ION BEAM TECHNOLOGY FOR OPTICAL APPLICATIONS

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Ion beam technology is playing an increasingly important role in the optics industry, from low-loss high end mirrors to diamond-like coatings on sunglasses. Ion beam sputter deposition, ion beam direct deposition, ion beam assisted deposition (reactive or inert), and ion beam precleaning are processes that greatly enhance optical surfaces and materials with which they interact. Broad beam Kaufman-type ion sources are capable of performing all of these applications. A beam of inert or reactive ions is generated in a discharge chamber by a hot filament and then accelerated to a work surface. The process is somewhat analogous to sandblasting on an atomic level. The beam of ions may be focused through apertures, known as grids, or may be widely divergent, covering a large area with no grids at all. The beam of ions operates independent of substrate material, angle, temperature, and system configuration for maximum versatility. Broad beam sources also allow independent control of ion energy, current density, and direction. Ion beam sources typically operate in the 10^{-5} – 10^{-4} torr operating range, making them ideal for low contamination process enhancements. Kaufman-type ion sources are designed with ease of use and maintenance in mind to provide a rugged and reliable piece of equipment.

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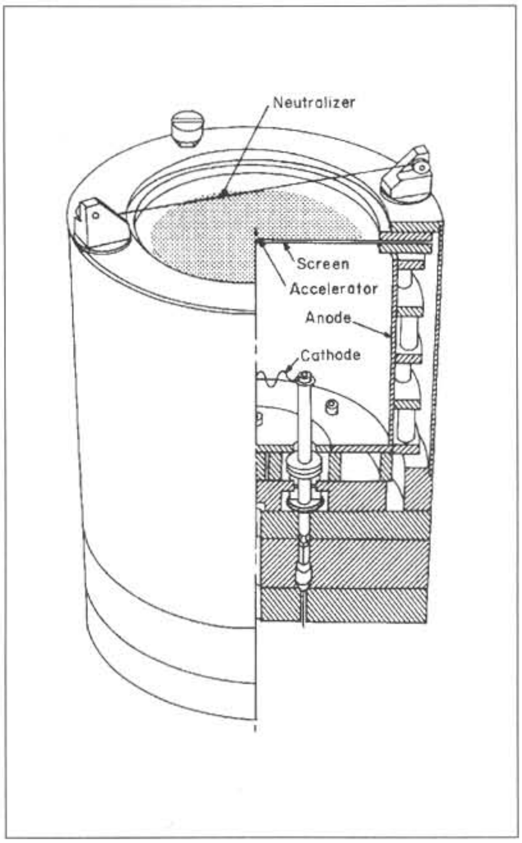
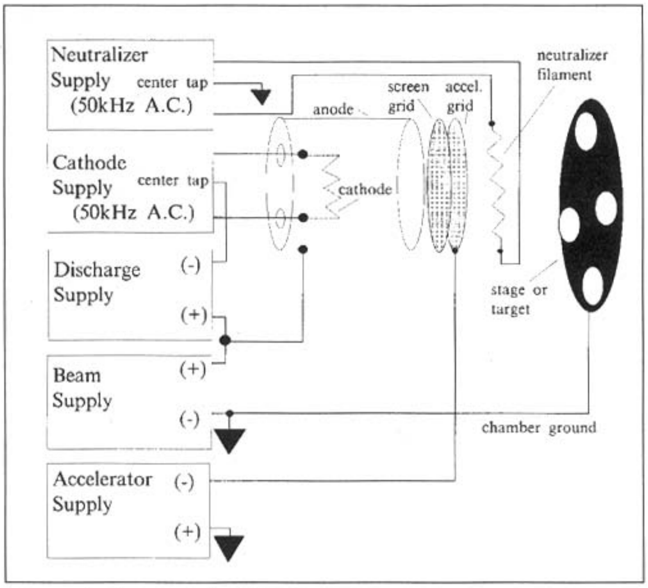


Kaufman type gridded ion source cutaway view.

