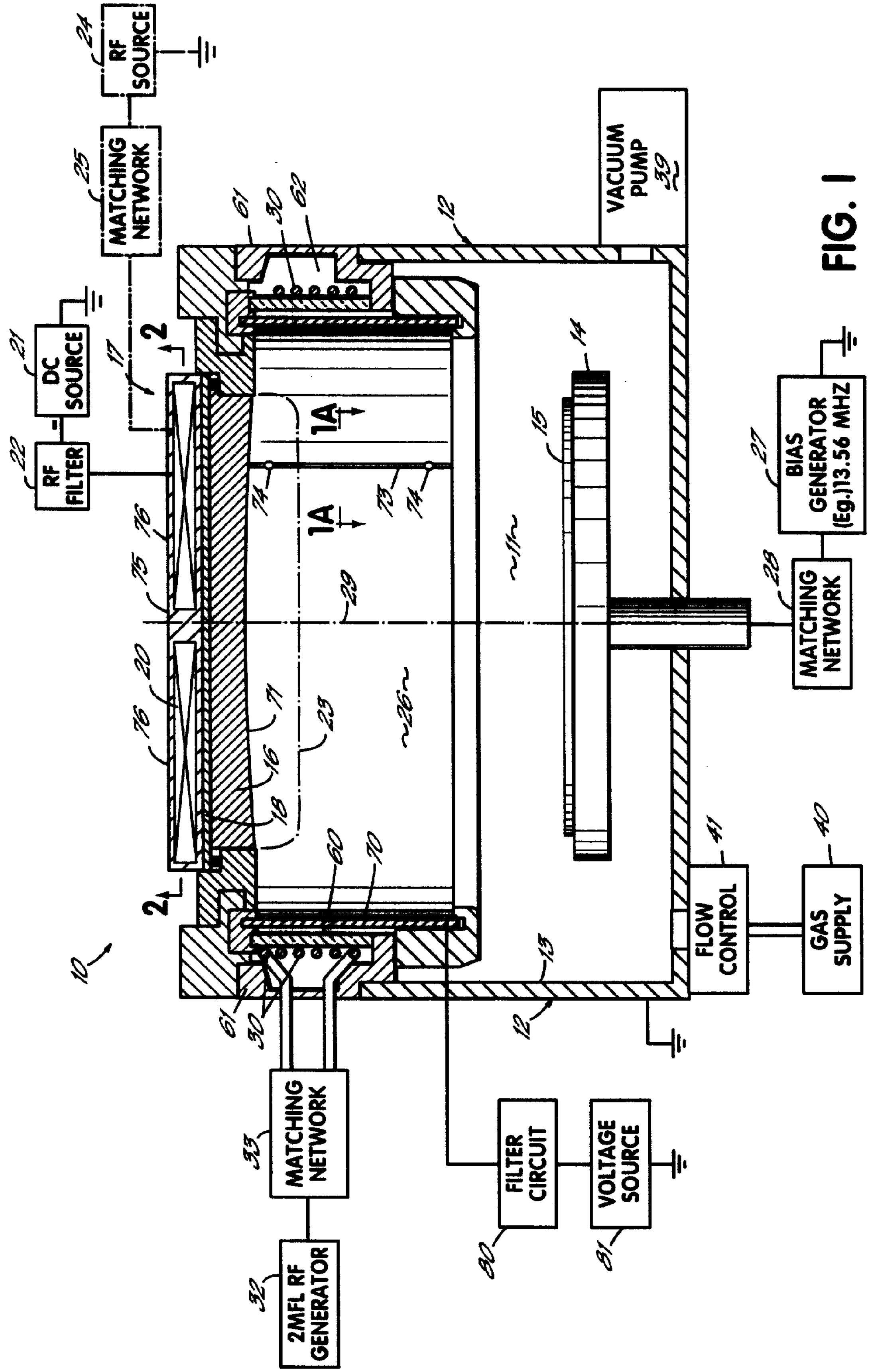

FIG. 1

