Applications of High Conductivity Traces in Thin Film Substrates

INTRODUCTION

Vishay MIC Technology's High conductivity processes have brought a significant contribution to the thin film world by enabling high current low resistance circuits to coexist with microwave transmission lines and structures. The purpose of this paper is to review the details behind this capability and the resulting advantages to the circuit designer.

STEP 1: CALCULATING TRACE RESISTANCE

The typical thin film metal system such as titanium-tungsten/ gold (TiW/Au) has a measurable resistance due to the cumulative resistivities of each of the metals. These resistance values are most clearly discussed by using sheet resistance where ohms per square are the unit of measure (just as resistors are measured). Due to the fact that the conductivities of metals are very high, the more meaningful units here are milliohms per square (m1/2/N). For a circuit trace consisting of a single metal layer, its total resistance can be calculated as:

R_{total} = trace length/trace width) x sheet resistance
= L/W x R_{sheet}

The sheet resistance is actually calculated by dividing the bulk resistivity (an intrinsic property) by its thickness.

R_{sheet} = bulk resistivity/thickness

Unfortunately, the reality of depositing or plating metals on ceramic is that the bulk resistivity drops somewhat. As an example, pure gold has a bulk resistivity of 2.2 µ1/2cm. When MIC Technology sputters gold, the resultant film has a bulk resistivity of 2.33 µ1/2cm, while plated gold measures out at 2.9 µ1/2cm. Table 1 provides some bulk resistivities of materials commonly used by MIC Technology. Using the above mentioned bulk resistivities, we can compute the sheet resistance of single metal systems of various thicknesses by dividing bulk resistivity by thickness. Table 2 indicates sheet resistances in m1/2/N for typical metal thicknesses:
The most noticeable fact from Table 2 is that the 2 mil thick copper sheet resistance is at least 20 times lower than that of the 150 µin thick gold, due primarily to its thickness advantage, and secondarily to its higher conductivity.

TABLE 1: SELECTED BULK RESISTIVITIES

Material	Pure Bulk Resistivity (µΩcm)	Conservative Value of Bulk Resistivity (µΩcm)
Au	2.2	2.4 (sputtered) 2.9 (plated)
TiW	—	95 (sputtered)
Cu	1.71	1.9 (plated)
Ni	7.48	8.2 (sputtered)
Pt	9.83	10.8 (sputtered)
A1	3.8	4.2 (evaporated)

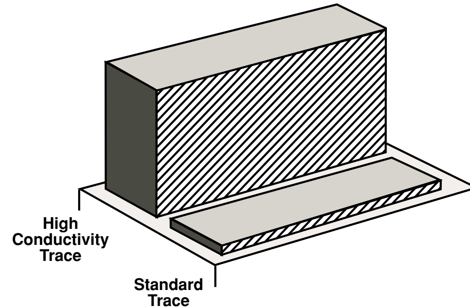


TABLE 2: SELECTED SHEET RESISTIVITIES

Metal	Thickness	Sputtered Sheet Resistance mΩ	Plated Sheet Resistance mΩ
Au	80 µin (2 µm)	10 - 11	15 - 16
	150 µin (4 µm)	5 - 6	7 - 8
	600 µin (15 µm)	1.5	2.0
Ni	20 µin (0.5 µm)	160	—
TiW	400 A	23,750	—
Cu	2000 µin (50 µm)	—	0.21

As a specific example of line resistance, assume you had a 5 mil wide line that was 500 mils long with 400 angstroms of TiW and 150 µin of sputtered gold. The total resistance would be computed by calculating how many squares of metal there are and then multiplying it by the effective sheet resistance of gold in parallel with TiW. As it turns out, the gold is so much more conductive than the TiW, only the gold determines the total resistance. Neglecting the conductivity of the TiW:

R_{total} = (500/5) x 6m1/2/N
= 100N x 6m1/2/N
= 0.6 ohms.

If we had included the TiW, the resistance would be:

R_{total} = R_{TiW} in parallel with R_{Au}
= (R_{TiW} x R_{Au})/(R_{TiW} + R_{Au})

Just as with the gold:

R_{TiW} = (500/5) x 23,750 m1/2/N
= 100N x 23.75 1/2/N
= 2,375 ohms.

