Thin Film Embedded Resistors

Jiangtao Wang and Sid Clouser
Gould Electronics Inc, 34929 Curtis Blvd., Eastlake, Ohio 44095

Abstract

Resistors embedded in a printed wiring board will be an enabler for miniaturizing packages with higher reliability and improved electrical performance. Integrating the resistor functionality into the laminate substrate frees up the PWB surface area consumed by discrete components, enabling increased device functionality by the placement of more active components.

Nickel-chromium alloys possess high electrical resistivity, which make them practical for use in a variety of applications. Nickel and chromium are alloyed with silicon and aluminum to improve temperature stability and lower the thermal coefficient of resistance. A thin film resistive layer based on nickel-chromium alloys has been deposited continuously onto rolls of copper foil to create a material for embedded resistor applications. The thin film resistive layer sandwiched between copper and laminate can be selectively etched to form discrete resistors. The chemicals for etching are common in PWB production processes. By controlling the thickness of the alloys, sheet resistance values from 25 to 250 ohm/sq. are obtained.

This paper will compare two nickel-chromium materials in their etching methodologies, uniformity, power handling, thermal performance, adhesion and etching resolution.

Introduction

As electronic devices become smaller and lighter, the printed wire boards (PWB) must be smaller and thinner. In addition to finer line and spaces for interconnections, integration of passive discrete components such as resistors into the PWB is also preferred. Embedding resistors in a printed wiring board will not only miniaturize the packages but also improve reliability and electrical performance. Integrating the resistor functionality into the laminate substrate frees up the PWB surface area consumed by discrete components, enabling increased device functionality by the placement of more active components.

The resistive material to be used for embedded resistors should have high electrical resistivity, low temperature coefficient of resistance (TCR), and ease of process. We have examined nickel-chromium alloys as the resistive material for our resistive foils. It was found that thin film of nickel-chromium alloys work very well as embedded resistors. In this paper, we will present two nickel-chromium materials and their performances as thin film embedded resistors in terms of their etching methodologies, uniformity, power handling, thermal performance, adhesion and etching resolution.

Thin film nickel-chromium alloys as embedded resistor materials

Nickel-chromium alloys have been chosen to be the resistive material for embedded resistor because nickel-chromium alloys possess high electrical resistivity that is widely used for thin film resistors [1, 2]. The sheet resistance of nickel-chrome alloy film containing 20% chromium can be as high as 2-3 kilo ohms and still maintain good stability. The temperature coefficient of resistance (TCR) for bulk nickel-chrome alloy is about 110 ppm/°C. By alloying a small amount of silicon and aluminum with nickel-chromium, the temperature stability is further improved.

Resistive foils are made by depositing a thin film of nickel-chromium alloys on copper foil through a roll to roll sputtering process. Generally, the resistive materials can be deposited on any copper foil with different weight, either on the matte or on shiny side. However, we found that the preferred copper foil for embedded resistors is reverse treated (RTC) thin copper foil (12 μm or ½ oz copper foil), where the resistive material was deposited on the untreated side. The advantages of using thin RTC foil is (1) the black oxide step can be eliminated after etching resistors, (2) thin copper foil has a better etching resolution.

For a given nickel-chrome alloy, the sheet resistance of a thin film resistive layer is determined by film thickness, film stress, and surface roughness of copper foils. Figure 1 shows the experiment results of the correlation of sheet resistance to alloy film thickness and copper substrates. It can be seen that the Ni/Cr/Al/Si has higher resistance than that of Ni/Cr at approximately the same thickness. The effect of copper surface roughness on the sheet resistance is also evidenced. The sheet resistance is inversely proportional to the thickness of the resistive layer. For a given copper foil, we can achieve a resistive layer with desired sheet resistance value by adjusting the sputter parameters, such as power, linear speed, etc. accordingly.

In addition to the factors mentioned above, the prepreg used and lamination conditions for the prepreg also play a role on the final sheet resistance. Since different prepreg uses different lamination cycle and lamination temperature, sheet resistance will be slightly altered after the resistors are embedded. Our experiment results show that this resistance change due to the thermal exposure is consistent and predictable. Therefore, it can be compensated by adjusting the sputtering process to tune the sheet resistance to desired value. Table 1 shows how the sheet resistance changes when the same material is laminated on different prepreg.

