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Micro Trace Resistive Technology

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Abstract
Micro Trace Resistor Technology allows thin film resistors to be built within a printed circuit trace that is less than 100 microns wide. Using standard subtractive printed circuit board processes, it is ideal for high density interconnect (HDI) designs where passive component placement is difficult or impossible. By utilizing the differential processes unique to the OhmegaPly® nickel phosphorous (NiP) resistive material, copper traces can be imaged and etched to define resistor widths that are precise and sharply defined, resulting in the creation of miniature resistors with consistent ohmic values. With low inductance and good tolerances, Micro Trace Resistors are ideal for line termination and pull-up/down applications.

Introduction
Embedded resistors have been used for many years as replacement for discrete surface devices in order to increase circuit density, improve reliability and enhance electrical performance. For many of those years circuit designs were able to accommodate embedded resistor footprints that were relatively large, typically with line widths greater than 250 microns (Fig 1). The evolution to greater I/O densities and routing constrictions made it very difficult, if not impossible, to embed

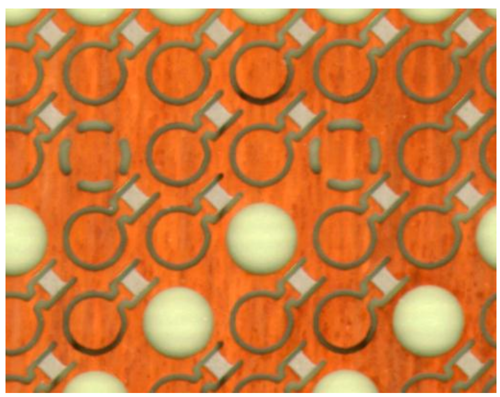

Figure 1 - parallel termination resistors

resistors with footprints of these dimensions, especially terminating resistors within the high density routing area of BGA devices. This lead to the development of a ten ohm per square sheet resistivity "Resistor Built In-Trace" technology that allowed termination resistors to be built within traces and eliminated the requirement for designing resistor footprints and placing them within the circuit layout (Fig 2). These resistors are typically about 125 microns in width.

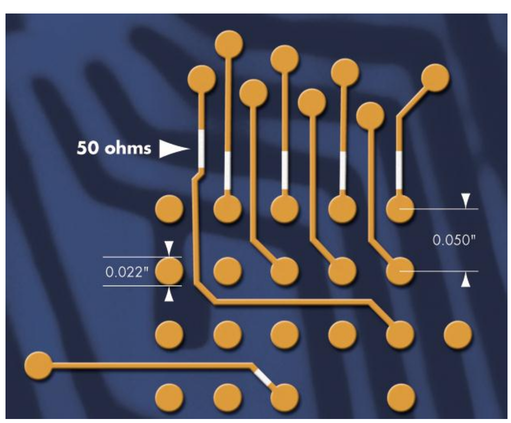

Figure 2 - resistors built in trace

However, as I/O densities continue to increase, there has been a new need for embedded resistors that could fit within uBGA footprints with pad pitches of 300 - 500 micron or less. Resistors with line widths of less than 100 microns are necessary to accommodate these new requirements. A project to evaluate such small resistor elements was initiated in order to determine the tolerance and power dissipation that could be expected.

Test Vehicle Design

The test vehicle was a four-layer multilayer PCB with the embedded resistors on layer two. Standard 170 Tg FR4 materials were used as the dielectric layers. Through-hole vias connected the embedded resistors to surface test points. Nickel-phosphorous (NiP) resistive material of 10, 25 and 50 ohm per square sheet resistivities on 17 micron copper was tested.

Circuit arrays, 50 mm x 50 mm in size, were designed with resistors of varying widths (50, 75, 100 and 125 microns), and varying lengths ratios of 2, 3, 4 and 6 squares. In addition, the spaces between resistors were designed to be the same width as the resistor s (e.g. 50 micron lines and 50 micron spaces). The resistors in each array were tied to a common ground for ease of testing (Fig 3). The test vehicle was 300mm x 450mm in size and consisted of six arrays of each line width, 24-up total (Fig 4).