Ion Beam Precleaning

Maintaining the integrity of a substrate surface and improving the adhesion of the thin film being applied to it can be achieved by bombarding the sample with a low energy ion beam prior to deposition. The ion beam will remove surface contaminants such as water vapor, hydrocarbons, native oxides, and other absorbed materials. If left intact, these materials can cause shifts in the index of refraction, film property instabilities, and peeling or flaking of the thin film. With the use of chlorofluorocarbon (CFC) cleaners becoming more of a high profile environmental issue, ion beam precleaning has become an attractive alternative for *in situ* sample preparation.

Reactive gases may be incorporated into the precleaning process, allowing high rates of removal for certain absorbed materials. For example, if hydrocarbons are the main concern, a beam of oxygen ions may be generated to bombard the sample. The oxygen ions will readily react with the hydrocarbons and provide a contamination-free surface for coating. Energy and current may be controlled, allowing the user to maximize cleaning while not damaging the substrate surface. Ion beam operation does not require substrate biasing, so only the area being bombarded is affected. Concerns about sputtering the surrounding sur-



Schematic diagram of gridded ion source.

faces onto the substrates are eliminated by the directionality of the ion source and the low background pressure under which it operates.

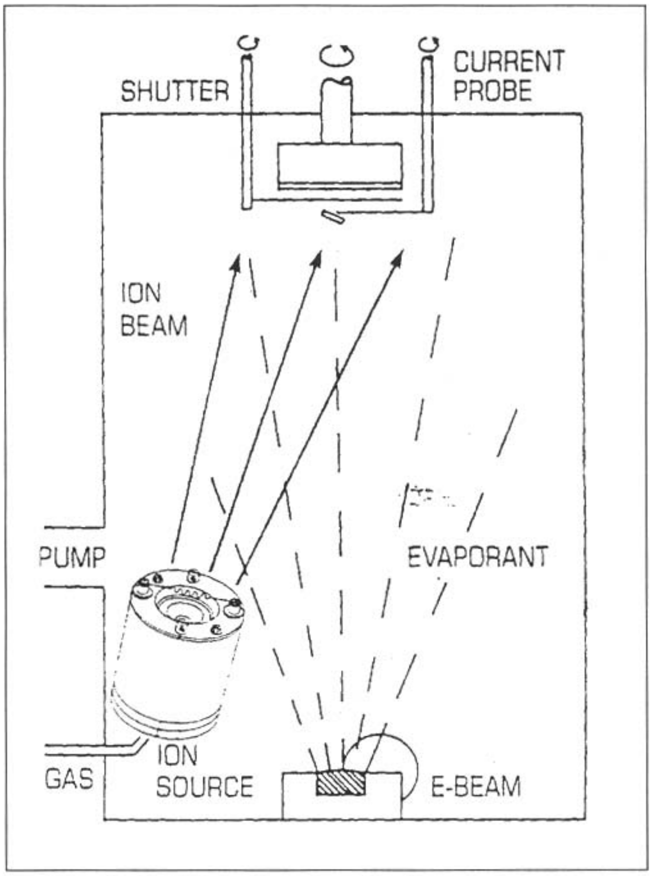
Ion Beam Assisted Deposition (IBAD)

Thin film stability throughout the life of the coating is a crucial factor in optical applications. Films deposited with electron beam evaporation typically have a low packing density, resulting in porosity or gaps in the columnar structure of the deposited films. The index tends to shift depending on exposure to atmosphere (air) and humidity. In addition, the elements that the film is exposed to work their way through the film and interfere with the bond between the substrate and deposited film. This results in peeling or flaking of the coating and failure of the coated optics. The performance of optical devices is strongly dependent on the quality of the coating. Improving the quality of the coating is best achieved by better controls on the deposition techniques and conditions.

By incorporating an ion beam source in the evaporation system for ion beam assisted deposition, several improvements in both film and process can be realized.

The ion source is typically mounted in the vacuum system so that the flux from the ion beam is covering the same region of substrate as the evaporant flux. Varying the energy and beam density will alter properties of the film, such as density, stress, adhesion, and refractive index. In general, it is desirable to keep the energy of the ions below the sputter threshold of the deposited material. This also prevents ions from being implanted below the surface, causing voids that will be unaffected by the ensuing IBAD process and causing scatter in the film. An ion source able to produce large current densities at low energies is the most suitable for most IBAD applications. The Kaufman End-Hall ion source is capable of producing high current densities throughout the operating range. This is a gridless ion source designed to operate in inert or reactive environments with electron beam evaporation or sputtering systems.