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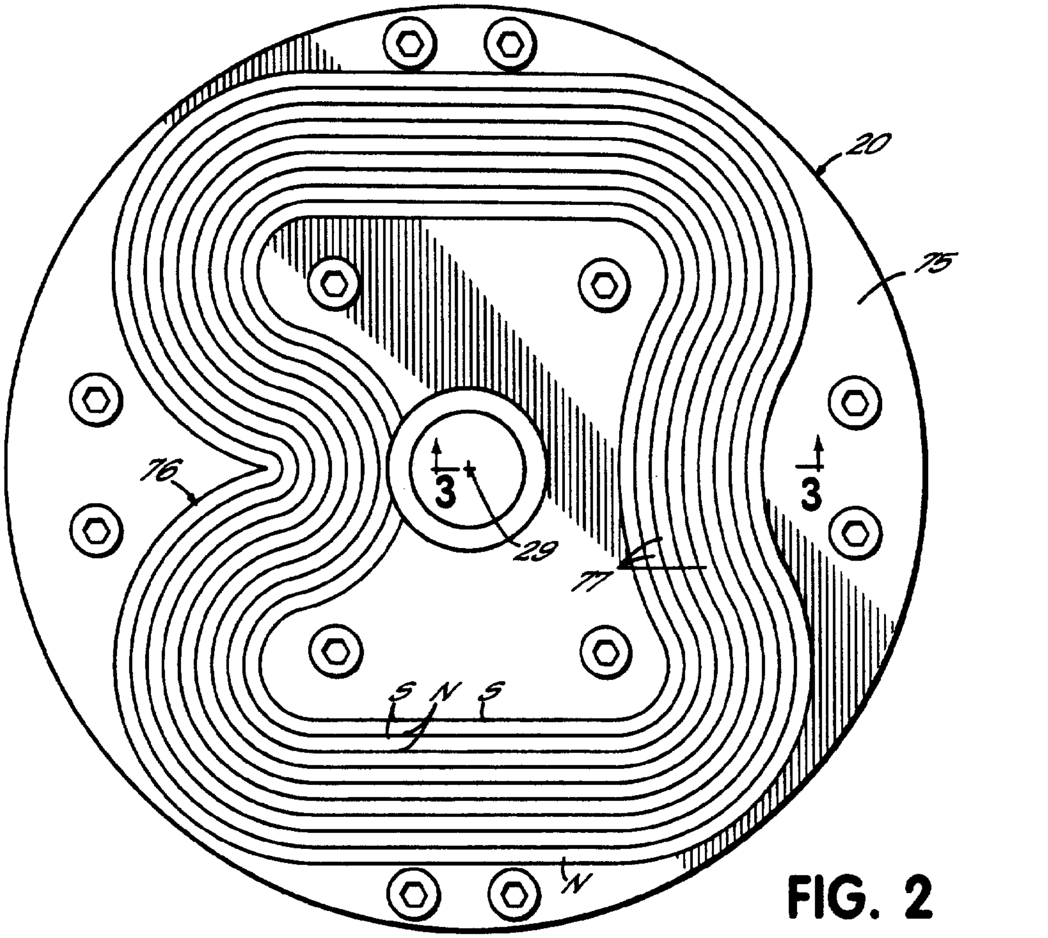

