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Transparent Electromagnetic Compatibility Coatings

Electromagnetic Compatibility Coatings (EMC) function to attenuate RF frequencies in accord with FCC Class A regulations (residential) or Class B (industrial) or MIL-STD-461A. EMC's are commonly known as EMI/RFI-shielding coatings, and are applied to displays, monitors, including computer and TV screens, and high intensity discharge lamps. In aircraft applications, they are applied to cockpit displays, lights, and windows. Their function is to contain internal noise emissions and to shield against external radiation. Attenuation in EMC's is achieved by reflection rather than absorption of the RF and is expressed as Screening Efficiency (dB). Attenuation requirements approach SE = 75 dB at frequencies near 30 MHz and 20 dB near 1 GHz. The SE of an EMC is related to its sheet resistance, Rs, (Ω/sq.), and as an example, Rs of 10 Ω/sq. is required to achieve SE ~60 dB at 100 MHz. A continuous electrical contact is required between the border of the EMC and its metal frame to prevent EMI leakage. This requires the deposition of a contacting bus bar border either by evaporation of a metal strip or with a conductive paint.

EMC techniques for achieving high RFI/EMI attenuation include the use of Cu, Au, or Al meshes having thickness <50 µm, open areas of ~10's µm and opaque borders of ~2 µm width. Mesh EMC shields can produce very high attenuations, and the SE decreases in proportion to frequency. However, their visible transmission is relatively low. Another serious problem encountered with meshes is the interaction of their spatially periodic structure with self-reflections or detector or screen pixels to produce bothersome Moire' patterns over the display.

Another EMC technique uses thin continuous metal films that can produce Rs values as low as 1 Ω/sq and therefore high SE. These films, however, reflect and absorb a significant amount of visible light, and consequently they have relatively low luminous transmissions. For example, a gold film 50 Å thick transmits ~70%, one 100 Å thick transmits ~50%.

The method of choice on flat panel and other displays and windows is the use of a transparent conductive layer of a doped semi-conductor such as In_2O_3, ITO, SnO_2, ZnO or others. ITO is generically 10% Sn added to In_2O_3. ITO is the most popular material because of its long successful history; *CMN* issues have discussed its properties and deposition methods in past issues. Doped semi-conductors have dual optical transmission and electrical conducting properties. Those mentioned above possess large band-gaps and are transparent between λ ~400 nm and ~800 nm. Such compounds begin to reflect at longer wavelengths so that by about λ = 2000 nm they behave like metals and reflect ≥ 90%. The high reflection continues to beyond

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What's New at CERAC?

CERAC recently signed agreements with two new representatives. Vacuum Engineering & Materials now services thin film materials customers in the western regions of the U.S. and P&T Consulting Ltd. is the new local contact for CERAC materials in the U.K and Ireland. Visit the **What's New** page of the CERAC web site at www.cerac.com for more information.

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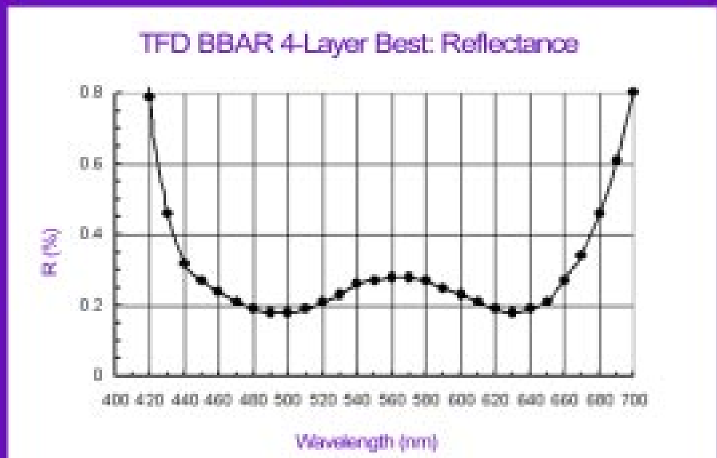
Citation Correction

Our apologies to Carolyn Aita, Wisconsin Distinguished Professor of Materials Engineering at the University of WI, Milwaukee who was incorrectly cited in previous issues of *CMN* as C. Alta.