It was found that the higher the lamination temperature and the longer the lamination cycle time, the larger the resistance changes. For Ni/Cr, the resistance decreases 2-3% after being embedded. Ni/Cr/Al/Si is relatively stable to heat compared to Ni/Cr. After being embedded, the resistance slightly increases by 0.5%.

One of the advantages of sputtering process for thin film deposition is good uniformity. The uniformity of thin film layer deposited, in terms of thickness and composition, is critical for the embedded resistor application because it determines the sheet resistance tolerance of the material. Figure 2 shows the typical variation of resistance cross 24-inch web. The variation of the resistance is less than ± 3%. The sheet resistance change along the web direction is caused by a cosine emission distribution of sputtered material and the edge effect, which can be further corrected by installing a correction mask. The resistance variation on the machine direction is very small, less than ± 1%, compared to that on the transverse direction.

Etching process of the nickel-chromium alloys thin film

The nickel-chromium alloys film can be easily etched by common PWB etching processes and chemicals. The procedures of etching Ni/Cr and Ni/Cr/Al/Si are shown in Figure 3 and Figure 4, respectively. For Ni/Cr resistive material, there are two etching steps involved. The first etching step defines the width of resistors. Cupric chloride solution was used to etch off both copper and Ni/Cr. The second etching step defines the length of resistors. Ammoniacal etching solution was used to selectively etch off copper. Since both cupric chloride solution and ammoniacal etching solution are common in PWB production processes, Ni/Cr resistive foil readily fits into current PWB production processes. For Ni/Cr/Al/Si, however, an additional etching solution is required to remove the resistive material after copper is etched in the first etching step. For example, a mixture of hydrochloride acid and glycerin can be used to remove Ni/Cr/Al/Si effectively.

Performance of embedded resistors

Various reliability and performance tests have been performed for these nickel-chromium resistive foils. The test boards were made of PLC-FR-226 1080 prepregs. The total thickness of the test board is about 12 mil with resistors embedded. Gould resistor test pattern was used to prepare the test boards. The test pattern includes 120 resistors with different size (10-125 mil) and different values (1-12 squares) on each of test boards. The sheet resistance for both Ni/Cr and Ni/Cr/Al/Si resistive foil used in the tests are 100 ohm/square. The resistance changes before and after tests are measured and listed in Table 2.

It can be noticed that the resistances of both Ni/Cr and Ni/Cr/Al/Si change after thermal exposure. The resistance of nickel-chromium alloy tends to be decrease after thermal exposure. Nickel-chromium with aluminum and silicon alloy is more thermally stable than nickel-chromium alloy. It has a smaller resistance change and the change is positive instead of negative for Ni/Cr alloy. Generally, the longer the time the material is exposed to high temperatures, the larger the change in resistance. This resistance change could be caused by (1) the resistive material itself, such as annealing effect, inter-diffusion of metal atoms and surface oxidation; (2) dielectric substrate, thermal expansion stress, and (3) possible chemical reactions (at high temperature).

The power dissipation ability of an embedded resistor is mainly a thermal management issue. Therefore, the test results are strongly dependent on the configuration of the test boards and the test conditions. The test boards we used are prepared by laminating the resistive material on single side of FR-4 pre-pregs (four plays) and the resistor size is 30 mil by 30 mil in square. The current was applied on the resistor for one hour, and the resistance after one hour was recorded. The resistance change at different current loads is shown in Figure 4. The higher the current, the higher the power and the higher the resistor's temperature that causes resistance change. Ni/Cr/Al/Si shows less resistance change than that of Ni/Cr at the same power level. The current load can go higher until the temperature reach a point when the dielectric substrate starts to burn. It is interesting that as current goes higher and resistor's temperature goes higher, the resistance of Ni/Cr increases instead of decreasing as it changes after thermal exposure (see Table 2). It was also found that the resistance values were almost back to original value after the applied current was turned off and the resistor was cool down. This behavior indicates that the resistance change during the high current loading may be caused by thermal expansion of substrate material.

The peel strength is one of critical specifications for all copper foil products. The peel strengths of the resistive materials laminated on FR-4 prepreg are shown in Figure 6. The resistive material were deposited on the matte side of reverse treated 12 µm copper foil. After lamination, the copper was plated up to 35 µm thick for peel strength measurement. The peel strength for Ni/Cr and Ni/Cr/Al/Si are 3 lb/in and 7 lb/in, respectively. Since resistive layer is deposited on a roughness controlled copper surface, the peel strength of resistive foil are relatively low compared to the normal copper foil because there is no bonding enhance treatment. The peel strength of Ni/Cr and Ni/Cr/Al/Si resistor foil is enhanced by the chromium in alloys. Chromium is widely used as an adhesion promoter. The higher peel strength of Ni/Cr/Al/Si than Ni/Cr is due to the higher chromium content in Ni/Cr/Al/Si.