FIG. 2

FIG. 1A

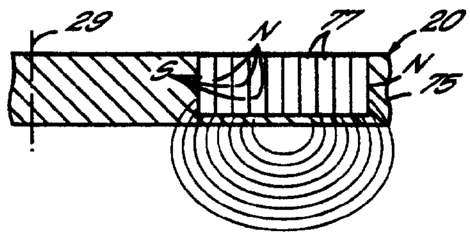

FIG. 3

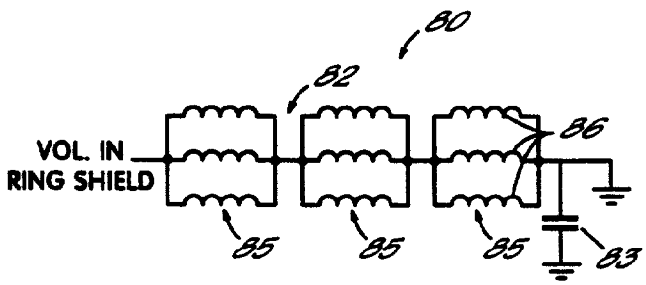

FIG. 4

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METHOD AND APPARATUS FOR INCREASING THE METAL ION FRACTION IN IONIZED PHYSICAL VAPOR DEPOSITION

This invention relates to sputter coating, and more particularly, to the Ionized Physical Vapor Deposition (IPVD) of coating material onto substrates.

BACKGROUND OF THE INVENTION

Smaller and higher aspect ratio features, such as vias, trenches and contact holes, in semiconductor manufacturing impose greater requirements on semiconductor processing equipment. For example, coating contacts on the bottoms of such features with liners and filling the features with conductive films using certain preferred physical vapor deposition (PVD) processes requires the achievement of a high degree of directionality in movement of the material being deposited toward the substrate. Smaller and higher aspect ratio features require greater directionality. To effectively coat contacts, for example, on the bottoms of narrow high aspect ratio holes on the surface of a substrate, it is necessary for the particles of coating material to move at angles to the normal that are not substantially larger than the angular openings of the features. Otherwise, excessive deposits on the upper sides of the features or a closing of the mouth of a feature will result.

A sputter coating process is typically carried out by placing a substrate and a target of high purity coating material into a vacuum chamber filled with an inert gas such as argon or a reactive gas such as nitrogen and creating a plasma in the gas. The plasma is typically generated by maintaining the target, either constantly or intermittently, at a negative potential, so that the target functions as a cathode to supply electrons that excite the gas in the chamber and form a plasma adjacent to the target surface. The plasma generation is usually enhanced with a magnetron cathode assembly in which magnets behind the target trap electrons at high density over the surface of the target where they collide with atoms of the process gas, stripping electrons from atoms of gas to produce positive ions. The gas ions accelerate toward the target, which is negatively biased, to collide with the target surface and eject from the target surface atoms and atomic clusters or particles of target material, as well as secondary electrons, which play a role in sustaining the plasma.

In conventional sputter coating, the large majority of the ejected atoms of target material are neutral in charge and propagate through the vacuum space in various directions with some striking the substrate, to which they adhere to form a film. The directions of travel of the ejected particles from the target surface follow a somewhat broad statistical distribution of angles to the target surface. Various schemes have been used to cause the propagating particles to move in straighter lines toward and normal to the substrate surface. In Ionized Physical Vapor Deposition or IPVD, coating material is sputtered from a target using magnetron sputtering, other conventional sputtering or evaporation techniques, and then the directionality of the particles is improved by ionizing the particles so that they can be electrostatically accelerated or otherwise electrically steered in a direction toward and normal to the substrate.

In IPVD, additional or secondary plasma is created in the space within the chamber between the target or source of the material and the substrate. The particles of sputtered material passing through this space collide with electrons or metastable neutrals of the ionized process gas, which tend to strip electrons from the atoms of the sputtered particles leaving the particles positively charged. Those positive ions of sputtered material that are positively charged are capable of being electrically accelerated toward the substrate, for example, by application of a negative bias to the substrate. The effectiveness of the IPVD process in normalizing the direction of coating particles at the substrate is proportional to the fraction of ionization of the sputtered material produced by the secondary plasma.