Therefore,
R_{total} = (0.6 x 2,375)/(0.6 + 2,375) = 0.599 1/2

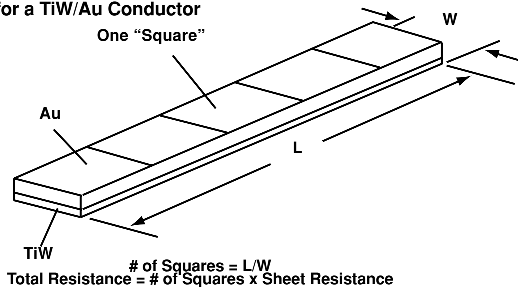
Obviously only the gold is significant in this situation because including the effect of TiW decreases the total resistance by only 0.03%. For reference, the squares concept is detailed in Figure 1.

VISHAY ELECTRO-FILMS • FRANCE +33.4.93.37.28.24 FAX: +33.4.93.37.27.31 • GERMANY +49.9287.710 FAX: +49 9287.70435 • ISRAEL +972.3.557.0945 FAX: +972.3.558.9121
• ITALY + 39.2.300.11911 FAX: +39.2.300.11999 • JAPAN +81.3.5464.6411 FAX: +81.3.5464.6433 • SINGAPORE +65.788.6668 FAX: +65.788.0988
• SWEDEN +46.8.594.70590 FAX: +46.8.594.70581 • UK +44 191 514 8237 FAX: +44 1953 457 722 • USA: (401) 738-9150 FAX: (401) 738-4389

STEP 2: MODULE DESIGN CONSIDERATIONS

The usefulness of high conductivity traces are quite simple when one considers the process that the typical module engineer employs during a module design. After completing the schematic for the module, the engineer begins a layout of thin film circuits which will connect all of the inputs and outputs to the proper places and not compromise electrical performance. In the case of lines that carry electrical currents to chips, the engineer computes the resistance of high current lines and multiplies those values times the expected current in each line. The resultant value is the voltage lost along the line. As an example, if the previously mentioned 5 mil wide line had 1 amp of current flowing through it, the voltage drop (computed using ohms law) is:
Voltage (V) = Current (A) x Resistance (1/2)
Or
V = IR
So: V = 1 x 0.6 = 0.6 Volts dropped along the line.
Figure 2 provides a similar but more graphic example and identifies situations where the line losses are and are not acceptable. The significance of this lost voltage is a problem for circuit designers but differs depending on the type of circuit. If the circuit is a digital type, such as a multichip memory module,
information is transferred from chip to chip as on or off signals. The on or off state is judged by a voltage level, such as 5 volts or 0 volts, respectively. If an interconnect or power supply line loses 0.6 volts, the 5 volt on state will now be 4.4 volts. This reduced voltage may result in undetermined states in the digital system.

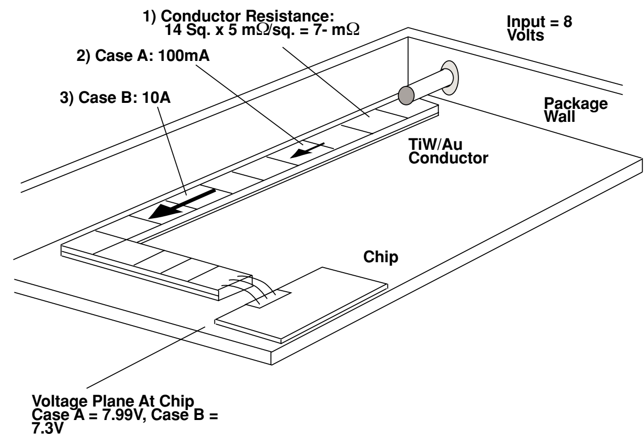
Figure 1: Sheet Resistance Calculation for a TiW/Au Conductor



The more familiar problem for MIC Technologys circuits is in analog or microwave type designs. Usually, these circuits employ MMIC chips which amplify microwave signals. The power that a chip can produce is directly proportional to the voltage applied to it. If voltage is lost in a supply line due to resistance, then a designer is throwing away available power from the MMIC chip. In many high power T/R modules, greater than 15 amperes of current flow to the MMIC chips. Engineers have employed MIC Technologys high conductivity traces in these situations to reduce voltage losses, from volts to tenths of a volt. In one specific case, high conductor losses would have meant a 10% reduction in output power and a module that didnt meet its output power specification. With a thick copper line, output power was only compromised by roughly 0.5%.

