Large area coatings quite often require compound layers. The compound coatings may be dielectrics, or transparent conductive oxides (TCOs), and they are often deposited by reactive sputtering. Dual magnetron sputtering (DMS) is often the method of choice for reactive deposition in large area coaters. And now, it seems the magnetrons are quite often of the rotatable variety. At the first look, it all seems straightforward. However, there are some subtle variables that can result in significant problems.

In reactive sputtering, the elemental or alloy material from the magnetron is combined with a reactive gas at the substrate (item being coated) to form a compound at its surface. The reactive gas also reacts with the target, forming a compound on its surface. These systems can operate in either the "metallic mode", where only a small fraction of the target is covered with the compound, or the "poisoned mode", where a large fraction of the target is covered with compound. In many cases, the compound has a sputtering yield which is much lower than the target material. In fact, the sputtering yield for a target completely covered with reactive compound (poisoned) may be 10% or less that of the native target material. Because of this, it is desirable to run these processes in a "transition mode" which is between the metallic and poisoned modes, to achieve a higher deposition rate. The transition mode is typically inherently unstable, so feedback control is required to stabilize the process there. Feedback can be, for example, process voltage, reactive gas partial pressure, or optical emission from the target material.

A common implementation of reactive sputtering is dual magnetron sputtering (DMS). A pair of rotatable magnetrons used for DMS is shown in Figure 1. The two magnetrons alternate roles as cathode and anode. This setup is representative of a typical industrial implementation. A key advantage is the absence of explicit anodes. Some of the challenges that come with explicit anodes are regular maintenance, disappearing anode when depositing dielectrics, and particle generation. DMS eliminates these issues. When a bipolar pulsed supply is used to drive the process, the power to each magnetron can be regulated individually. Fast read backs of power, voltage, and current for each magnetron can be provided to the user for use in monitoring and controlling the process. In DMS systems, targets can end up with uneven consumption due to differences in reactive sputtering working point and differences in power delivered to each magnetron of the pair.

Balancing Target Consumption
Industrial large area coating systems are designed to operate 24/7 for weeks at a time. Successful long term operation has a few implications. One is adequate target material inventory. Another is efficient usage of the target material inventory. A key aspect of efficient usage is balanced target consumption, which means that each of the targets in the pair is consumed at the same rate.

In order to achieve fully balanced target consumption, it is necessary for both targets to be at substantially the same working point in the transition mode (coverage fraction), and to deliver equal power to each target. As a consequence, in many embodiments both the working point of the two targets and the power delivered to each of the targets is balanced.

In a pulsed dual magnetron system, it is possible to control the power delivered to each of the targets independently. For many practical reactively sputtered compounds, voltage is an excellent indicator of the fraction of the target surface covered with the reactive compound, and can be used as a feedback signal to control the process. Figure 2 shows the voltage versus reactive gas flow control space of a dual magnetron system. Voltage in this case is the quasi-DC voltage of the magnetron discharge. A key point is that each magnetron has its own control curve, and they are different due to inevitable asymmetries in the system. Differences may include magnetic field strength and profile, gas flow, and target material thickness. For a given reactive gas flow, and with identical power delivered to each magnetron, the voltage will likely be different. A difference in discharge voltage indicates a different fraction of the target covered with compound, and a different target material removal rate for each target.

The highest performance strategy to match the target material removal rate for each magnetron would match the voltage of each magnetron and the power to each magnetron. In this case, there are two things to be controlled, so two control inputs are required. Power balance can be achieved explicitly by the pulsed power supply. Voltage balance can be achieved by modifying the flow of reactive gas to one magnetron relative to the other, by using a secondary gas manifold and means of controlling gas flow. When rotatable magnetrons are used, it is also possible to move the transition curve to the left by increasing the rotation speed, as shown in Figure 2 [1].

Figure 1. Industrial high power large area dual magnetron arrangement.