Conclusions

A thin film resistive layer based on nickel-chromium alloys has been deposited continuously onto rolls of copper foil to create a material for embedded resistor applications. The thin film resistive layer sandwiched between copper and laminate can be selectively etched to form discrete resistors. The chemicals for etching are common in PWB production processes. By controlling the thickness of the alloys, sheet resistance values from 25 to 250 ohm/sq. are obtained. The embedded resistors made of nickel-chromium alloys demonstrated an excellent performance.

References:

1. R. W. Berry, p. M. Hall and M. T. Harris, *Thin Film Technology*, Litton Education Publishing, 1979, 337-338.
2. C. A. Harper, *Handbook of Components for electronics*, McGraw-Hill, 1977, 7-49 to 7-52.

Table 1: Sheet resistance change due to the lamination temperature.

	FR-4, 350°F	DriClad, 365°F	Arlon, 430°F,
Ni/Cr	103 Ω/□	99 Ω/□	96 Ω/□
Ni/Cr/Al/Si	103 Ω/□	104 Ω/□	105 Ω/□

Table 2: Reliability test results of thin film embedded resistors.

Resistance Change	Ni/Cr	Ni/Cr/Al/Si
Humidity resistance test MIL-STD-202, Method 103B 40°C, 95%RH, for 240 hrs	0.5%	0.3%
Thermal cycling MIL-STD-883, Method 1010.7 conditions C. –65 - 150°C	-0.7% after 50 cycles -1.05% after 100 cycles -2.75% after 500 cycles -4.2% after 1000 cycles	0.15% after 50 cycles 0.8% after 100 cycles 0.85% after 500 cycles 1.55% after 1000 cycles
Convection reflow test EIA/JEDEC 22-A112-A Preconditioning at 30°C, 60RH for 192 hr Max. Temp. 220°C	-0.85 % after 3 cycles -1.7 % after 6 cycles -2.0 % after 10 cycles	0 % after 3 cycles 0.1 % after 6 cycles 0.6 % after 10 cycles
Soldering Heat MIL-STD-202, Method 210A, Condition C 260°C, 10 sec	-2.2%	0.45%

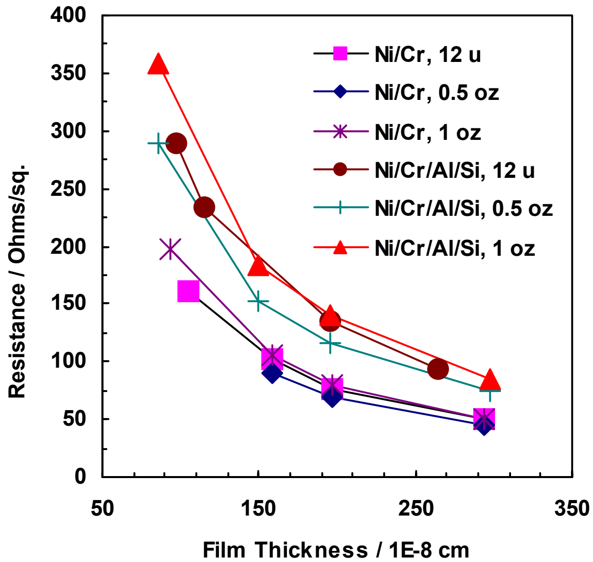

Figure 1: the correlation of sheet resistance to alloy film thickness and different copper substrates.

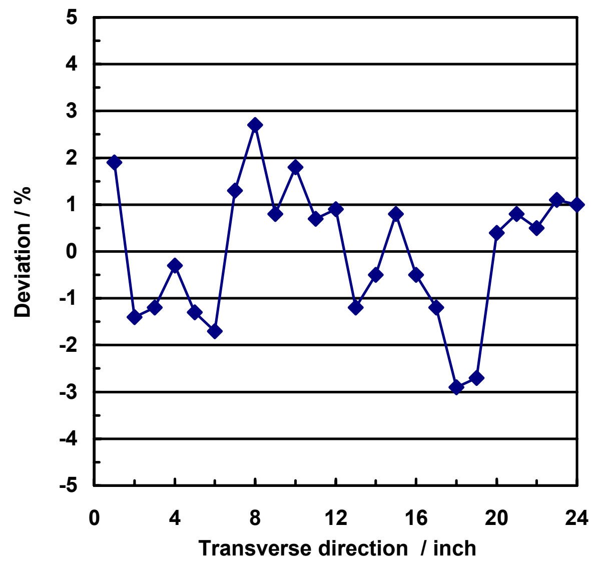

Figure 2: Sheet resistance uniformity in the transverse direction. Ni/Cr alloy on ½ oz RTC foil.