Although much of the previous discussion refers to selectively thickened copper traces, MIC Technology has the ability to apply selective thick gold plating to lines as well. As noted in Table 2, 600 µin gold has a sheet resistance of about 1.5 mΩ. This approach is 4 times less resistive than standard metallization and may be a more economical solution to the customers needs for current levels up to a few amps. Each case should be reviewed with the factory but in some instances, this approach can yield a more cost-effective circuit solution. For a customer already purchasing air bridges, a thick gold plating step is already used so selective thick conductors are available without added processing steps.

Figure 2: Voltage Drop from Module Input to Chip



STEP 3: THICK FILM COMPARISON

Thick film technology has increasingly competed with thin film in some applications. A review of the materials data reveals thin film to be a superior performer. First, although not the subject of this paper, the 96% alumina used for thick film applications typically has 25% more loss to microwave energy than the 99.6% material. Next, the metal systems used in thick film, because they utilize pastes consisting of glass particles, metal particles and binders, are inherently more resistive than pure metals. Due to the screening process used to apply the pastes, the conductor thicknesses are typically 5 to 10 times that of thin film. These thicker conductors do, however, help to offset the higher bulk resistivities of the pastes. Unfortunately, the thickness variations and irregular cross-section following screening tend to reduce these gains. The following table compares the resistances of various thick film approaches. The above table indicates the comparable DC performance of these approaches. Thin film, however, still provides more performance with thinner materials. In addition, the paste conductors have inherently non-uniform surface characteristics which degrade their solderability and wire bondability. Variation in total resistance, lot to lot, is also a cause for concern, due to its reliance on paste variations, firing temperature and duration.

TABLE 3: RESISTIVITY COMPARISON

Technology	Conductor Description	Nominal Thickness	Sheet Res. mΩ	Comment
Thin Film	Au, sputtered	150 μin	5	MIC Std Approach
	Cu, plated	2 mil	0.21	MIC Thick Cu Approach
High Temp Cofire	Tungsten Paste	1 mil	12 - 50	Buried conductors in ceramic
	Tungsten Paste w/Gold Overplate	1.2 mil	5 - 10	External traces on ceramic
State-of-the-Art Thick Film	Gold Paste	0.3-0.6 mil	5	Standard Base Metal System
		3 mil	0.5	Thick Film High Conductivity Approach

HIGH CONDUCTIVITY COATINGS QUICK REFERENCE GUIDE

SELECTED BULK RESISTIVITIES

Material	Pure Bulk Resistivity (μΩcm)	Conservative Value of Bulk Resistivity (μΩcm)
Au	2.2	2.4 (sputtered) 2.9 (plated)
TiW	—	95 (sputtered)
Cu	1.71	1.9 (plated)
Ni	7.48	8.2 (sputtered)
Pt	9.83	10.8 (sputtered)
A1	3.8	4.2 (evaporated)

SELECTED SHEET RESISTIVITIES

Metal	Thickness	Sputtered Sheet Resistance mΩ	Plated Sheet Resistance mΩ
Au	80 μin (2 μm)	10 - 11	15 - 16
	150 μin (4 μm)	5 - 6	7 - 8
	600 μin (15 μm)	1.5	2.0
Ni	20 μin (0.5 μm)	160	—
TiW	400 A	23,750	—
Cu	2000 μin (50 μm)	—	0.21

TYPICAL PLATING SPECIFICATIONS

Plating Option	Metal	Thickness
Thick Copper	TiW	250 - 750 A
	Au	100 - 150 μin
	Cu	2200 ± 400 μin
	Ni	80 - 250 μin
	Au	100 - 200 μin
Thick Gold	TiW	250 - 750 A
	Au	400 - 1000 μin

SUMMARY

High conductivity traces are important technological additions to the thin film industry. MIC Technology's unique capabilities in this area provide the customer with a low resistance solution for high power circuits that was previously unavailable. The several metallization options available to the designer enable cost effective, manufacturable circuits for a wide variety of applications.

VISHAY ELECTRO-FILMS • FRANCE +33.4.93.37.28.24 FAX: +33.4.93.37.27.31 • GERMANY +49.9287.710 FAX: +49 9287.70435 • ISRAEL +972.3.557.0945 FAX: +972.3.558.9121 • ITALY + 39.2.300.11911 FAX: +39.2.300.11999 • JAPAN +81.3.5464.6411 FAX: +81.3.5464.6433 • SINGAPORE +65.788.6668 FAX: +65.788.0988 • SWEDEN +46.8.594.70590 FAX: +46.8.594.70581 • UK +44 191 514 8237 FAX: +44 1953 457 722 • USA: (401) 738-9150 FAX: (401) 738-4389