Figure 1



Measured reflectance of a 4-layer broad-band AR coating made from sputter-deposited silicon dioxide and niobium pentoxide. Courtesy of Thin Film Devices, Anaheim, CA

λ = 30 cm (GHz). Windows subject to ice frosting or condensation often employ transparent conductive coatings as surface heaters.

Transparent conducting semi-conductors can be applied to glass by several methods; among them are spray pyrolysis which requires high-temperature reaction of liquid precursors, thermal evaporation, and sputtering. The spray pyrolysis method is suited for high-volume coatings on highly curved glass surfaces such as runway and aircraft lights, but it suffers from thickness inconsistency and low transmission. Thermal evaporation processes are used in industry also for high-temperature tolerant materials such as glass. ITO EMC coatings are efficiently and repeatedly deposited for flat panel and other display screens by magnetron sputtering, where a 3- or-4 layer AR coating can be sequentially applied in the same in-line deposition process. Large glass areas and even polymer film in rolls (web) can be coated without risk of damage by overheating. Sputtering has the advantages of producing dense adherent smooth coatings with very low particulate content. The latter property is important for laminating the ITO conductive surface to LCD panels because coating particulates can be manifested as defects or inoperative pixels. Density and adherence are essential for long-term stability of optical and mechanical properties.

Sputtered ITO coatings with Rs = 10 Ω/sq. can transmit >98 % average in the visual spectrum when properly AR coated, nearly twice that of thin metal layers and meshes, and can provide attenuations exceeding 60 dB. SE ~70 dB and visual transmittance ~90 % can be achieved for ITO with Rs values <5 Ω/sq. Visual T is an inverse trade with Rs and thus with SE. T and Rs are determined in the sputter process by controlling the degree of oxidation of the ITO layer. Higher oxidation produces high transmission but lower Rs, and *vv*. Finally, maximum transmission is achieved by immersing the ITO layer in a multi-layer AR coating designed to match the refractive index of the ITO, and thereby reduce surface reflections to ~0.5% average. [1]. Simultaneously, the elimination of reflected ambient light illumination improves the visual contrast of the screen. Modern flat panel displays, LCD devices, and other image displays incorporate laminated ITO EMC screens.

Sputter Deposition of Compounds

The deposition of dielectric compounds by sputtering involves a different set of parameters than the sputtering of metals. Dielectric compounds are created by sputtering of a metal target in a reactive atmosphere (plasma), and an oxide or nitride compound is grown on substrates. A mixture of the Ar working gas and a partial pressure of chemically reactive oxygen or nitrogen ions is provided, depending on the desired resulting compound. Thornton established that, contrary to the magnetron sputtering of metals, pressure is of secondary importance in reactive D. C. sputtering. [3].

During the reactive sputtering process, the metal target surface becomes covered with oxidized metal and the sputter rate decreases dramatically. The sputter rate for metallic oxide and nitride compounds can be 1/5 to 1/10 that of metals. Power is then increased to sputter away the compound formed on the target, causing the metal content to increase and its rate to increase, only to decrease again with the build up of the insulator. This cyclic process between metal and insulator target surface follows an hysteresis loop of pressure vs gas flow rate at constant sputtering power. A similar behavior is observed with changing power at constant gas flow. As a complication, other surfaces in the sputter chamber participate in the consumption of the reactive gas and sputtering of the compounds formed. Thus the three dominating parameters involved in stoichiometric compound film deposition

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Process Parameter Influences on Stresses in Sputtered Metal Films

D. C magnetron sputtering is used to deposit metal and dielectric films over large areas at rates comparable to e-beam deposition but at lower substrate temperature. Typical large-area applications for high-volume industries include metallization of plastic film for food packaging, AR and solar thermal control coatings for architectural glass, video and data-storage disk metallization, etc. Integrated circuit metallization using alloys of aluminum with silicon or copper followed by the addition of a passivation or an insulating layer is accomplished by sputtering in the electronics industry. Thin film resistors composed of, for example Ta-Al or TaN, are also conveniently sputter deposited. The sputter deposition process has evolved many variations. We discuss a fundamental property specific to D. C. magnetron sputtering of metals.

