

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

## Broad-beam Reactive Plasma Sources-DC Sources

**R** eactive deposition occurs when an element (*e.g.*, silicon) is vaporized and the deposited material then reacts with an ambient gaseous environment (oxygen) to form a compound such as SiO<sub>2</sub>. In quasireactive deposition, the SiO or SiO<sub>2</sub> compound is vaporized and a reactive gaseous ambient (oxygen) is used (1) to replace the gaseous species lost in the vaporization/condensation process, or (2) to raise the oxygen content of the compound (*e.g.*, from SiO to SiO<sub>2</sub>).

In both types of reactive deposition, it is desirable to have an "activated" reactive species to enhance chemical reactions on the surface. It is also preferable to have an ionized species that can be accelerated to a high kinetic energy to bombard the growing film. This concurrent bombardment can enhance chemical reactions and have a number of desirable effects on the film properties, such as densifying the depositing film material.

When depositing an electrically insulating material, such as most oxides, it is a good idea to have electrons available in order to neutralize any charge buildup on the insulating surface that would cause arcing over the surface or through the film. A plasma source can provide both ions and electrons.

When depositing oxide films for optical applications, deposition over large areas is usually required, so a broad-beam plasma source is recommended. By accelerating the ions away from the plasma source to bombard the growing film, there is no need to have a bias applied to the surface of the electrically insulating film. For high deposition rates, a high-current-density plasma source is recommended, becauthe reaction process is the rate-limiting step the deposition proces

There are a number of designs for plasma sources. They all depend on having a source of electrons, accelerating the electrons to 100 eV o so to ionize atoms, an often use a magnetic field to confine the electrons and cause them to spiral, thereb increasing the ionization path length. Man of these ion and plasr sources were developed in the 1960s for ion propulsion space

engines, and in the '70s and '80s for fusion reactor power applications. In some sources, the plasma is contained and the ions are extracted using a grid structure to give a collimated, monoenergetic ion beam. After extraction, electrons are added to the ion beam from a thermoelectronemitting "neutralizer filament" to make a plasma beam. The grids are usually made of carbon, which has a low sputtering yield, but they are rapidly eroded by an oxygen plasma.

A gridless structure is most often used in broad-beam reactive-gas plasma sources. In one type of source, a direct current (DC) power source is used, and electrons are produced from a hot thermoelectron-emitting surface or a hot, hollow cathode electron source. In other types of sources, ionization is produced in a radio



Gridless End-Hall plasma source.

frequency (rf) or microwave discharge. After a plasma is produced, it may be confined and guided (steered) using electric and/or magnetic fields. The plasma beams produced by these sources characteristically have a large spread in ion energies and a nonuniform plasma distribution across the beam diameter.

Plasma sources are used to reactively or quasi-reactively deposit metal oxide films for single- and multilayer optical coatings. Although the source material (SiO,  $Ti_3O_5$ , etc.) is usually vaporized by electron-beam evaporation, the use of sputtering is increasing. The depositing film material is continuously or periodically bombarded with reactive ions, or a mixture of reactive and inert ions during deposition. The oxide films formed under bombardment during deposition are found to be very dense and have an index of refraction close to that of the bulk material. The "humidity shift" in the index of refraction is very low for the dense films. These films can also provide corrosion protection and abrasion resistance for the underlying material.

Ion bombardment energies can be up to several hundred electron volts (eV), but higher bombarding energies can introduce defects that increase the optical absorptivity of the film. A typical deposition rate is 10–20 Å/sec. Other materials of interest for optical applications include fluorides, such as MgF<sub>2</sub>. To date, reactive plasma sources using fluorine have not been used successfully to obtain improved optical performance of deposited fluoride films.

The DC-type broad-beam sources are the most commonly used plasma sources for depositing oxide films for optical applications. Several source designs are commercially available. The figure shows an End-Hall gridless plasma source. In this source, the electrons emitted by the hot filament are attracted toward the anode and are caused to spiral around the magnetic field lines.

The incoming reactive gas, which generally is a mixture of argon and oxygen (25/75%), must pass through the dense electron beam and some of the gas atoms are ionized. The positive ions are then accelerated away from the anode. Such a source typically will operate at a chamber pressure of ~ $10^{-4}$  Torr, a gas flow rate of 50 sccm, a beam diameter of 3 in. and an ion current density of ~ $10^{16}$  particles/cm<sup>2</sup>-sec at the substrates.

It is estimated that the average energy of the ions leaving the source is about 60 percent of the anode voltage. At an anode voltage of 150 volts, the ions therefore will have ~90 eV energy. This is well below the damage threshold for optical damage to the deposited oxide film. The thermoelectron-emitting filament also provides the electrons to give a neutral plasma beam. The filament must be replaced periodically, but it is in an exposed location and can be easily replaced.

Other DC plasma sources have been constructed. One of the largest, for example, is a plasma-source interaction experimental facility for testing materials for fusion reactor studies. This plasma source uses a large-area lanthanum hexaboride or La-Mo thermoelectron emitter surface and magnetic confinement of the plasma. This source provides a largearea plasma source  $(70-80 \text{ cm}^2)$  with a continuous current density of 6 x 10<sup>18</sup> particles/cm<sup>2</sup>-sec, with a controllable ion energy of 50-500 eV. It is expected that further development of plasma sources for manufacturing will be forthcoming.

Next month's column, Rf and Microwave Sources, will discuss other types of broad-beam plasma sources. PESF

## Reference

D.M. Goebel, G.A. Campbell and R.W. Conn, "Plasma-surface Interaction Experimental Facility for Material and Edge Physics Studies (PISCES)," *J. Nucl. Mat.*, **121**, 277 (1984).