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Arc Handling in RF-Superimposed DC Processes

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RF-superimposed DC sputtering processes are characterized by specific plasma and discharge properties that lead to favorable effects for the growth of various thin films, in particular transparent conductive oxides. Field-proven Pinnacle® Plus+ DC/pulsed-DC and Cesar® RF power supplies provide a highly reliable method of detecting and handling arcs in these processes. This allows you to safely run RF/DC processes for large-area and high-power applications without the need for any additional protective or arc suppression circuitry. This simplifies setup, which enables high reliability for real processes and easier handling in the field.

Products

Pinnacle® Plus+ DC/pulsed-DC power supply

Cesar® RF power supply

Navigator® digital matching network or VM analog matching network

Applications

RF-superimposed DC sputtering for industrial coating

RF-superimposed pulsed-DC sputtering for industrial coating

Who Benefits

OEM and end-user process engineers

Motivation

Today, industrial coating processes have reached a highly advanced level in terms of process equipment and the resultant layer quality. One widely used technique is magnetron sputtering, which is applied to deposit thin films of various types of materials, such as metals, semiconductors, and insulators. In many cases, the materials are sputtered from targets of the same or similar chemical composition using only argon (Ar). Here, one usually applies DC or pulsed-DC power, which often yields good material quality at reasonably high deposition rates and moderate costs. Another widely employed technique is radio frequency (RF) sputtering, used to deposit highly insulating materials such as SiO_2 or Al_2O_3, whenever high layer quality and good process control are required.

One of the intrinsic characteristics of the classical DC magnetron sputter process is the relatively high process voltage necessary to sustain the discharge by secondary electron emission from the target, which leads to high sputter rates. In RF processes, on the other hand, ionization is mainly driven by oscillating electrons in the plasma bulk [1], which leads to substantially lower discharge voltages. In addition, in RF processes there is an enhanced substrate bombardment by plasma ions (mainly Ar^+) of moderate energy. This is due to the higher difference between plasma and floating potential $V_p - V_f$ in an RF discharge [2], [3]. Such a moderate-energy ion bombardment can assist the film growth and lead to better and denser films. Drawbacks of the RF process, however, are the lower sputter rates that result from the lower discharge voltage, the higher complexity of the equipment, and the difficulty and thus higher cost of applying high powers on large areas.

An interesting alternative is to add a certain amount of radio frequency (RF) power to the applied DC power, a technique known as *RF-superimposed*

DC sputtering. With this technique it is possible to obtain an increase in substrate ion bombardment which enhances grain growth, while still maintaining a reasonably high sputter rate, to get “the best of both worlds.” The most common example here is the deposition of ITO (indium tin oxide), which is in standard use in the flat panel display industry as a transparent front contact. Through application of the RF/DC technique, it is possible to obtain better film quality of ITO films at similar rates or to obtain similar film quality at lower substrate temperatures than with pure DC processes, which leads to a significant process and cost advantage [4], [5].

A schematic sketch of discharge voltage, sputter rate, and ITO conductivity as observed by Bender et al. [4] illustrates the advantages of the RF/DC technique for the example of ITO (Figure 1). Note that discharge voltage and ITO resistivity drop significantly already at 25% RF fraction, while sputter rate is still high. This shows that only 25% of RF added into the DC process already yields a significant process improvement.

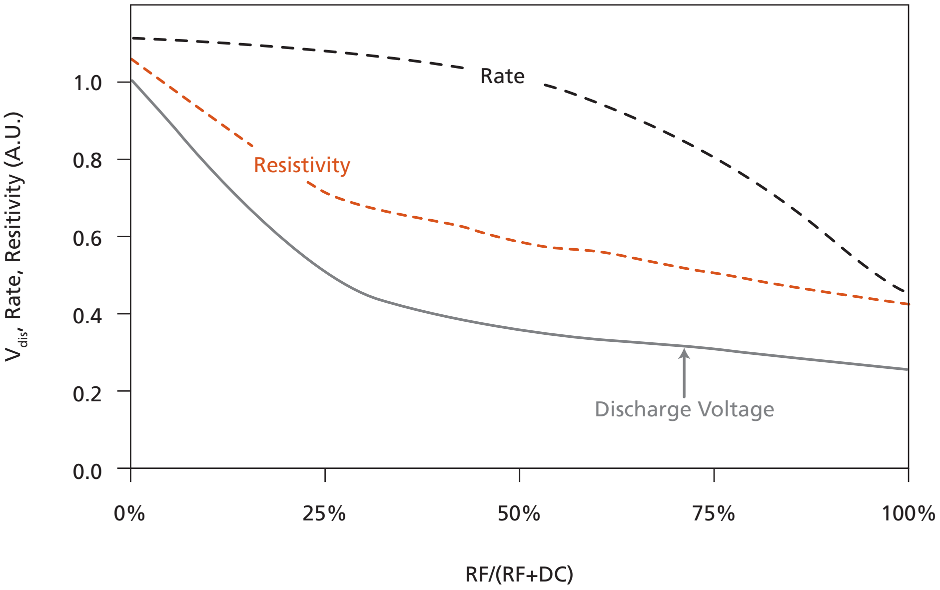

Figure 1. Typical behavior of discharge voltage V_{dis}, sputter rate, and film resistivity in an RF-superimposed DC sputtering process of ITO as a function of RF-fraction (sketch based on data published by Bender et al. [4])