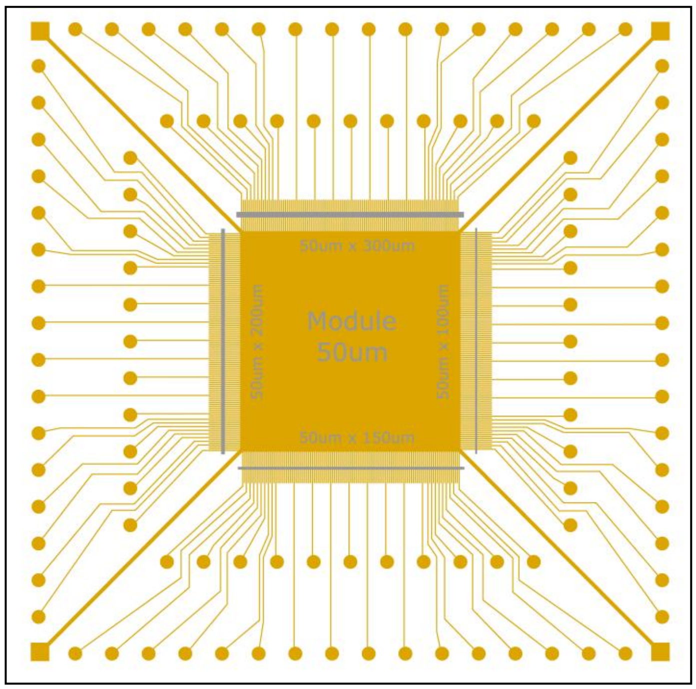

Figure 3 - test array design

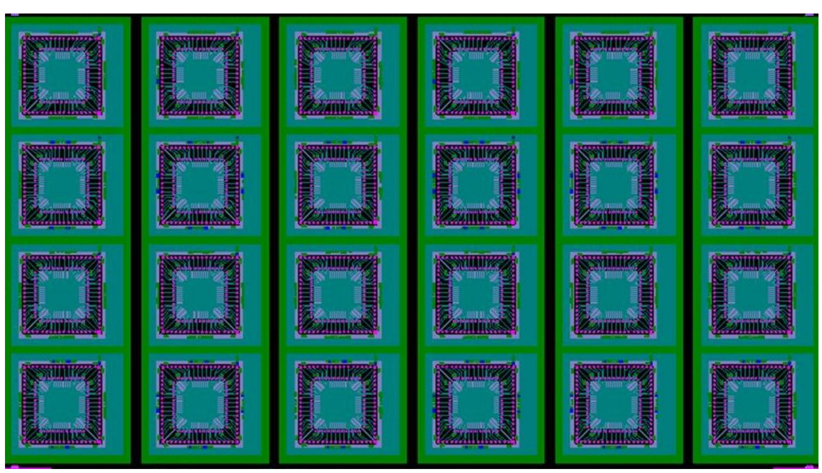

Figure 4 - test artwork layout

Processing of the Test Vehicle

A commercial board shop with experience processing the NiP resistive material was selected for building the test boards. LDI (laser direct imaging) was used for both the primary and secondary print operations. LDI has the advantage of greater precision, straight sidewalls and near perfect registration for the second imaging that defines the resistor length. This means that the overlap of the photoresist defined window over the resistor element needed for the second print and etch operation can be smaller and this becomes critical when working with lines and spaces of 150 microns or less using conventional print and etch processes.