Classical work by Thornton and Hoffman in the 80's on the effects of various sputter process parameters revealed the existence of a distinct transition boundary in film properties. On one side of the boundary identified by the presence of compressive stress, the films exhibited near bulk-like properties for electrical resistivity, reflectance, surface smoothness, and entrapped work gas. On the other side of the boundary, the films exhibited tensile stress, columnar microstructures, and less included gas. The compressive stress side occurs with lower sputter-gas pressures, high-mass materials, light gases, low deposition rates at normal incidence, and close target-to-substrate distance. The tensile side is associated with high pressures, high-mass gases, light target materials, greater separation, and oblique incidence. Subsequent work suggested that the shape of the cathode (planar, cylindrical or co-axial target) is another process variable [2]. The mechanism that alters the intrinsic stress is believed to be bombardment ("peening") of the growing films by rebounding neutralized scattered argon ions. The energy and flux density of these bombarding ions is a function of the angle of emission from the target and the mass of the target material relative to the Ar ion. Larger angles of incidence as with the planar magnetron geometry and higher material masses decrease the zero-stress transition pressure.

Experimental data for planar magnetron and cylindrical-post sputter depositions of Cr, Mo, Ta, and Pt as functions of argon pressure and atomic mass of the metal were presented [2]. Deposition conditions were: rate 1 nm/s; distance target-to-substrate 76 mm. These metals have very high levels of stress, 1.4 GPa or 2 x 10^5 psi. Tensile-to-compressive stress reversal (zero stress) occurred at ~2mTorr for Mo, 10 mTorr for Ta, and 20 mTorr for Pt. Films of Cr never became compressive, instead their tensile stress passes through a maximum with increasing pressures and decreases approaching zero stress near 10 mTorr. The sequence of zero-crossing is consistent with increasing mass. When the amount of entrapped argon in different metals sputtered by both techniques is compared, a ~2 – 8 times higher percentage is incorporated in the cylindrical-post magnetron depositions. Typical values for the planar magnetron films are: <0.05 At. % for Cr; 0.1% for Mo, ~1.3% for Ta and W. Again, the Ar concentration increases with mass of the metal. Furthermore, the concentration is maximized by sputtering at low Ar pressures and decreases with increasing pressure. The change in slope of the trend is abrupt, and the breaking point coincides with the zero-stress crossing. When the influence of temperature-induced stresses on the transition point are considered, a temperature increase during sputtering is only significant for the heavier metals and not for Cr and Mo. For the heavy metals, the result will be a reduction in the compressive stress magnitude.

This study provides important process-parameter related data that should contribute insights into explaining the sometimes mysterious observations of high-stress depositions of metals. Pressure is one controlled, but critical, variable in sputter deposition. Other influential variables for metals include energy, surface conditioning, and deposition rate.

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P.O.Box 1178
Milwaukee, WI 53201-1178
Phone: 414-289-9800
FAX: 414-289-9805
web: www.cerac.com
e-mail: marketing@cerac.com

Editor:
Russ De Long
Manager, Advanced Technologies Group
CERAC, inc.

Principal Contributor:
Samuel Pellicori
Pellicori Optical Consulting
P.O. Box 60723
Santa Barbara, CA 93160
Phone/FAX: 805-682-1922
e-mail: pellopt@silcom.com

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CERAC
P.O.Box 1178
Milwaukee, WI 53201-1178
USA

are the sputter rates, the quantity of reactive + working gas, and the power. The relationship is approximately represented as W/F ∞ 1/So, where W is sputtering power, F is the volumetric flow rate of the reactive gas component and So is the sputtering efficiency of the metal [4]. A couple examples are shown: To deposit Al_2O_3 from Al, W/F ~50; TiO_2 from Ti, W/F ~70, SiO_2 from Si, W/F ~80. Tight closed-loop control is required to maintain a workable deposition rate and achieve the desired stiochiometry. That control is achieved by monitoring the gas species in the plasma through the use of plasma emission spectrometry [5], permitting a repeatable process to be developed for sputtering dielectric layers for optical, electrical, and mechanical applications.

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