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SPECIFICATION

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High Deposition Rate Sputtering

Background of Invention

[0001] Sputtering is a well-known technique for depositing films on substrates. Sputtering is the physical ejection of atoms from a target surface and is sometimes referred to as physical vapor deposition (PVD). Ions, such as argon ions, are generated and then directed to a target surface where the ions physically sputter target material atoms. The target material atoms ballistically flow to a substrate where they deposit as a film of target material.

[0002] Diode sputtering systems include a target and an anode. Sputtering is achieved in a diode sputtering system by establishing an electrical discharge in a gas between two parallel-plate electrodes inside a chamber. A potential of several kilovolts is typically applied between planar electrodes in an inert gas atmosphere (e.g., argon) at pressures that are between about 10^{-1} and 10^{-2} Torr. A plasma discharge is then formed. The plasma discharge is separated from each electrode by what is referred to as the dark space.

[0003] The plasma discharge has a relatively constant positive potential with respect to the target. Ions are drawn out of the plasma, and are accelerated across the cathode dark space. The target has a lower potential than the region in which the plasma is formed. Therefore, the target attracts positive ions. Positive ions move towards the target with a high velocity. Positive ions then impact the target and cause atoms to physically dislodge or sputter from the target. The sputtered atoms then propagate to a substrate where they deposit a film of sputtered target material. The plasma is replenished by electron-ion pairs formed by the collision of neutral molecules with secondary electrons generated at the target surface.

[0004] Magnetron sputtering systems use magnetic fields that are shaped to trap and to concentrate secondary electrons, which are produced by ion bombardment of the target surface. The plasma discharge generated by a magnetron sputtering system is located proximate to the surface of the target and has a high density of electrons. The high density of electrons causes ionization of the sputtering gas in a region that is close to the target surface.

[0005] One type of magnetron sputtering system is a planar magnetron sputtering system. Planar magnetron sputtering systems are similar in configuration to diode sputtering systems. However, the magnets (permanent or electromagnets) in planar magnetron sputtering systems are placed behind the cathode. The magnetic field lines generated by the magnets enter and leave the target cathode substantially normal to the cathode surface. Electrons are trapped in the electric and magnetic fields. The trapped electrons enhance the efficiency of the discharge and reduce the energy dissipated by electrons arriving at the substrate.

[0006] Conventional magnetron sputtering systems deposit films that have relatively low uniformity. The film uniformity can be increased by mechanically moving the substrate and/or the magnetron. However, such systems are relatively complex and expensive to implement. Conventional magnetron sputtering systems also have relatively poor target utilization. The term "target utilization" is defined herein to be a metric of how uniform the target material erodes during sputtering. For example, high target utilization would indicate that the target material erodes in a highly uniform manner.

[0007] In addition, conventional magnetron sputtering systems have a relatively low deposition rate. The term "deposition rate" is defined herein to mean the amount of material deposited on the substrate per unit of time. In general, the deposition rate is proportional to the sputtering yield. The term "sputtering yield" is defined herein to mean the number of target atoms ejected from the target per incident particle. Thus, increasing the sputtering yield will increase the deposition rate.

Brief Description of Drawings

[0008] This invention is described with particularity in the detailed description. The above and further advantages of this invention may be better understood by referring to the following description in conjunction with the accompanying drawings, in which like numerals indicate like structural elements and features in various figures. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0009] FIG. 1 illustrates a cross-sectional view of a known magnetron sputtering apparatus having a pulsed power source.

[0010] FIG. 2 illustrates a cross-sectional view of a prior art cathode assembly having a cathode cooling system.

[0011] FIG. 3 illustrates a known process for sputtering material from a target.

[0012] FIG. 4 illustrates a cross-sectional view of an embodiment of a magnetron sputtering apparatus according to the present invention.

[0013] FIG. 5A through FIG. 5D illustrate cross-sectional views of the magnetron sputtering apparatus of FIG. 4.

[0014] FIG. 6 illustrates graphical representations of the applied voltage, current, and power as a function of time for periodic pulses applied to the plasma in the magnetron sputtering apparatus of FIG. 4.