Films deposited by RF/DC sputtering are also extremely smooth, a requirement that is essential especially for displays based on organic materials (OLEDs) (see Tak et al. [6]). Furthermore, in the search for a medium-term alternative to the increasing expense of ITO (due to the high indium price), the RF/DC technique is gaining more and more interest for other transparent conductors such as zinc oxide (ZnO). Detailed investigations of ZnO deposition by RF/DC sputtering have been conducted by Ellmer et al. [2] and Cebulla et al. [1].

The Challenge: Arc Handling

Despite the reported benefits of the RF/DC sputtering solution for many types of films, engineers are somewhat reluctant to use it, as the addition of RF power to a DC process adds a substantial amount of complexity to the setup. In addition to the necessary RF matching network and the design of a suitable RF-blocking filter to protect the DC generator from the RF signals, probably the biggest concern is arc handling. Arcs are localized discharges of extremely high current density that are very common in many deposition processes. If unhandled, they can cause major damage to substrates or equipment. Therefore, they have to be reliably handled by the power supply, for example by simply shutting off output until the arc is extinguished. In the case of RF-superimposed DC sputtering, a reliable and fast shutdown mechanism of both the DC and the RF generator is needed to ensure that the destructive effects of arc events are completely avoided. Otherwise, if the DC power supply were to shut down in reaction to a hard arc condition, the RF generator would keep feeding the arc and could potentially cause major damage. With increasing process power and substrate sizes, this issue becomes increasingly important.

The Solution

Advanced Energy® has developed complete equipment solutions to realize an RF/DC process with all the necessary features described above, which is viable also for large-area industrial coaters. All Advanced Energy generators (both DC and RF) feature industry-leading arc detection and arc handling technology to detect arcs in the sub-µsec range and shut off power output for a user-selectable, process-dependent time to extinguish the arc.

For RF-superimposed DC processes, we have chosen the Pinnacle® Plus+ pulsed-DC generator product line in combination with the Cesar® RF generator product line, which incorporate special features to allow for the required fast and reliable arc shutdown of both DC and RF power. Note that the Pinnacle Plus+ generator can be run both in DC mode and in pulse mode up to a pulsing frequency of 350 kHz. Figure 2 shows a simplified block diagram of the setup. Unlike previous solutions, necessary adjustments of the arc handling feature have been made as easy as possible for the user and allow for a fast and 100% reliable setup.

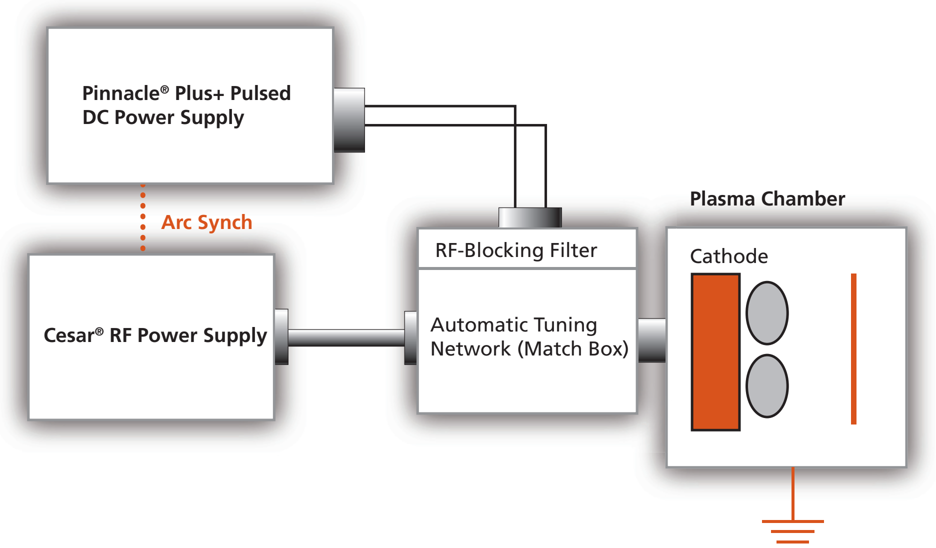

Figure 2. Schematic block diagram of an RF/DC system consisting of Pinnacle® Plus+ pulsed-DC and Cesar® RF power supplies, a fully automatic matching network, an RF-blocking filter, and arc handling capability