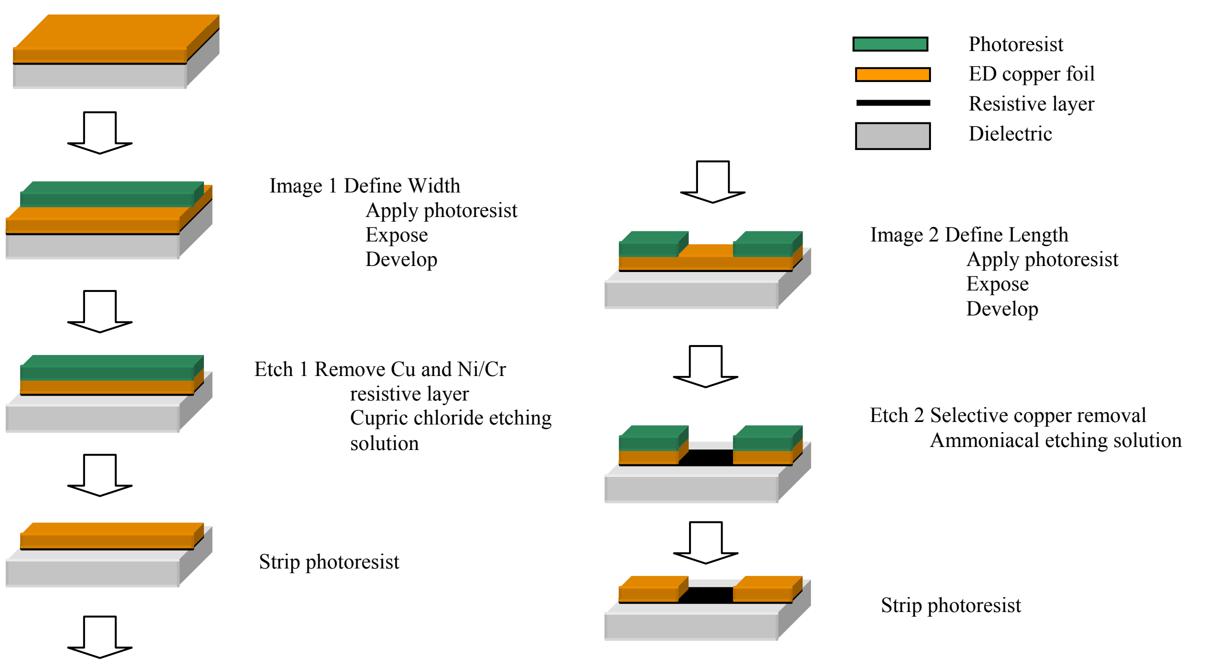

Figure 3: Schematic of etching sequence of Ni/Cr resistive layer.