Another key aspect of the processing was the use of a unique NiP differential etch technology. As line widths become narrower, the effect of undercut on the circuit becomes more pronounced, resulting in more line variation and wider tolerances. Line edges that are over etched become ragged or uneven. This contributes to wider tolerances and degrades electrical performance in high frequency applications. When micro trace resistors of 100 microns or less are etched in the primary copper etchant, whether acid or alkaline, the dwell time is especially critical because the narrower the resistor element, the greater the variation in width has on the ohmic value of the resistor.

After primary copper etching, the exposed NiP layer has to be stripped to limit the resistive layer to the boundaries of the etched copper features. The NiP differential etch is a selective copper sulfate solution that will strip the exposed resistive material without etching the copper features. In addition, it is a self-limiting bath that ceases to work after all of the exposed NiP resistive material is stripped away. It will not undercut copper to etch any underlying NiP resistive material. The importance of the congruence of the resistive trace to the copper trace is that as the resistor widths become narrower, the width variation has a greater effect on the resulting percent tolerance in ohmic values. After the differential strip, the use of LDI for the second print enables precision copper etching and tight tolerance miniature resistor elements.

After the final print and etch operation, conventional PCB processes were used to complete the board. The resistors were dimensionally measured to determine actual line widths and lengths (Fig 5) and electrically tested. The layers were then oxide treated and the completed multilayer circuit board produced (Fig 6).

