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PVD Processes: Optically Transparent, Electrically Conductive Oxide Thin Films

Optically transparent electrical conductors are used as anti-static coatings (<1000 ohms/sq)*, transparent resistive heaters (<10 ohms/sq), and are a necessity for the electrodes (<100 ohms/sq) of many types of optically-active thin film devices, such as flat panel displays and electrochromic devices. There are several optically transparent oxide materials that have lattice-defect-related (anion deficient) electrical conductivity. These include indium oxide (In_2O_3) and tin oxide (SnO_2). The most commonly used transparent thin film material is an alloy of 90 wt percent In_2O_3 and 10 wt percent SnO_2 (indium-tin-oxide or ITO). The transparent conductor material is commercially deposited on glass, and polymers such as glass and molded polycarbonate windows and PET, OPP and PTFE webs.

ITO can be deposited by reactive deposition in oxygen from a mixed-metal (In:Sn) sputtering target or by non-reactive sputter deposition from a mixed-oxide target (tin oxide has a solubility limit of 10 wt percent in indium oxide). The deposited film may be annealed after deposition in an oxygen, hydrogen or forming gas (90% N_2:10% H_2) atmosphere to increase the density and electrical conductivity. Ion bombardment during deposition (IBAD process) can increase the weatherability of thin ITO films. The properties of the ITO films depend strongly on the deposition technique, deposition parameters, the properties of the sputtering target and post-deposition treatment.

Typically reactively deposited ITO has a higher density and higher index of refraction than does non-reactively deposited material. With anti-reflection (AR) coating, the visible transmission can be greater than 90 percent for sputtered deposited ITO films 1500 Å thick. Typical values for some properties of ITO prepared by reactive and non-reactive sputter deposition are shown in the table.

Typical As-deposited Properties of Sputter-deposited ITO

	Sputter deposition technique	
Property	**Non-reactive**	**Reactive**
Thickness	205 Å	313 Å
Electrical resistivity	170 μohm-cm or 84 ohms/sq	260 μohm-cm or 82 ohms/sq
Carrier concentration	12 x 10^{20} cm^{-3}	9 x 10^{20} cm^{-3}
Hall mobility	30 cm^2/v-sec	29 cm^2/v-sec
Optical transmission	89.6%	87.0%
Optical reflection	9.2%	12.2%
Optical adsorption	1.2%	0.8%
Index of refraction @ 633 nm	1.790	1.874
Extinction coefficient @ 633 nm	0.025	0.018
Etch rate @ 55 °C in aqua regia	25 Å/sec	13 Å/sec

In many applications, large area substrates must be coated with a high degree of uniformity. This is often easier to accomplish using non-reactive sputtering of oxide targets than with reactive sputtering where the uniformity of the reactive gas distribution can be a problem. In some applications, pinholes are a major concern, which means that the cleanliness of the deposition system is important. Some fabricators maintain that less-than-fully dense oxide sputtering targets produce fewer particulates in the deposition system than do fully dense oxide targets. When sputtering either the mixed-oxide or mixed-metal target, high-resistivity nodules form on the target surface. These nodules reduce the sputtering yield of the target and must be periodically removed mechanically, which is a problem in high-volume production. The origin of these nodules is poorly understood.

Other electrically conductive transparent oxides include: Fluorine and chlorine-doped oxides, such as tin oxide (SnO_2:F), antimony doped tin oxide (SnO_2:Sb), cadmium oxide (CdO), Cd_2SnO_4 and aluminum-doped zinc oxide (ZnO:Al). Non-transparent electrically conductive oxides include: Chromium oxide (Cr_2O_3), copper oxide (CuO), lead oxide (PbO), bismuth trioxide (Bi_2O_3) and rubidium oxide (RbO). In addition to sputter deposition, conductive oxide films can also be prepared by spray pyrolysis, reactive evaporation and chemical vapor deposition. ❑

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*The electrical resistivity (R) of a conductor is given by: $R = \partial L/A$ where ∂ is the bulk resistivity in ohm-cm, L is the length of the conductor in cm, and A is the cross-sectional area of the conductor in cm^2. For a square of a film of thickness (t) and side length (L), the cross-sectional area becomes L x t and resistance from side-to-side of any size square will be the same. This gives rise to the common thin film resistivity unit of ohms/square (ohms/sq), called the sheet resistance. To find the resistivity of the material in ohm-cm, the thickness of the film must be known.