Gridded Kaufman ion sources offer a wider energy operating range, but compromise current density in the low



Ion Beam Assisted Deposition schematic diagram.

energy range. If the key desire is to modify or dramatically alter the stress of a thin film, in tungsten for example, the energy range of a gridded source may be required, and will typically allow a full stress transition as a function of energy. For the majority of optical applications, controlling the density, adhesion, and refractive index are the key concerns. By using ions of several tens of electron volts, the film surface mobility is kept in an active or energetic state. This surface mobility tends to disrupt the columnar growth found in most evaporated optical films. The resultant films have smaller grain sizes and higher packing densities. The increased densities can approach those of bulk materials and will also result in an increase in the index of refraction. In many cases, the need for substrate heating is either greatly reduced or eliminated altogether.

Control of stoichiometry and film density can be further enhanced by incorporating any required reactive gas components directly through the ion source. By using the gas in a reactive state rather than a molecular state, less gas is required, reducing the system pressure and further eliminating gas inclusion into the thin film. Kaufman-type ion sources are, for the most part, non-selective about the gas they use as a source of the ions. Some of the gases used in processing of optical films include O_2, N_2, CH_4, SF_6, Ar, Xe, and Cl.

Ion beam assisted deposition has been incorporated into electron beam evaporation systems, sputtering systems, laser ablation systems, and ion beam sputtering systems. It has allowed the deposition of hard wear resistant coatings on to plastics and other laminates and has enhanced the properties of coatings on glass.

Ion Beam Sputter Deposition of Optical Films

Ion beam sputtering is a momentum transfer process by which an energetic beam of ions, typically inert, is directed at the desired coating material (target) and sputtered onto the substrate. The beam or beam flux is kept neutral via a source of electrons that is coupled to the beam. The ion beam is completely non-selective, allowing any material to be deposited. Controls of the ion source allow from a few angstroms/sec to several tens of angstroms/sec of the desired film with excellent repeatability and control of virtually any material. Incorporating a reactive gas such as oxygen, nitrogen, or fluorine allows reactive deposition and control of the film stoichiometry. For instance, silicon dioxide may be sputtered by bombarding a nitride target with an ion beam in an oxygen background. This offers several advantages, including: (1) high purity silicon targets are readily available, and (2) the same target may be used for several materials, *e.g.*, SiO_2, SiO, and SiN. The kinetic energy of the arriving ions is typically several tens of electron volts, resulting in films with smaller grain size than similar evaporated films. Additionally, this results in higher density films with better adhesion and less intrinsic stress. Several ion sources may be operated in the same environment at the same time, further enhancing the capabilities of ion beam sputtering. An example of this co-deposition of different materials during processing is alloying of thin films. The ratios may be altered and controlled easily by varying the ion source operating parameters. This is a very useful technique for making complex optical thin films such as waveguides. An ion source directed at the sample may be incorporated to allow ion assisted deposition, further reducing stress and improving overall film quality. Most ion beam sputtering systems have the added advantage of adjusting the angle of incidence in the deposition chamber. By adjusting the angle of incidence, uniformity, deposition rate, and step coverage may be optimized.

Direct Ion Beam Deposition

Recent advances in direct deposition of thin films have led to several commercial applications of ion beams in the formation of optical thin films. The substrate is separated from the plasma source, allowing lower substrate temperatures and processing of materials, such as polycarbonates. The ion source is a standard dual grid Kaufman-type source allowing variance of energies from $\approx$10 eV to 1500 eV. Typically the ion source uses a low energy ion beam of a specialized gas or mixture of gases. The ion energy is controlled to enhance the condensation of metals or materials from the reactive gas mixture and prevent the physical sputtering of the deposited film.