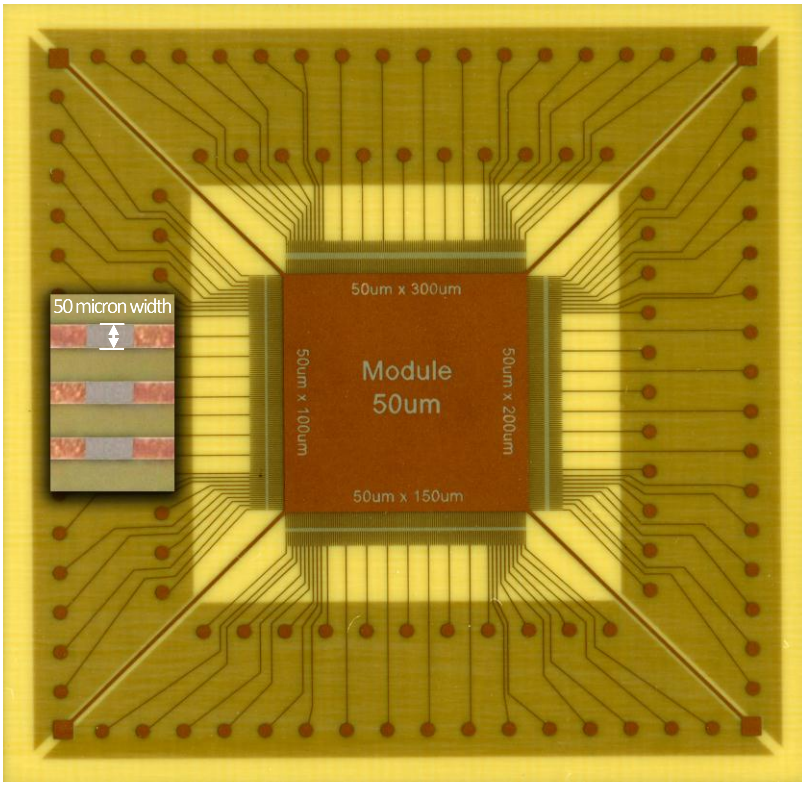

Figure 5 - inner layer

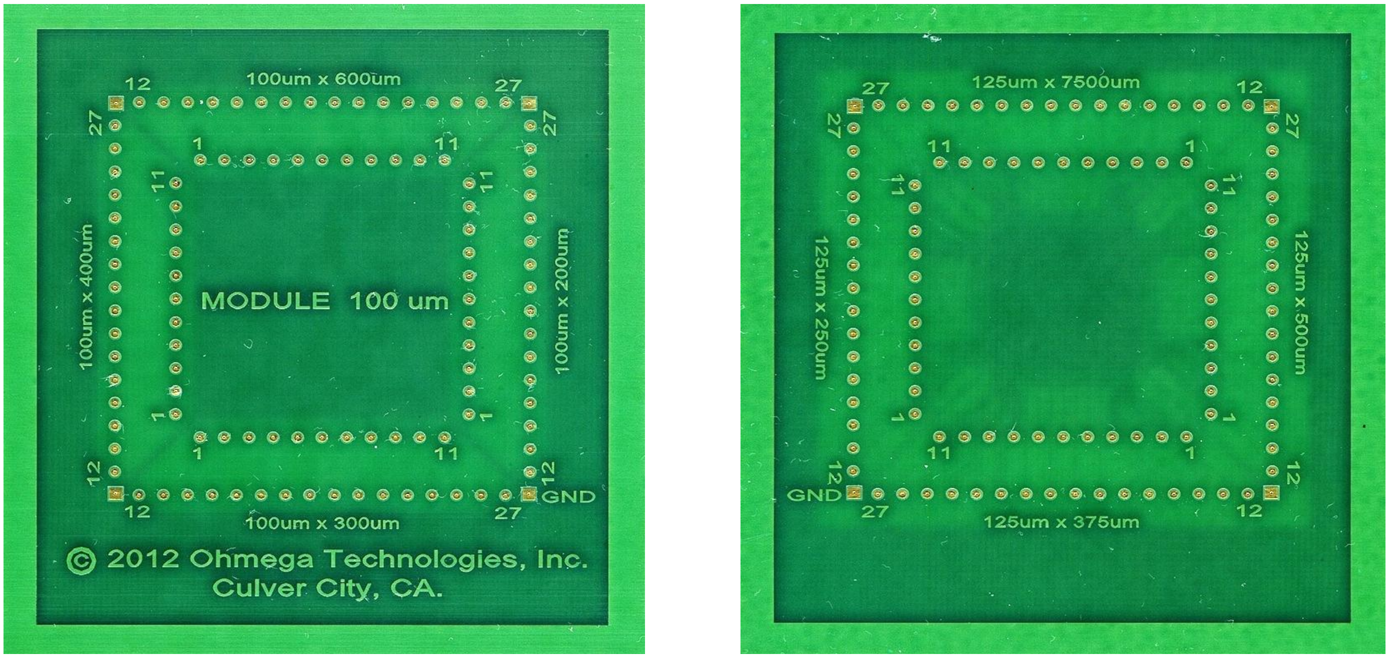

Figure 6 - multilayer board

Measurements of the resistor values were conducted and are summarized in Table 1.

Table 1 - Resistor size versus tolerance

Resistivity	Resistor Width	TWO SQUARES		FOUR SQUARES		SIX SQUARES	
		Resistance (Ohm)	Tolerance (%)	Resistance (Ohm)	Tolerance (%)	Resistance (Ohm)	Tolerance (%)
10 ohm/sq.	50 Micron	20	40	40	40	60	40
	75 Micron	20	25	40	25	60	25
	100 Micron	20	15	40	15	60	15
	125 Micron	20	15	40	15	60	15
25 ohm/sq.	50 Micron	50	40	100	30	150	25
	75 Micron	50	20	100	20	150	15
	100 Micron	50	15	100	15	150	15
	125 Micron	50	15	100	15	150	15
50 ohm/sq.	50 Micron	100	25	200	25	300	25
	75 Micron	100	20	200	15	300	15
	100 Micron	100	10	200	10	300	10
	125 Micron	100	10	200	10	300	10

Test Results

Analysis of the tolerance data showed an unexpected result. Typically, the tolerance of NiP embedded resistors improves as the sheet resistivity decreases. The sheet resistivity of the NiP resistive alloy is a function of film thickness—the thicker the film, the lower the sheet resistivity.

For example, with the same copper profile on the same substrate:

25 ohm/square is about 0.4 microns thick.
50 ohm/square is about 0.2 microns thick.

