Plasma Ion Assisted Deposition (PIAD)

PIAD is an energetic deposition process that produces high quality optical thin film layers. PIAD films have the desired properties of complete oxidation and high packing density distributed over a wide substrate area. The film layers exhibit high refractive indices with low absorption. An advantage that PIAD has over IAD- and sputter-deposited films is low intrinsic stress.

In functional contrast to the other two deposition processes, PIAD fills the vacuum chamber with energetic plasma that consists of electrons and ionized evaporant atoms as well as reactive gas ions and momentum-carrying Ar ions. The metal walls of the chamber act as one electrode, and the entire contained volume is filled with the reactive plasma. This phenomenon creates uniformly distributed high-energy reactions. The result is the production of consistent film properties over a larger area than that covered with strictly ion sources such as IAD. With IAD, current density is contained within a more restricted solid angle and therefore limited area coverage.

The presence of the reactive evaporant species and composition gas ions as well as the bombarding Ar ions results in compact (dense) film growth with complete stoichiometry insured. The composition gas can be oxygen or nitrogen to deposit oxide or nitride compounds. Using a high discharge current, PIAD sources generate dense electron plasma within a contained magnetic field. The plasma is extracted through a nozzle and spreads throughout the chamber where ionizing and activating reactions occur. Figure 1 shows the basic internal configuration.

![Figure 1. PIAD source basic components.](image)
Typical current density distribution uniformity over the substrate area is shown in Figure 2.

![Figure 2. Spatial uniformity of current density](image)

A recent publication compared the properties of oxide materials the three deposition processes: IAD, PIAD, and sputtering by Pulsed DC Magnetron Sputtering (PDCMS) [1]. IAD and PIAD used E-beam sources. PIAD and IAD refractive indices for low-index materials are listed in Table 1. The indices produced are the same, but IAD produces higher absorption in the short wavelengths than PIAD.

<table>
<thead>
<tr>
<th>Starting Material</th>
<th>Deposition Process</th>
<th>Index n at 308 nm</th>
<th>n, k at 160 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2 (SiO)</td>
<td>PIAD</td>
<td>1.500</td>
<td>1.67, 0.0015</td>
</tr>
<tr>
<td>(SiO)</td>
<td>IAD</td>
<td>1.504</td>
<td>1.67, 0.006</td>
</tr>
<tr>
<td>Lima</td>
<td>PIAD</td>
<td>1.493</td>
<td>1.66, 0.001</td>
</tr>
<tr>
<td></td>
<td>IAD</td>
<td>1.493</td>
<td>1.66, 0.0035</td>
</tr>
</tbody>
</table>

*Table 1. Oxide Compound Refractive Indices as Deposited by Different Processes*

Materials such as HfO2 and ZrO2 grow with index-thickness inhomogeneity. The refractive index is larger near the substrate where nucleation density is high and decreases as the column grows in height, and gradually tapers to a smaller diameter causing the index to decrease. Index differences between the top and bottom of a layer can be as large as 0.07 for IAD HfO2 films, and are one-third as large for PIAD films [1]. The PIAD process produces better homogeneity than the IAD process.

Typical optical substrates of glass, crystals, plastics and IR materials have been coated. In addition to oxide and nitride compound coating materials, high quality films of IR materials including ZnS, fluoride compounds, Si and Ge have been deposited.
Summary

The PIAD process has the following advantages compared with IAD:
- More uniform energy density distribution over a larger area
- Refractive indices comparable to IAD, but with lower UV absorption.
- Better index depth profile homogeneity.
- Lower intrinsic stress.

Reference