Obtaining a high ion fraction of sputtered material requires the secondary plasma to have a high electron density. Loss of electrons from the secondary plasma into the main plasma at the target, or into chamber structure such as walls or shields, can cause a substantial reduction in the effectiveness of the secondary plasma to ionize sputtered material and can result in the extinguishing of the secondary plasma. It is important to minimize the depletion of electrons from the secondary plasma and to otherwise produce a high ionization fraction of sputtered material in IPVD processing.

In addition, structure such as walls or shields that bound a secondary plasma is in direct contact with the secondary plasma in a region called the sheath. The sheath width depends in part on the potential difference between the secondary plasma and this structure. Where the structure is electrically grounded, the typical sheath width is a few electron Debye lengths of about 0.14 mm, for example, where the electron density and temperature are about 10^{10} cm^{-3} and 4 volts, respectively. However, if a negative DC potential is allowed to exist on this structure, it has the effect of attracting positive ions from the plasma due to an increase in the width of the plasma sheath, which thereby reduces the effectiveness of the plasma in producing a high ion fraction of the sputtered material. Where it is necessary to facilitate the coupling of energy into the secondary plasma, such as from a peripheral coil to form an inductively coupled plasma, the plasma surrounding shields and other structure are electrically floating, which increases the tendency for electrons, which have a higher velocity than the positive ions in the plasma, to build up a negative DC charge on the shield or other structure. This causes the plasma sheath to encroach into the space desired for the secondary plasma.

Accordingly, there is a need for an IPVD apparatus and method that will provide a high ionization fraction of sputtered material, and particularly that will minimize the loss of electrons from the plasma that is provided for sputtered material ionization. Further, there is a need for an IPVD apparatus and method that will provide a high ionization fraction of sputtered material, particularly by avoiding an extension of the plasma sheath that surrounds the plasma provided for sputtered material ionization into the space of the secondary plasma.

SUMMARY OF THE INVENTION

A primary objective of the present invention is to provide a method and apparatus by which a high ionization fraction of sputtered material is achieved in ionized physical vapor deposition. A particular objective of the present invention is to provide such a method and apparatus in which the loss of charged particles from a plasma that is provided for coating material ionization is minimized or reduced.

A further objective of the present invention is to provide an ionized physical vapor deposition apparatus and method in which the components are configured and operated to prevent adverse affects on electro-magnetic fields within the region occupied by the plasma provided to ionize the coating material.

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A further objective of the present invention is to provide a method and apparatus for ionized physical vapor deposition that utilizes a magnetron magnetic field source to provide a main plasma for sputtering coating material efficiently from a sputtering target and that employs a secondary plasma by which is produced a high ionization fraction of the material sputtered from the target. A more particular objective of the present invention is to provide such a method and apparatus in which the loss of charged particles from the secondary plasma is minimized or reduced.

A still further specific objective of the present invention is to provide an ionized physical vapor deposition method and apparatus with walls, shields or other structure that physically bound the secondary plasma that will reduce the diversion of positive ions from the secondary plasma. A more specific objective of the present invention is to provide an ionized physical vapor deposition apparatus and method in which a secondary plasma bounding shield or other structure resists the build-up of negative potential thereon or the diversion of positive ions from the plasma without interfering with the coupling of energy into the plasma.

The present invention is predicated at least in part upon a principle that substantial loss of charged particles from a secondary plasma and a resulting reduction in the ionization fraction of sputtered material by the plasma, and even the extinguishing of a secondary plasma, can be prevented by configuring components in ionized physical deposition processes to affect the electromagnetic fields in the region occupied by the secondary plasma to optimize retention of the charged particles in the plasma.

The present invention is further predicated in part upon a principle that a substantial loss of positive ions from a secondary plasma and a resulting reduction in the ionization fraction of sputtered ions by the secondary plasma, and even the extinguishing of a secondary plasma, are prevented when electrically conductive shields employed in ionized physical deposition processes on the periphery of the secondary plasma used for the ionization of the sputtered material are prevented from developing a substantial negative DC potential. The invention is further predicated in part upon the concept that the existence of conductive shields or chamber walls bounding the secondary plasma, if prevented from developing a strongly negative DC potential or if kept far from the center of the chamber, will reduce the steering of positive ions from the secondary plasma into the walls or shields, and decrease the width of the plasma sheath. The invention is particularly predicated on the concept of providing these effects while maintaining an RF shield that will allow effective and efficient coupling of energy into the secondary plasma.

