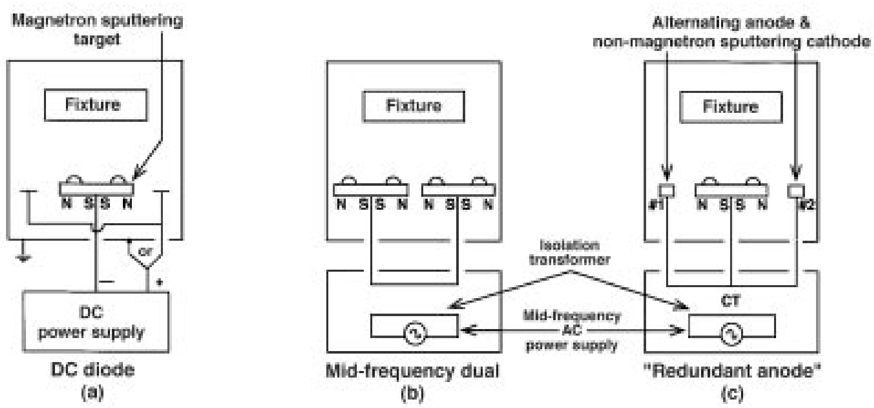
SVC Topics

Donald M. Mattox, Technical Director • Society of Vacuum Coaters
71 Pinon Hill Place N.E. • Albuquerque, NM 87122
505/856-7188 • FAX: 505/856-6716 • www.svc.org

PVD Processes: Mid-frequency Magnetron Sputtering

DC diode magnetron sputtering uses a DC power supply to continuously bias a stuttering target negatively with respect to a plasma. The most common configuration is the DC planar magnetron sputtering configuration shown in the accompanying figure (a). In the planar magentron configuration, a magnetic field confines the secondary electrons emitted by ion bombardment close to the surface in a closed path called a "racetrack." This configuration allows a dense plasma to be formed near the surface at a relatively low pressure, compared to DC diode sputtering without magnetic confinement. The anode of the DC circuit is usually the chamber walls, but may be an electrically isolated electrode near the cathodic "target."



Planar magnetron sputtering configurations: (a) DC diode magnetron (grounded or floating anode), (b) mid-frequency dual magnetron sputtering (MF-DMS) and (c) redundant anode sputtering (RAS).

In DC magnetron sputtering, the target must be an electrical conductor. If the surface is electrically insulating, a surface charge will be built up and will prevent the acceleration of ions to the surface, thereby making sputtering impossible. If a portion of the target surface becomes electrically insulating by reaction with gases in the system ("poisoned"), surface charge buildup can cause arcing over the target surface. This arcing produces particulates in the system and can be destructive to the power supply.

DC magnetron sputtering of a metal can easily be used to deposit compound films by reactive sputter deposition when the resulting compound is electrically conductive (carbides, most nitrides and a few oxides). When depositing insulating films (most oxides, a few nitrides), careful control of the partial pressure of the reactive gases can allow sputtering from a clean metal surface in the racetrack. Target poisoning, however, can cause arcing and the deposition of the insulating film on surfaces, which should act as an anode, can lead to a condition called the "disappearing anode effect."

Disappearing Anode Effect

In the disappearing anode effect, the plasma parameters and plasma uniformity change with time and, in the extreme, the plasma may not be sustainable and is extinguished. This requires that the system be opened and the anodic surfaces cleaned or replaced. Various attempts to keep a "clean anode" have been used, including:

- Shielding the anode from deposition and reaction ("hidden anode")
- Gas purging of the anode region
- Making the anode cathodic to the plasma, while still anodic to the sputtering cathode (cathodic-anode)

The cathodic-anode allows some sputtering cleaning of the anode in a non-magnetron sputtering mode, but the effect is very specific to the system geometry and plasma parameters, and the sputtering rate will always be low compared to that of the magnetron sputtering target.

A version of the "disappearing anode" effect can be encountered in the deposition of what would normally be the reactive deposition of a good electrical conductor, such as titanium nitride. In the deposition of TiN, if the reactive-gas availability is insufficient, a substoichiometric, dark-colored TiN_{1-x} will be deposited, which will have a much higher resistivity than the desired gold-colored TiN. This high-resistivity film can change anodic characteristics of surfaces and, therefore, the plasma parameters for that and subsequent runs.

Mid-frequency Dual-cathode Magnetron Sputtering

Mid-frequency dual-cathode magnetron sputtering (MF-DMS) uses an AC potential in the frequency range of 25 to 500 kHz to bias two magnetron sputtering targets alternately positive and negative, as shown in the figure (b). In such an arrangement, the surface is cleaned during sputtering and acts as anode when not being sputtered. If the frequency and sputtering rate are such that the anode surface is not significantly poisoned during the anodic cycle, there will be no "disappearing anode" effect. There are, however, other effects. The presence of the magnetic field over both electrodes tends to divert the electrons from reaching the electrode on the shortest path. This can lead to non-uniformity in the plasma density as a function of position along the cathodic electrode. For there to be equal erosion of the two cathodes, they must have the same area, magnetic field configuration and target age.

Another effect in MF-DMS involves the decay of the plasma above the electrode as it becomes an anode, and the re-ignition of the plasma above the electrode as it becomes a cathode. The plasma decay is not a simple exponential, but exhibits a fast initial decay, then a slower decay consistent with diffusion of the lower-energy particles. On re-ignition of the plasma, a voltage "spike" is seen before steady-state conditions are reached. The plasma decay and re-ignition, therefore, are frequency-dependent, with the higher frequencies seeming to be the most susceptible to instability and non-uniformity problems, particularly on long cathodes. This is unfortunate, because higher frequencies aid in suppressing arcing in areas where insulating films and electric fields lead to surface charge buildup.

Redundant Anode Sputtering

An interesting variation in mid-frequency AC dual-cathode sputtering is shown in the figure (c). It is called "redundant anode sputtering" (RAS) by the inventors (Scholl and Schatz). Note that electrodes #1 and #2 do not have magnetic fields associated with them and act alternately as an anode—as in fig. (a)—or as a non-magnetron sputtering cathode. In this configuration, there is one anode and two cathodes at any one time. During each half-cycle, the magnetron sputtering cathode, powered from the center-tapped (CT) isolation transformer, will reach a cathodic potential of one-half of the transformer voltage, while electrode #1 is acting as an anode and electrode #2 will be at a cathodic voltage that is the full transformer voltage (*i.e.*, twice the magnetron cathode voltage). During the second half-cycle, electrode #2 will become the anode and electrode #1 will become the higher-voltage cathode and be sputter-cleaned. The high voltage on the non-magnetron sputtering cathode allows effective sputter cleaning, though it can produce a large number of reflected high-energy neutrals that can affect the film formation process.

Meanwhile, the voltage on the magnetron sputtering cathode will decay toward zero, but will be at a voltage less than that needed to sustain a discharge for much less time than in the MF-DMS mode of operation. This will give less plasma decay and less voltage spiking on re-ignition than in MF-DMS. The voltage on the magnetron cathode will have the appearance of a full-wave-rectified AC voltage.

This RAS design requires three large-area electrodes that will be sputtered at some time during each cycle. If a pure film is desired, all three electrodes must be of the same material. It is expected that the plasma non-uniformity and instabilities that can occur in the MF-DMS design can be minimized and higher frequencies can be used to help suppress arcing in the system. P&SF

Reference

R. Scholl, A. Belkind & Z. Zhao, "Anode Problems in Pulsed Power Reactive Sputtering of Dielectrics," *42nd Annual Technical Conference Proceedings*, p. 169. Society of Vacuum Coaters (1999).