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Plasma Sputtering for Thin Film Deposition

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Plasmas are ionized gases that contain charged particles such as electrons and ions (atoms missing an electron or having an extra electron). Plasmas can be used to deposit excellent thin films from almost any element or combinations of elements. Ions from the plasma can be used to bombard a target surface and sputter (knock off) its atoms that deposit on a substrate, which may be a tool or any surface that needs to be coated to enhance its properties. Typical examples are hard coatings on cutting devices or scratch-resistance protective layers on optics. This deposition process can be realized on very different substrate sizes. The largest plasmas are three meters long and a few tens of centimeters wide. They are used to deposit heat insulation layers on architectural glass substrates with sizes of three meters x six meters. These substrates are transported on a conveyer belt in front of such a plasma source and a continuous oxide layer is deposited on top of the glass. Every modern-day skyscraper is equipped with plasma-coated glass panes.

The most common plasma deposition device is a so-called magnetron, as shown in Figure 1: A metal target material is placed on top of magnets facing a substrate on the opposite side. A plasma is ignited in a low-pressure argon gas environment above that target by applying a voltage. The electrons are then confined (trapped) in the magnetic and electric fields, as depicted in Figure 1, undergo a pendulum motion, collide with the argon atoms and very efficiently ionize them. A plasma torus (donut shape) is formed that is defined by the shape of the magnetic field. Typically, one percent (1%) of the atoms are ionized. Figure 2 shows an image of such a plasma torus on top of a circular magnetron target with a diameter of two inches. The ions in the plasma follow the electric field lines pointing towards the target, are accelerated, and induce collision cascades when penetrating into the target material. Some target atoms in this collision cascade are kicked out of that surface, the so-called sputtering, and travel towards the substrate. They experience almost no collisions during this transport at low pressure and arrive at the substrate with a high velocity before they condense. That way, metallic films, for example, can be deposited on this substrate.

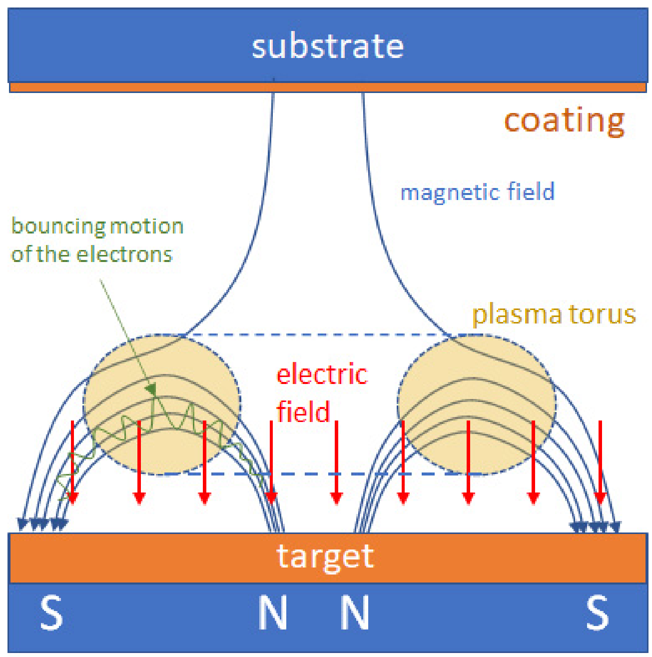

Fig. 1 Schematic of a magnetron plasma. The target (material to be sputtered) sits on a magnet and the substrate (material to be coated) faces the target.

This deposition process by using sputtering in a magnetron plasma as particle source is completely different to an evaporation process where a crucible is heated and, for example, metal atoms are simply evaporated before they condense on a substrate. The species (mostly the ions) out of a plasma are typically 10 times more energetic compared to species in evaporation. This enables a completely different

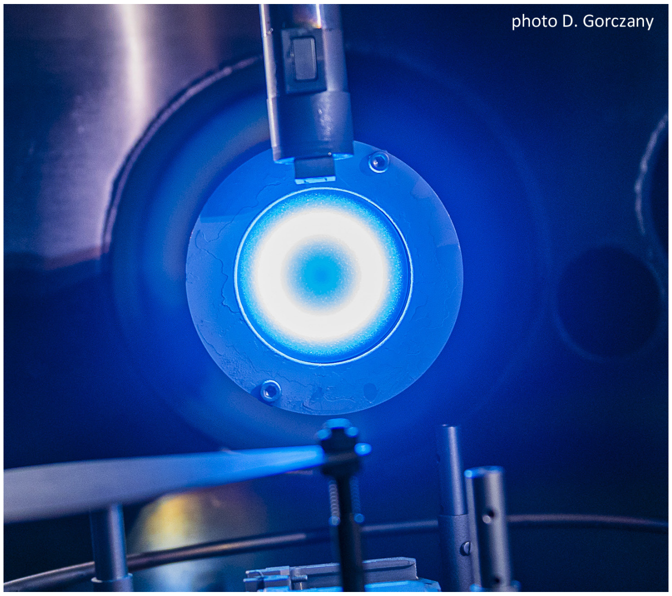

Fig. 2 Image of magnetron plasma (bright ring-shaped object) on top of a 2-inch circular target.

film growth process on the substrate, where the arriving energetic species sample a few surface sites before they eventually condense. This allows them to reach the most stable place on a growing crystal surface leading to much better materials compared to evaporation. This growth process can be tuned with respect to the energy of the arriving species and the substrate temperature. As a result, a multitude of crystalline materials can be synthesized which are not accessible by conventional chemistry or crystal growth.

In the so-called reactive magnetron discharges, gases such as oxygen or nitrogen are added to the argon gas plasma. The plasma also dissociates these gas components and the oxygen or nitrogen atoms are condensed at the substrate together with the sputtered metal atoms. The creation of oxides or nitrides on these substrates becomes possible. One example is alumina (aluminum oxide, Al2O3) that can be synthesized in very different crystalline phases including the alpha phase also known as sapphire.

In recent years, the magnetron deposition process has been developed further by applying very high voltages and power loads to the target leading to almost fully ionized plasmas (almost all the atoms of the gas lose at least one electron each). The target power load can reach values up to several kilowatts per square centimeter. At such a high power load, the target material would melt. Therefore, to avoid melting the material, the power is applied (turned on) only in very short pulses (or bursts) with time durations of a few 100 microseconds at most. The power is turned off for tens of milliseconds between pulses to keep the average power on the target surface rather low. These plasmas are almost fully ionized creating an ion flux towards the surface that is even more energetic compared to conventional magnetron sputtering. As a result, the quality of the deposited material is even further improved.

Summarizing, magnetron plasmas for thin film deposition are an absolute workhorse for many modern technologies and applications. Huge areas are deposited each day ranging from the heat insulation layers on the very large panels in many sizes of architectural glass, to protective hard coatings on the medium sizes of cutting tools and optics, to electronic materials on the very small scale of microelectronic circuits.

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