The most common application of this technique is the formation of amorphous diamond-like carbon (DLC). In di-

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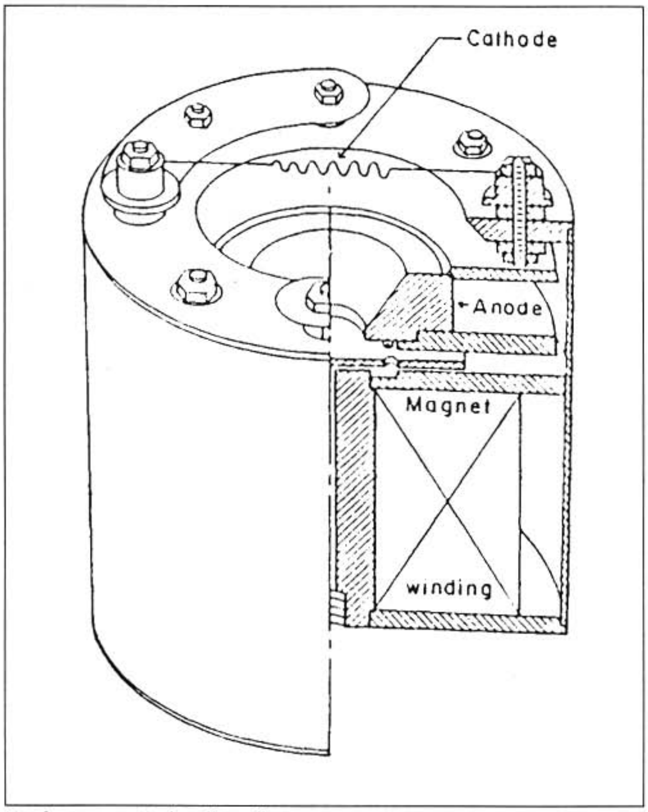
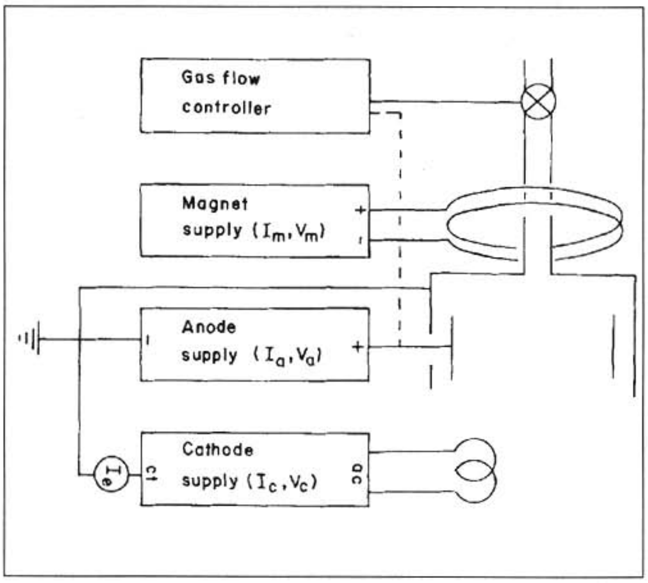


Kaufman-type End-Hall gridless ion source cutaway view.



Schematic diagram of End-Hall gridless ion source.

rect ion beam deposition of DLC, a hydrocarbon based gas or combination of gases is run through the ion source. The resulting ion beam is directed at the substrate, and the resultant reaction produces a DLC layer. The resultant films have been shown to be transparent in the visible and infrared, chemically inert, and offer a low coefficient of friction and a high hardness. A second ion source can be used for ion assisted deposition to improve uniformity, packing density, and microstructure while limiting residual stress. DLC use is expanding rapidly in the areas of eyeglass coating, semiconductors, thin-film heads, and any application where an ultrathin wear and scratch resistant coating is desired. Any gas that is a metal organic and dissociates into metal deposits can be direct deposited in the same manner.

Summary

Continuing requirements for high quality, high performance coatings in optical applications will require further process enhancements to meet future demands for quality and reliability. Ion sources continue to be developed to meet the needs of the optical industry. Gridded and gridless sources are mentioned here; new sources for the optical industry include linear and RF ion sources. Ion beam technology will remain an integral part of the optical industry for years to come.

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Further Reading

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