[0015] FIG. 7A through FIG. 7D illustrate various simulated magnetic field distributions proximate to the cathode assembly for various electron *ExB* drift currents in a magnetically enhanced plasma sputtering apparatus according to the invention.

[0016] FIG. 8 illustrates a graphical representation of sputtering yield as a function of temperature of the sputtering target.

[0017] FIG. 9 illustrates a process for sputtering material from a target according one embodiment of the present invention.

[0018] FIG. 10 illustrates a cross-sectional view of a cathode assembly according to one embodiment of the invention.

[0019] FIG. 11 is a flowchart of an illustrative process of enhancing a sputtering yield of a sputtering target according to the present invention.

Detailed Description

[0020] The sputtering process can be quantified in terms of the sputtering yield. The term "sputtering yield" is defined herein to mean the number of target atoms ejected from the target per incident particle. The sputtering yield depends on several factors, such as the target species, bombarding species, energy of the bombarding ions, and the angle of incidence of the bombarding ions. In typical known sputtering processes, the sputtering yield is generally insensitive to target temperature.

[0021] The deposition rate of a sputtering process is generally proportional to the sputtering yield. Thus, increasing the sputtering yield typically will increase the deposition rate. One way to increase the sputtering yield is to increase the ion density of the plasma so that a larger ion flux impacts the surface of the target. The density of the plasma is generally proportional to the number of ionizing collisions in the plasma.

[0022] Magnetic fields can be used to confine electrons in the plasma to increase the number of ionizing collisions between electrons and neutral atoms in the plasma. The magnetic and electric fields in magnetron sputtering systems are concentrated in narrow regions close to the surface of the target. These narrow regions are located between the poles of the magnets used for producing the magnetic field. Most of the ionization of the sputtering gas occurs in these localized regions. The location of the ionization regions causes non-uniform erosion or wear of the target that results in poor target utilization.

[0023] Increasing the power applied between the target and the anode can increase the production of ionized gas and, therefore, increase the target utilization and the sputtering yield. However, increasing the applied power can lead to undesirable target heating and target damage. Furthermore, increasing the voltage applied between the target and the anode increases the probability of establishing an undesirable electrical discharge (an electrical arc) in the process chamber. An undesirable electrical discharge can corrupt the sputtering process.

[0024] Pulsing the power applied to the plasma can be advantageous since the average discharge power can remain low while relatively large power pulses are periodically applied. Additionally, the duration of these large voltage pulses can be preset so as to reduce the probability of establishing an electrical breakdown condition leading to an undesirable electrical discharge. However, very large power pulses can still result in undesirable electrical discharges and undesirable target heating regardless of their duration.

[0025] FIG. 1 illustrates a cross-sectional view of a known magnetron sputtering apparatus 100 having a pulsed power source 102. The known magnetron sputtering apparatus 100 includes a vacuum chamber 104 where the sputtering process is performed. The vacuum chamber 104 is positioned in fluid communication with a vacuum pump 106 via a conduit 108. The vacuum pump 106 is adapted to evacuate the vacuum chamber 104 to high vacuum. The pressure inside the vacuum chamber 104 is generally less than 100Pa during operation. A feed gas source 109, such as an argon gas source, is coupled to the vacuum chamber 104 by a gas inlet 110. A valve 112 controls the gas flow from the feed gas source 109.

[0026] The magnetron sputtering apparatus 100 also includes a cathode assembly 114 having a target 116. The cathode assembly 114 is generally in the shape of a circular disk. The cathode assembly 114 is electrically connected to a first output 118 of the pulsed power supply 102 with an electrical transmission line 120. The cathode assembly 114 is typically coupled to the negative potential of the pulsed power supply 102. In order to isolate the cathode assembly 114 from the vacuum chamber 104, an insulator 122 can be used to pass the electrical transmission line 120 through a wall of the vacuum chamber 104. A grounded shield 124 can be positioned behind the cathode assembly 114 to protect a magnet 126 from bombarding ions. The magnet 126 shown in FIG. 1 is generally shaped in the form of a ring that has its south pole 127 on the inside of the ring and its north pole 128 on the outside of the ring. Many other magnet configurations can also be used.

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