Test Results

In the following, we will present data obtained in an RF/DC sputtering process. Figure 3 shows voltages at the output of the Pinnacle Plus+ power supply, the Cesar RF generator, and the cathode, respectively. The Pinnacle Plus+ power supply was used in DC mode. Power levels were 500 W for DC and 250 W for RF. The functionality of the arc shutdown was investigated by recording hard arc events such as the one illustrated in Figure 3. The Pinnacle Plus+ power supply shuts down for the selected shutdown time of 500 µsec. Simultaneously, RF power (channel 2) and hence the total power to the cathode (channel 3) are also interrupted, so that the arc is allowed to clear. After the shutdown time has expired, the arc is extinguished, plasma re-starts, and normal operation is resumed. Note that the total arc rate dropped to about 1 arc per sec for the RF/DC process, whereas it was around 200 arcs per sec for pure DC excitation. We have not recorded any single event where the arc shutdown of only one or both generators together did not work. This means that the applied method of arc handling for the RF/DC process using the Pinnacle Plus+ pulsed-DC and Cesar RF generators is highly reliable and therefore also suited for large-scale industrial use.

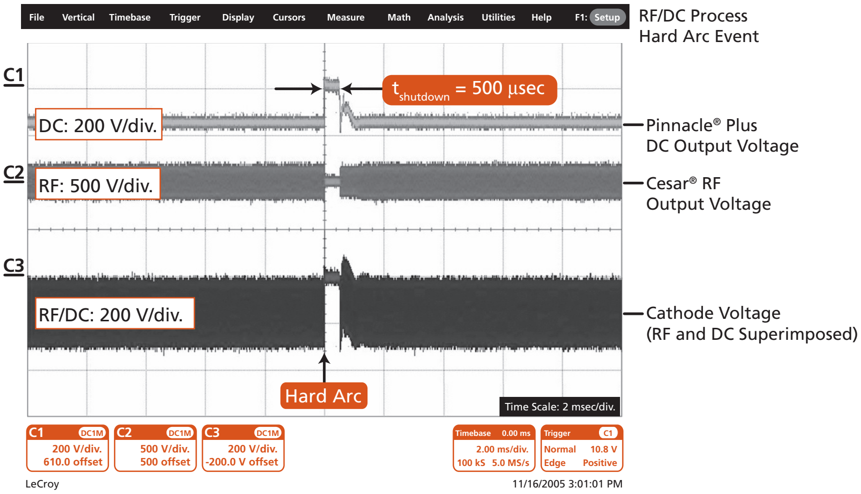

Figure 3. Pinnacle® Plus+ power supply output voltage (channel 1), RF generator output voltage (channel 2), and cathode voltage (channel 3) in an RF-superimposed DC sputtering process—The Navigator® matching network was tuned to the process impedance. Time scale is 2 msec/div. The figure shows a hard arc event, indicated by the arrow. Both DC (channel 1) and RF power (channel 2) and hence the total power to the cathode (channel 3) are interrupted for the selected shutdown time of 500 µsec so that the arc is allowed to clear. After the shutdown time has expired, the arc has extinguished, plasma re-starts, and normal operation is resumed

It is also possible to combine a *pulsed*-DC output voltage with an RF signal. To test this configuration, the Pinnacle Plus+ generator was used in pulse mode, which produces positive voltage pulses of a user-selectable duration in a wide frequency range (5 to 350 kHz). The rest of the setup remained the same.

Figure 4 shows the respective voltage signals at Pinnacle Plus+ and Cesar generator outputs and at the cathode in normal operation. In case of an arc event, the same shutdown mechanism applies as in the case of straight DC sputtering and both the pulsed-DC and the RF generator shut down for the length of the shutdown time, which was again set to 500 µsec. This is illustrated in Figure 5.

Unlike RF-superimposed DC sputtering, no systematic studies of film properties using this RF/pulsed-DC technique exist. Hence, up to now it is not clear how this technique will influence film properties like conductivity, roughness, or density. The goal of these experiments was to demonstrate the feasibility of such an approach, including in particular the reliable arc handling technology of the Pinnacle Plus+ and Cesar generator combination used here. Additional technological questions, such as a possible required change in RF-filter design, still have to be addressed, and may be the subject of future work.

