SVC Topics

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Metallic Thin Film Electrical Conductors

Metallic conductor films are widely used in the hybrid microelectronics and semiconductor industry, where thin film "blanket metallization," which covers the whole surface, is etched into conductor patterns, or material is deposited through a mask to form a conductor pattern on the surface. Masking techniques are useful on conductor geometries down to about 2–5 microns in width.

The electrical resistivity (R) of a conductor is given by:

R=∂ 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 thin film, the resistance side-to-side of a square, whose side is L centimeters, is given by A=L x t, where t is the thickness in centimeters. The resistance from side-to-side of any square area on a thin film of constant thickness is the same, therefore, no matter the size of the square. This gives rise to the common thin film resistivity unit of ohms/square, though to get the resistivity of the film material, the film thickness must be known. The resistance of a thin film is usually measured by the "four-point probe" technique, where there are four electrodes in a linear array. The outer electrodes inject current into the film, and the inner pair measure the voltage drop. This avoids the contact resistance problems that are encountered when a two-point probe technique is used. For delicate films, mercury contacts can be used to minimize the probe pressure on the film surface.

The table gives the bulk resistivity of a number of metals used as electrical conductors. Gold has the advantage that it does not oxidize; therefore, wires can easily be bonded to the gold surface by soldering, thermocompression bonding, or ultrasonic bonding. Gold has the disadvantage that it does not adhere well to oxide surfaces. Silver is easily corroded, does strange things in the presence of moisture, and is not often used as a metallization material. Copper is a very desirable thin-film conductor material, though it does not bond well to oxide surfaces when deposited by PVD techniques. Aluminum, deposited by PVD techniques, adheres strongly to oxide surfaces. Tungsten and tungsten-titanium alloy (10-percent titanium) are used in silicon technology as a diffusion barrier between the silicon and metallizations, such as aluminum. The diffusion barrier prevents the aluminum from diffusing into the silicon during deposition, and in subsequent high-temperature processing. Conductive compounds, such as TiN, are also used as diffusion barrier materials.

Typical Electromigration
"Burn-in" Curve

Material	Bulk Resistivity (20 °C, ohm-cm)
Silver	1.6×10^{-6}
Copper	1.7×10^{-6}
Gold	2.4×10^{-6}
Aluminum	2.8×10^{-6}
Tungsten	5.5×10^{-6}
Titanium	$\approx 50 \times 10^{-6}$

Multilayered Systems

Many metallization systems are multilayered to combine desirable properties. In metallizing an oxide surface, or surface having an oxide surface layer, for example, the first material to be deposited is an oxygen-active material, such as chromium or titanium, to act as a "glue layer." Before the chromium or titanium can oxidize, copper or gold (both soluble in chromium and titanium), are deposited as the electrically conducting layer. When depositing copper, a thin gold topcoat film may be deposited to form an oxidation-resistant surface.

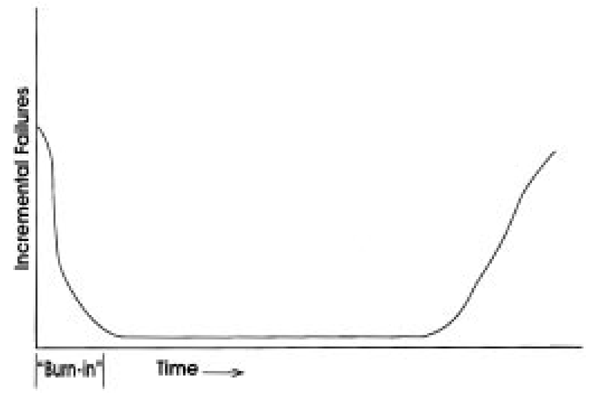
When titanium and gold are in contact, they form a galvanic corrosion couple. In the presence of an electrolyte, such as in wet chemical etching, or if there is trapped ionic material in the films, interfacial corrosion can occur, resulting in a loss of adhesion. To disrupt this galvanic corrosion couple, a layer of platinum or palladium can be deposited between the titanium and the gold. Thus, a metallization system might be: Ti (500 Å)-Pd (1000Å)-Cu (>10,000Å)-Au (500Å).

All of these materials can be easily evaporated. The thickness of high-elastic modulus materials, such as Ti and Cr, should be limited to less than 500Å to limit the total residual film stress. Nichrome (80% Ni/20% Cr) is sometimes used instead of chromium. Chromium has a higher vapor pressure than nickel, so the deposit will be chromium-rich at the interface, and nickel-rich on the surface.

Avoiding Complex Systems

To avoid complex metallization systems, aluminum metallization may be preferable. Aluminum metallization is easily etched, using either wet-chemical etching or a BCl_3 plasma. In semiconductor technology, the conductor is often encapsulated in a glass (PSG) film, deposited by chemical vapor deposition (CVD) at about 450 °C. At this temperature, the initial fine-grained aluminum metallization will experience grain-growth, with the grains attaining the size of the conductor width (1–5 microns). Because of the high thermal coefficient of expansion of the aluminum, when it is encapsulated, it will be subject to a high-tensile stress when it cools down. Over a long period of time, voids will form to relieve this stress. These voids will precipitate on the grain boundaries and can give rise to an "open" conductor with a high resistivity. To avoid this problem, an aluminum alloy containing 1–2 percent copper is sputter-deposited. On heating, aluminum-copper (Al_2Cu) phase nuclei will precipitate within the aluminum grains. The voids will precipitate on these nuclei, as well as on the grain boundaries, thereby, diminishing the chance of forming an "opening" in the conductor line.

"Electromigration" can also cause an open conductor. In electromigration, a high-current density (10^6 A/cm^2 in aluminum) causes the movement of atoms, the loss of material in some regions, and the formation of "hillocks" in others. Electromigration failure is very sensitive to the deposition process, the point defect concentration in the material, and the processing environment. Conductors that are susceptible to this failure are removed during the "burn-in" process, where the conductors carry a current for a period of time before they are marketed. Silicon, at one percent, can be added to the aluminum to increase the resistance to electromigration. This makes a sputter-deposited Al-Cu(2%)-Si(1%) alloy a common metallization in silicon device technology. The accompanying figure shows a typical "bathtub" curve for electromigration failure as a function of time for a typical "good" batch of aluminum metallization. Copper metallization is less prone to electromigration failure than is aluminum.



This figure illustrates a typical "bathtub" curve for electromigration failure over time, for a typical "good" batch of aluminum metallization.

One limiting factor in the use of PVD metallic films is the poor ability of the PVD techniques to fill high-aspect-ratio (narrow and deep) holes (vias), which are used to connect various levels in semiconductor devices. Chemical vapor deposition (CVD) techniques have a better ability to fill the holes with a high-density metallization. Tungsten CVD is often used for this purpose.

There are other thin film electrical conductors, such as many carbides, nitrides and silicides film, transparent electrical conductors such as indium-tin-oxide (ITO), and the high temperature oxide superconductors. These have specialized uses. o