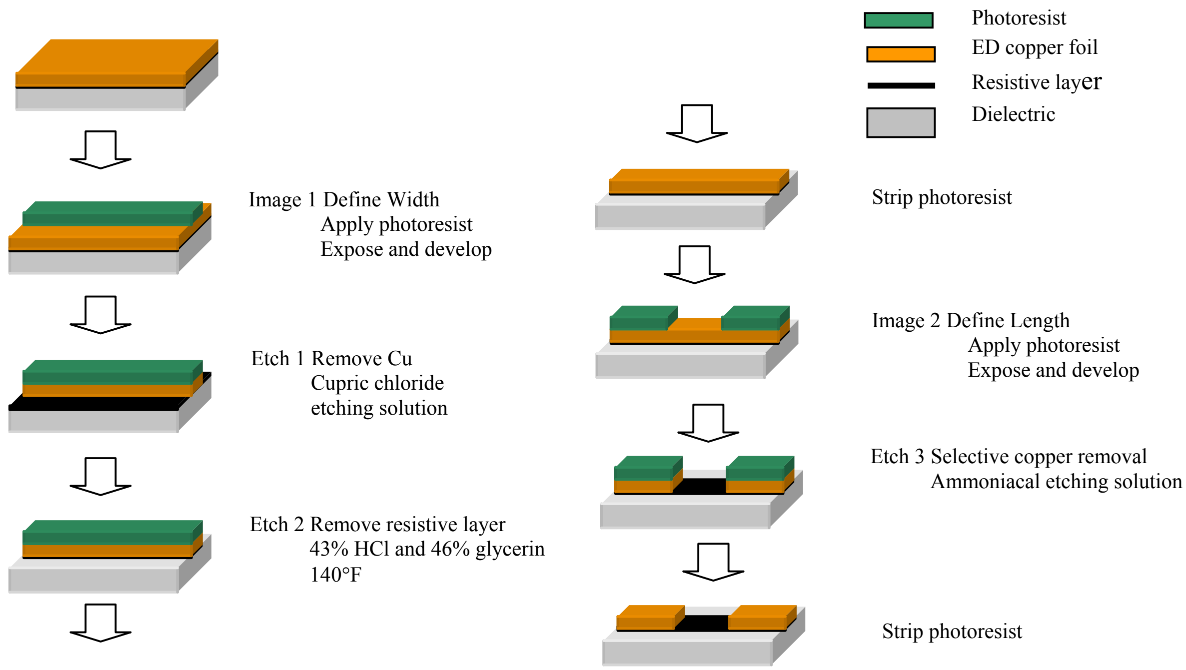

Figure 4: Schematic of etching sequence of Ni/Cr/Al/Si resistive layer.

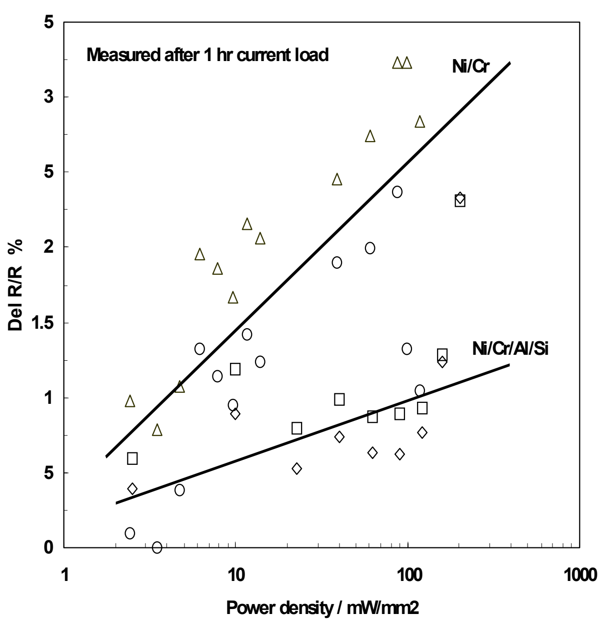

Figure 5: Resistance changes under current load. Resistive material was laminated on single side of FR-4 pre-pregs and the resistor size is 30 mil by 30 mil.

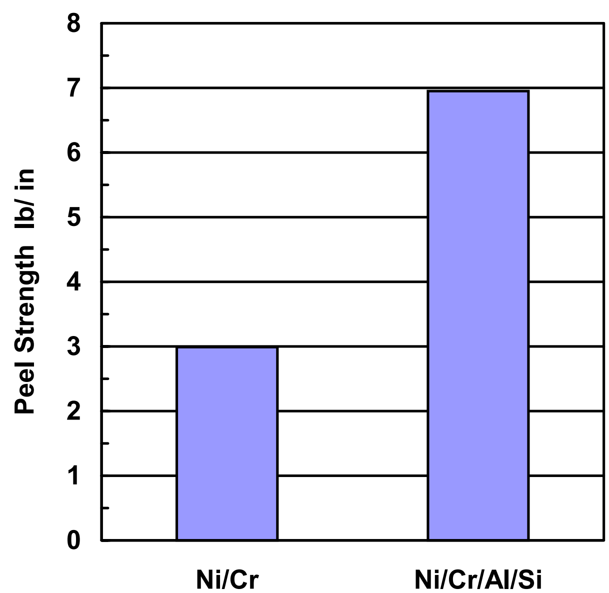

Figure 6: Peel strength of resistive material laminated on FR-4. Resistive materials sputtered on the untreated side of 12µm RTC foil. Sheet resistance is 100 ohm/sq.