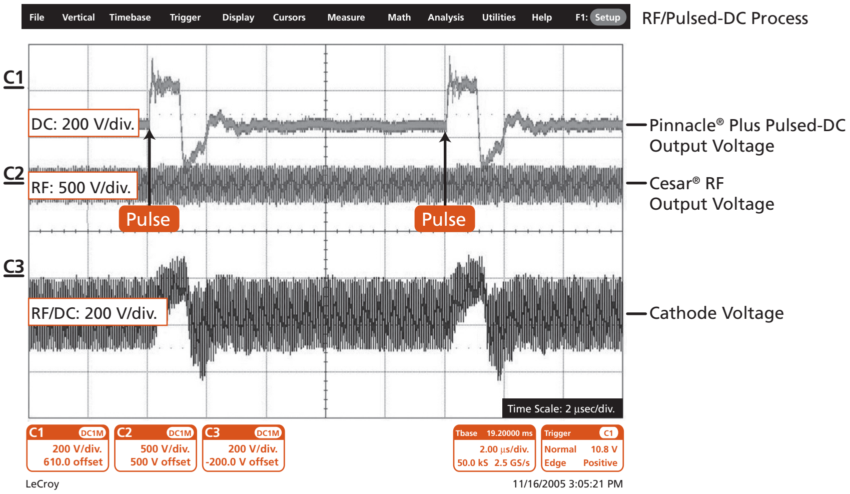

Figure 4. Pinnacle® Plus+ power supply output voltage (channel 1), RF generator output voltage (channel 2), and cathode voltage (channel 3) in an RF-superimposed pulsed-DC sputtering process—The Navigator® matching network was tuned to the process impedance. The pulse reverse time was 1 µsec and pulsing frequency was set to 100 kHz. Note the time scale of 2 µsec/div. allowing recording of the individual pulses. No arc event was recorded here

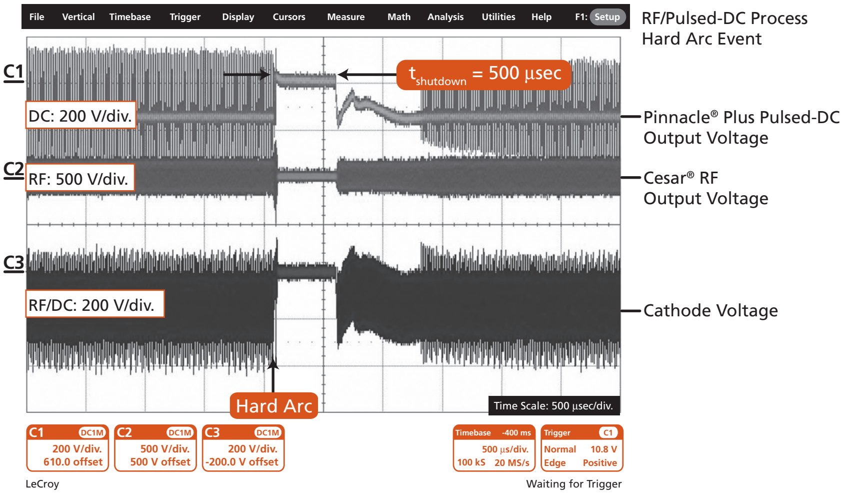

Figure 5. Pinnacle® Plus+ power supply output voltage (channel 1), RF generator voltage (channel 2), and cathode voltage (channel 3) in an RF-superimposed pulsed-DC sputtering process—Shown is a hard arc shutdown with a shutdown time of 500 µsec. The Navigator® matching network was tuned to the process impedance. Time scale is 500 µsec/div. The pulse reverse time was 1 µsec and pulsing frequency was set to 100 kHz, as in Figure 4. Note that the 1 µsec pulses of the Pinnacle® Plus+ power supply only appear as narrow spikes due to the time resolution setting (500 µsec/div.) of the oscilloscope

Conclusions

RF-superimposed DC sputtering processes are characterized by specific plasma and discharge properties that have been shown to lead to favorable effects for the growth of various thin films, in particular transparent conductive oxides. We have demonstrated a highly reliable way of detecting and handling arcs in these processes using field-proven Advanced Energy Pinnacle Plus+ (DC and pulsed-DC) power supplies and Cesar RF generators. The same feature will also be available for the Advanced Energy Pinnacle DC generator product line in late 2006. This allows you to safely run RF/DC processes also for large-area and high-power applications without the need for any additional protective or arc suppression circuitry, leading to a simple and easy-to-use setup. This will lead to the highest reliability for real processes and simplified handling in the field. The described method is thus a solution to a problem that has caused field engineers many headaches. It will avoid much of the fear that people who work with sputtering currently have when it comes to adding a "mystic" RF process to their DC systems. Furthermore, RF-superimposing a pulsed-DC signal by running the Pinnacle Plus+ generator in pulsed-DC mode (5 to 350 kHz) opens up even more possibilities for innovative process development.

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