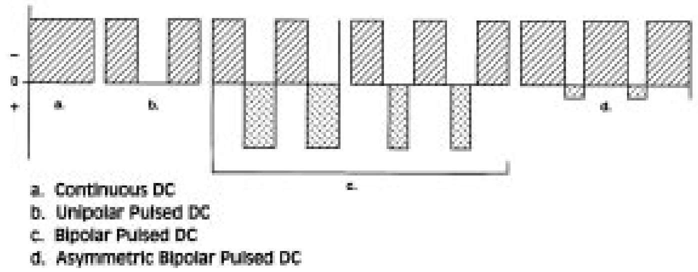
SVC Topics

Donald M. Mattox
Technical Director
Society of Vacuum Coaters
440 Live Oak Loop
Albuquerque, NM 87122
505/856-7188 • FAX: 505/856-6716 • Internet: http://www.svc.org

PVD Processes: Pulsed DC for Sputtering & Biasing

When sputtering material from an electrically insulating (dielectric) target material or depositing dielectric films under substrate bias conditions, radio frequency (RF) voltages are often used to prevent surface charge buildup and arcing. This RF voltage can be applied alone or in conjunction with a continuous direct current (DC) potential. The RF frequency range extends from a few kilohertz (~200 kHz) to the high megahertz (100s MHz) range with 13.56 MHz and its harmonics being common industrial frequencies. Some disadvantages of RF are that the power supplies are relatively expensive, impedance matching of the RF electrode and plasma to the power supply is necessary, there is high-energy ion bombardment only during a small portion of the voltage cycle, and the RF electrode acts as an antenna that often radiates power non-uniformly into the plasma-gas, creating non-uniform plasma conditions around the electrode. When RF is used in conjunction with a continuous DC potential, an RF choke must be included in the DC circuit to prevent RF power from entering the DC power supply. Pulsed DC with various waveforms, such as depicted in the figure, is emerging as a substitute for RF power in many thin film deposition applications.

Pulsed DC typically operates in the frequency range of 10–250 kHz, where the voltage, pulse width, off-time (if used) and pulse polarity can be varied. The voltage rise and fall is very rapid during the pulse. There are several waveforms that can be used. The pulse can be unipolar, where the voltage is typically negative with a no-voltage (off) time, or bipolar, where the voltage polarity alternates between negative and positive, perhaps with an off-time between the positive and negative pulses.



DC and pulsed DC waveforms.

The on-time for a voltage pulse can be as short as a few microseconds. The bipolar pulse can be symmetric, where the positive and negative voltages are equal and the pulse duration can be varied, or asymmetric, where the relative voltages and duration time are variable, as shown in the figure. Generally, in asymmetric pulsed DC sputter deposition, the negative pulse (*e.g.*, -500 V) is greater than the positive pulse (*e.g.*, +100 V). The negative pulse time is 80–90 percent of the voltage cycle, and the positive pulse is 20–10 percent of the voltage cycle. High-energy bombardment then occurs over much more of the cycle than with an RF potential.

During the positive bias (and off-time), electrons can move to the surface from the plasma and neutralize any charge buildup generated during the negative portion of the voltage cycle, which prevents arcing over the dielectric surface and through a dielectric film being deposited on a pulsed DC biased metallic substrate. During the negative portion of the cycle, energetic ion bombardment can sputter dielectric surfaces and dielectric layers that have been deposited on metallic targets during reactive sputter deposition (“poisoning”). The bombardment also allows compaction (atomic peening) of deposited insulator films.

The pulsed DC can be used in a dual magnetron sputtering configuration where the two magnetrons are alternately biased, positively and negatively. This helps eliminate the “disappearing anode” effect found when sputter depositing electrically insulating films with continuous DC power. The dual cathode system also allows the codeposition of condensable materials to form complex films, such as (Ti,Al)N. By varying the pulse power to each magnetron, the film composition can also be varied.

When a plasma is in contact with a large-area surface, it assumes a positive potential (sheath potential) with respect to the surface, because of the higher mobility of the electrons vs. the ions. When pulsed DC is applied to a metal electrode that is completely covered with a dielectric material, the surface of the dielectric is polarized to the same polarity and nearly the same voltage as the metal electrode. This voltage adds to the sheath potential to give a surface potential with respect to the plasma. If the surface potential is negative, ions are accelerated out of the plasma to bombard the surface, giving sputtering, secondary electron emission, atomic peening and heating. Because the secondary electron emission coefficient of an ion-bombarded surface is generally less than one, however, the surface will build up a positive surface charge, the bombardment energy will decrease, and then bombardment will cease.

In bipolar pulsed DC bombardment, a positive surface potential will attract electrons from the plasma to neutralize any positive surface charge, and excess electrons will increase the plasma sheath potential. When the polarity becomes negative again, this high sheath potential will add to the applied potential, accelerating ions from the plasma at a potential greater than the applied potential. This will increase the sputtering rate. If a metallic surface is partially covered (poisoned) with a dielectric film, the insulating films will be preferentially sputtered as compared to the metallic portion. This removes the poisoned portion of the target surface.

The optimal frequency of pulsing, the pulse duration, and the relative pulse heights depend on the material being sputtered and deposited. When sputtering a good electrically insulating material such as Al_2O_3, for example, a frequency of ~ 50 kHz is best. When sputter depositing a somewhat conductive material, such as TiN or indium-tin-oxide (ITO), a higher frequency (150 kHz) is best, because of the rapid conduction of the surface charge away from the surface. The accompanying table gives some comparative rates of reactive sputter deposition of TaN films from a metallic target.

Sputter Deposition Rate Comparison for Deposition of TaN*

Reactive Deposition Technique	Deposition Rate
RF diode sputter deposition	1.06
RF magnetron sputter deposition	2.00
DC magnetron sputter deposition	3.53 (unstable, arcing)
Asymmetrical pulsed DC magnetron sputter deposition	3.48 (stable)

*Sellers

Unipolar pulsed DC can be generated by using fast voltage-interrupter circuits with conventional DC power supplies. Bipolar DC requires switching voltage polarity and special power supplies. Power supplies with pulse powers of up to several hundred kilowatts are commercially available. In substrate biasing applications involving complex surfaces, an off-time is often desirable to allow the plasma to re-establish its uniformity after each pulse. The pulsed DC power supplies are also provided with arc suppression circuitry, which further diminishes arcing in the system. *P&SF*

References

J. Sellers, “Asymmetric Bipolar Pulsed DC: The Enabling Technology for Reactive PVD,” *39th Annual Tech. Conf. Proc.*, Soc. of Vacuum Coaters Publications (to be published).

S. Schiller, K. Goedicke, V. Kirhhoff, T. Kopte, “Pulsed Technology—A New Era of Magnetron Sputtering,” *38th Annual Tech. Conf. Proc.*, 239, Soc. of Vacuum Coaters Publications (1995).