Typically, the thicker the plate, the tighter the tolerance of the resistive film and the resulting etched resistive element. For the micro trace resistors, the 50 ohm per square sheet resistivity product had a significantly better tolerance than either the 25 ohm per square or 10 ohm per square product.

For instance, the 75 micron wide by 300 micron long (4 square) resistive element using a ten ohm per square product had a tolerance of +/-25% while the corresponding twenty-five ohm per square product had a tolerance of +/-20% and the fifty ohm per square product had a tolerance of +/-15%.

This data was not only unexpected but counter to well established tolerances for larger area resistors. In order to eliminate the possibility of an anomaly in the sample preparation, new samples were prepared and the test repeated at another board shop with the same results. The “reversal” of the expected percent tolerances in ohms versus sheet resistivity in ohms per square indicated that the smaller resistors are more sensitive to variation in etching and in the effects of the chemical processes used in the PCB manufacturing process procedures.

Furthermore, even the thicker lower-Ohmic nickel-phosphorous layers required improved chemical resistivity. Subsequent research and development resulted in an enhanced version of the basic NiP resistive material. This enhanced version, with greater processing stability and tighter tolerances for micro trace resistors is now “patent pending,” and commercially available as OhmegaPly® MTR™ in standard sheet resistivities.

The power dissipation of embedded resistors is a function of layer thickness; the thicker the resistive film, the greater the power dissipation of the resistive element, and the area of the resistor, so that for a given material, the greater the area, the more the power that can be applied. Table 2 summarizes the power rating of the resistive elements and the results are in line with expectations. Further, the data suggests that NiP micro trace resistors of very small areas can handle a surprising amount of power, well above the requirements normally associated with termination and pull-up/down applications.

Table 2 - Resistor size versus power

Resistivity	Resistor Width	TWO SQUARES		FOUR SQUARES		SIX SQUARES	
		Resistance (Ohm)	Power rating (mW)	Resistance (Ohm)	Power rating (mW)	Resistance (Ohm)	Power rating (mW)
10 ohm/sq.	**50 Micron**	20	60	40	90	60	110
	75 Micron	20	110	40	140	60	155
	100 Micron	20	125	40	180	60	180
	125 Micron	20	150	40	215	60	300
25 ohm/sq.	**50 Micron**	50	40	100	50	150	55
	75 Micron	50	60	100	80	150	80
	100 Micron	50	70	100	100	150	125
	125 Micron	50	90	100	125	150	165
50 ohm/sq.	**50 Micron**	100	30	200	45	300	55
	75 Micron	100	45	200	65	300	80
	100 Micron	100	60	200	85	300	115
	125 Micron	100	80	200	100	300	120

Micro-thin Copper Base Foil

It was noted that the declining percent tolerance between 10 and 25 ohm per square material only appeared at the narrow widths, 50 to 75microns. At 100 and 125 micron widths there was minimal difference regardless of the geometry of the resistive elements. We interpreted this finding to be the result of variations in undercut of the 17 micron copper at the first etch becoming greater as the widths diminished. Normal artwork compensation may not be sufficient for micro trace resistors. One method of tolerance improvement is the use of thinner copper foil. A five micron thick copper on a seventeen micron peelable copper carrier was successfully produced with the enhanced micro trace resistive alloy and is now under final test.

Conclusions

The results of the micro trace resistor test vehicle showed that resistors with line widths less than 100 microns can be successfully built with good tolerances and acceptable power ratings. The production of such resistors was enabled by the convergence of specialized manufacturing technologies of Laser Direct Imaging and NiP differential etching. The resulting test data provided insight into the mechanisms that yielded better tolerances in the micro trace resistors across a range of sheet resistivities. This insight subsequently directed the research and development of an improved NiP resistive alloy with greater processing stability and tighter tolerances for micro trace resistors.

Acknowledgements

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