Figure 2. Reactive DMS control curves and trends.
In cases where a second control input is not available, there are two clear possibilities. The first is to simply balance the power delivered to each magnetron. The second is to match the voltage of the two magnetrons, and accept the power imbalance. This may actually result in the minimum difference in target material removal rate, since removal may be such a strong function of voltage. With a fast read back of the power delivered to each magnetron, it is possible to monitor the power imbalance, and predict the mismatch in target consumption.

A waveform for driving pulsed DMS arrangements is shown in Figure 3. Here, the waveform interval to be averaged for fast voltage feedback is defined. The voltage in this interval reflects the quasi-DC discharge voltage of the magnetron, and as such is a good indicator of the fraction of the target surface covered with the compound, and therefore, the sputtering yield of the target surface.

The approaches described here address the need to balance DMS target consumption. A pulsed power supply configured to independently control power to each of the magnetrons and provide measurements of voltages at each of the magnetrons is the required component. One or more inputs effectively control the voltages at each of the magnetrons using the measurements provided by the pulsed power supply, and the consumption of the target material is balanced by the control of the power and voltage applied to each of the magnetrons. The control inputs may be gas flow controllers (to control the flow of reactive gas to one magnetron relative to the other magnetron) and/or motor drives to control the rotation speed of each magnetron.

Modularity
From a system design perspective, modularity is important. Here, modularity was implemented in two dimensions. First, the DC power source is separated from the pulsing module. Second, DC power supplies can be master-slaved (M/S) to achieve higher power. The pulsing section is also designed for M/S connection. This allows systems to be constructed with just the power required for the process, with powers from 30 kW to over 200 kW and a granularity as small as 10 kW. Both DC supplies and pulsing modules are rack mountable. The pulsing module from Advanced Energy is shown in Figure 4. Their compact size, rack mounted, allows for efficient use of space and enables industrial systems to be implemented with modern aesthetic sensibilities. Systems driving adjacent magnetron pairs can be synchronized to eliminate crosstalk and coordinate arc handling with common exciter (CEX) functionality. Maintenance is another benefit of modularity. Typical pulsed and AC supplies in the 100 kW and up class are large and heavy. When service is required, service personnel usually visit the factory to do the maintenance or repair. By contrast, modular components, such as those shown in Figure 4, can be easily shipped to a service depot for maintenance or repair. Spare units can be kept on hand by the user and swapped into the system as required.

Figure 4. Ascent DMS dual magnetron pulsing module.

Conclusion
A method for sputtering that provides for balancing consumption of the target material by balancing power and voltage applied to the magnetron pair is described. Voltage balancing may be achieved by modifying the flow of reactive gas to one magnetron relative to the other magnetron and/or adjusting the rotation speed of each of the magnetrons. The pulsed power supply includes switching components configured to receive DC power and apply pulsed-DC power to the magnetrons. A control system directs the switching components to balance application of power to each of the two magnetrons, and a sophisticated voltage measurement system provides measurements of voltages at the magnetrons to enable control of voltages at the magnetrons. In principle, it is possible for the DMS supply to provide control outputs to one or more actuators (e.g., a gas flow controller and/or magnetron rotation controllers) to balance the voltage at the two magnetrons.

Pulsed power supplies for DMS can be used to solve two key problems faced by users of large area DMS systems. Target consumption can be balanced by taking advantage of the power supply’s ability to balance the power delivered to each magnetron, while providing fast quasi-DC voltage measurements for use in balancing the magnetron voltages. Modularity enables efficient system design, and expedient system maintenance and repair.

Reference

About the Author
David Christie
David Christie received his PhD from Colorado State University, is currently Director, Engineering with Advanced Energy, and has served on the SVC Board of Directors. His first SVC paper was in 1996, on pulsed dual magnetron sputtering. He has more than 35 thin film related publications, and 6 related patents.

For further information, contact David Christie, Advanced Energy Industries, Inc., Fort Collins, CO, at dave.christie@aei.com