According to certain principles of the present invention, an ionized physical vapor deposition (IPVD) method and apparatus are provided utilizing a target energized with a DC or pulsed DC source to energize a main plasma adjacent to a sputtering target and an RF reactively coupled source to energize a secondary plasma in the space between the target and a substrate oriented preferably parallel to the target at the opposite end of a sputtering chamber. The space in which the secondary plasma is generated is bounded by electrically conductive structure that is electrically floating and presents a high impedance to the RF source. This structure is further connected through a low pass filter which provides a low impedance DC path to ground or to some other potential.

In accordance with a preferred embodiment of the invention, an IPVD method and apparatus employs a direct current (DC) rotating magnetron cathode that includes a rotating magnet assembly positioned behind a target to produce a main sputtering plasma close to the surface of the target. The target is situated at one end of a deposition chamber opposite a substrate support parallel to the target at the other end of the chamber and preferably centered on the axis of the target and chamber. A radio frequency source is inductively coupled into the volume within the chamber between the target and the substrate, to produce an inductively coupled plasma (ICP) preferably in the volume between the main plasma and a substrate mounted on the substrate support. The lateral boundaries of the ICP are defined by the walls of the chamber and a quartz dielectric window or barrier behind which is positioned a coil that encircles the volume within the chamber to couple energy into the volume of the chamber to support the secondary plasma. Preferably, the window is sealed in an opening in the wall and constitutes part of the vacuum containment structure of the chamber, with the coil situated in an atmospheric pressure environment outside of the vacuum environment of the chamber. A metal shield positioned inside of the window shields the window from the deposition of conductive sputtered material thereon which, if permitted to accumulate on the window, would isolate the chamber from the coil. The properties of the magnet producing the magnetron magnetic field, or MMF, are also useful where the coil is situated inside of the chamber and energy is at least in part capacitively coupled into the secondary plasma.

The shield is electrically floating with respect to the RF plasma, presenting a high impedance to the RF plasma. A low pass filter, for example in the form of an LC circuit, is connected between the shield and either ground or some other predetermined fixed or otherwise controlled potential to present a low DC impedance to the shield while maintaining high impedance to the RF energy of the plasma. Preferably also, the shield is situated radially outwardly from the rim of the target, preferably by a distance of one to two inches. As a result, negative potential is prevented from accumulating on a surface close to the volume of the chamber, between the target and the substrate, where it is desirable to maintain the secondary plasma. Preventing the formation of the DC potential from accumulating on the surface will decrease the length of the near sheath or pre-sheath and raise the plasma potential of the secondary plasma. Decreasing the pre-sheath and increasing the potential difference between the secondary plasma and the substrate will lead to an increase in the ion density bombarding the substrate.

The present invention maintains a dense secondary plasma, which may have an ion density of, for example, 1000 times that of a typical sputtering plasma, and which occupies the volume between the target and the substrate, enabling the secondary plasma to produce a high ionization fraction of the sputtered material passing from the target to the substrate. The application of electrical or magnetic fields applies forces to the charged particles to enable them to be electrically steered toward the substrate. In particular, establishing a bias potential on the substrate increases the component of the direction of the ionized sputtered material at angles normal to the substrate surface, providing superior coating of the bottoms of high aspect ratio features on the substrate.

With the present invention, high aspect ratio holes can be effectively filled and contacts at the bottoms of such features can be more effectively coated.

These and other objectives and advantages of the present invention will be more readily apparent from the following detailed description of the preferred embodiments of the invention, in which:

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