Arc Reduction in Magnetron Sputtering of Metallic Materials

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Arcing is a common source of numerous issues in magnetron sputtering. In contrast to the preferred uniform glow for stable sputtering, arcs are characterized as intense, localized concentrations of plasma supported by collective emission of electrons from the sputtering surface [1]. The concentration of energy at an arc site easily forms a molten region in the immediate vicinity of the arc. Explosive ejection of macro-particles results upon the formation of this molten region. Macro-particle formation is one of the most damaging byproducts of arcs, and can occur while sputtering any material in any ambient gas.

Multiple mechanisms promote the formation of arcs in sputtering processes. Reactive sputtering of dielectrics is particularly problematic because the formation of insulating regions can promote severe arcing. It is well established in reactive sputtering that reverse-voltage pulsing can dramatically reduce arcs in even the most arc-prone reactive processes [2,3]. Properly chosen pulsing parameters are necessary to optimize the benefit, but once implemented, the impact can be a significant reduction in arc activity [4].

In metal sputtering, the most common source of arcs often involves localized charging of inclusions within or impurities on the surface of a target (Figure 1). Even on a metal target, such impurities at the surface can result in local charging regions. As DC power is applied, charge accumulates at these defects to a point of breakdown when the collective process of electron emission is initiated. Wickersham [5] demonstrated how particles embedded in the body of a target can promote the formation of arcs, resulting in particle release. Particles ejected from sputtering arcs can range from sub-micron to many microns in size [6].

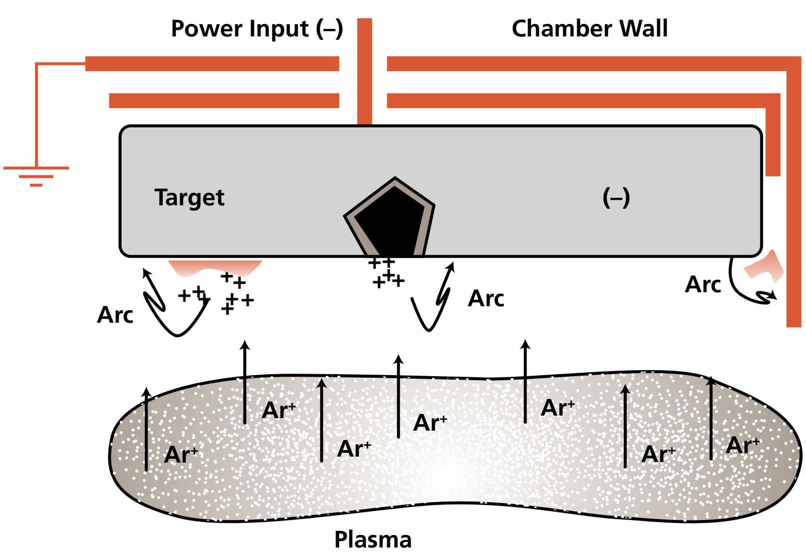

Figure 1. Common sources of arcing during sputtering [7]

Over the years, advancements in the fabrication of highly pure sputtering materials [8] have reduced the incidence of arc-promoting defects within sputtering targets. Further, the evolution of arc detection and handling in DC power supplies has enabled fast detection and response to arcs, and reduced the total energy released to events that do occur [9]. These advancements, while significant, still provide no means for actively suppressing the collection of charge in regions prone to such behavior. Thus, for even the most pure target materials powered by the latest, state-of-the-art DC power supplies, arcs are still likely to occur at some rate over the life of a target and chamber cycle.

Until recently, innovation in sputtering arc management meant increasingly fast arc detection and ever-decreasing stored energy released to the events as they occur. The downside to this approach is that such controls are only initiated after the arc event has already occurred. As device geometries continue to scale, the need for increasingly sophisticated controls and active arc-density reduction has continued to evolve. Reverse-voltage pulsing offers the first ever means to actively suppress the buildup of charge before the arc occurs, in many cases preventing the events altogether.

Reverse-voltage pulse modulation offers a unique advantage to arc management by providing active charge clearing during each off-cycle of the pulse (Figure 2). A temporary reversal in voltage showers the cathode with electrons in order to clear charge buildup, inhibiting the formation of arcs and more effectively quenching the arcs that may still occur.

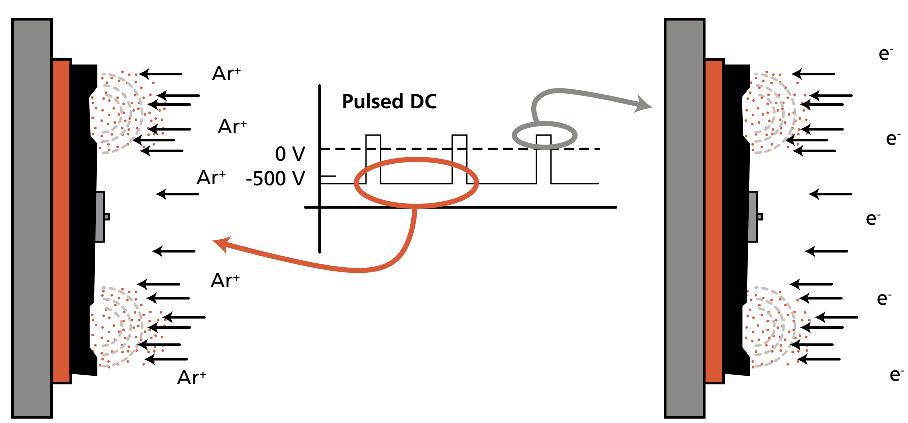

Figure 2. Reverse-voltage pulse-modulation for active charge clearing and arc prevention [10]

As discussed above, reverse-voltage pulsing has proven highly effective in stabilizing the most challenging reactive sputtering processes. For metal processes, pulse modulation can be equally effective in preventing a significant portion of arcs from occurring. As an illustration of the effectiveness of pulsing, arc data collected from a low-purity aluminum alloy target sputtered using both DC and pulsed DC (100 kHz, 60% duty factor) power is shown in Figure 3.

Average power in these tests was regulated at 500 W for both the DC and pulsed-DC cases, and all other operating conditions were held constant. Arc counts were tabulated real-time through the extended runs for both conditions. The rapidly accumulating arc counts during DC operation indicate that numerous arc-promoting defects were present on the sputtering target. The data for the pulsed-DC case clearly shows a significant reduction in arc events. The reduction in arc counts for the pulsed-DC case is attributed to the effectiveness of the charge clearing provided by the reverse-voltage pulse modulation.

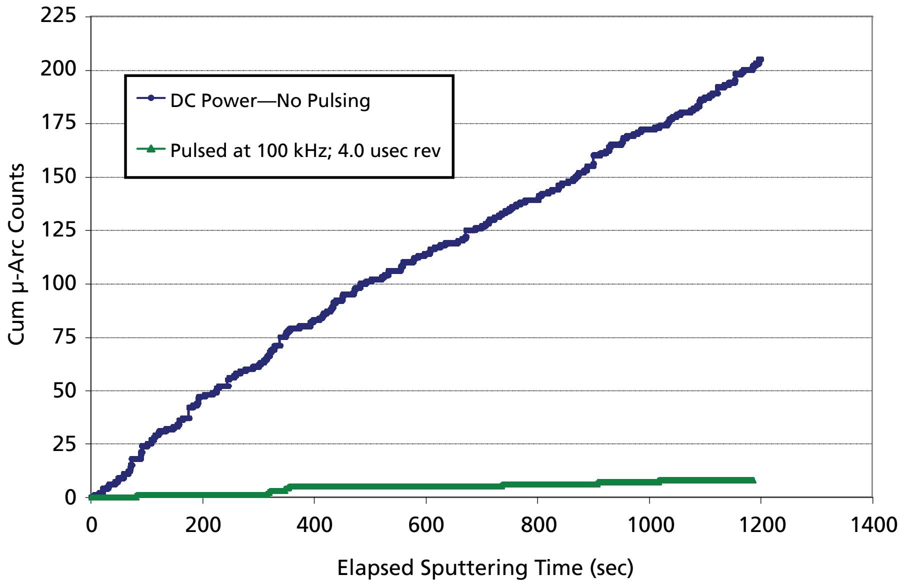

Figure 3. Reduced arc rates in aluminum sputtering through application of reverse-voltage pulsed-DC power

Summary

The increasingly demanding requirements for thin-film deposition quality have driven continued innovation in arc management and suppression in power supply design. Even for sputtering applications where DC power is traditionally effective, the growing need to eliminate damaging arcs is driving the adoption of more sophisticated power-delivery methods. For this reason, reverse-voltage pulsed-DC sputtering is being adopted for its significant advantages in arc suppression over conventional DC sputtering.

Through the use of reverse-voltage pulse modulation, arc events occurring even on metal targets can be effectively reduced by an order of magnitude or more, leading to fewer macro-particles, improved defect densities, and higher film qualities.

References

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