Thick Film Polymer Resistors
Embedded in Printed Circuit Boards

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Abstract

The high level of current interest in embedded passives in printed circuit boards is driven by the tremendous pressure to pack more circuitry into smaller spaces. However, adoption has been limited due to design, prototyping and infrastructure issues, as well as the stability and tolerances necessary for widespread replacement of discretes. The focus of this work has been to develop a polymer thick film resistor technology to incorporate reliable organic resistors inside printed wiring boards using standard PWB processing. The resistor materials are based on a novel hydrophobic polyimide resin developed specifically to serve as a polymeric thick film resistor material. Sheet resistivities range from 10 ohms/square to 1K ohms/square, with TCR's of 0± 200 ppm/ ^{o}C. The compositions are printed on an etched copper inner layer and cured in a standard convection oven, infra-red furnace, or a thermal belt furnace. Laser trimming can be processed at this time to achieve tight tolerances. Copper terminations without silver plating and standard ceramic thick film laser trimming speeds can be used with these materials, thereby providing options not previously available. This is followed by lamination of the remaining board layers. The result is copper circuitry with resistive components inside a multilayer PWB. This paper describes the process, presents the performance, and discusses preliminary design guidelines for polymer resistor materials with the embedded passive technology.

Introduction

Present-day trends toward increased device functionality translate to dramatic increases in the number of electronic components that must be strategically integrated. This is especially true for passive elements, which account for a large percentage of the component count in wireless and mobile systems. As device operating speed and complexity increase, the enabling technologies that deliver required performance such as low impedance, low cross-talk, and minimal parasitic inductance in a cost- and size-effective manner will be the packaging strategies of choice. For many reasons, the ultimate answer may lie in eliminating the passive components from the surface of the circuit by embedding them within the inner layers of the printed wiring board.

The use of embedded passives significantly increases the maximum achievable active component density for a given package. The ability to locate termination resistors within the array of a pin grid array (PGA) or ball grid array (BGA), for example, improves performance and provides greater design flexibility. Additionally, embedded passives improve wireability due to the elimination of vias, resulting in the potential elimination of one or more layers of the board. In addition to favorable economic consequences, embedded passives have significant performance advantages.

In order to be successful with the embedded resistor technology, the materials used must meet the standard surface mount resistor requirements, as well as be a cost effective process. Table 1 list the key product attributes that the embedded resistor materials are being developed against. It is important to note that the polymer resistor materials tested for this report meet the RoHS July 2006 lead free requirement.

Table 1 Material Requirements

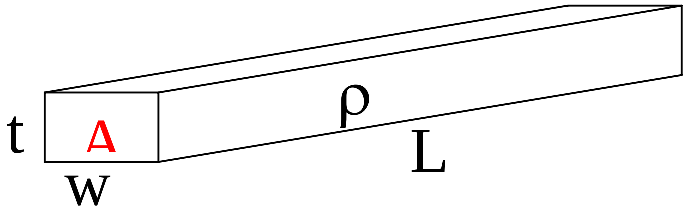
Customer Requirement	Key Product Attributes
EP technology that is compatible with existing circuit manufacturing infrastructure including rigid and flex processes	Screen printable formulations Fully consolidated at 175°C Broad printing process latitude Stability during board assembly
High performance PTF resistor	Target resistance 10 ohm – 1 Mohm Blendable compositions 20% Print Tolerance Trimmable to <1% Temperature coefficient resistance Short term overload Power handling ESD stability Initial adhesion
Reliable performance of completed circuit	Drop test Thermal cycling Thermal shock Aged adhesion (HAST) 85°C/85% RH performance Mechanical shock
Environmentally friendly	Composition restrictions Halogen and lead free

We have worked to develop a new series of resistor composition, Interra™ polymer resistor, to meet the needs of embedded resistors for the high density multilayer PWB market. These thick film polymer resistor materials provide the thermal, electrical, and reliability performance needed fro embedded resistors. This paper describes the resistor design, processing, and performance of these compositions.

Designing

The overall performance of polymer resistor materials is related to the optimized circuit design and fabrication process. The materials and process parameters of polymer resistors must be taken into account in order to successfully achieve the performance requirements of circuit designs. For example, the decision on what aspect ratio to use for a particular resistor depends on a number of factors. These include target resistance values, electrical considerations, available paste resistivity values, trimming requirements, and the distribution of resistances of all the resistors present on the same layer of the board. As shown in Fig. 1, the resistance of a linear resistor is written as:

$R= \rho \times L/A = (\rho/t) \times (L/w) = R_s (L/W).$



$\rho \equiv$ resistivity,
L: trace length
w: line width

$R_s \equiv$ sheet resistance in Ω/sq
A: cross section area
t: thickness

Figure 1 The geometry of a resitor

The resistance value can be designed based on the equation of R= $R_s \times$ N, where N is the number of squares, or aspect ratio[1]. Using these standard resistor thick film equations, along with actual resistor linearity and blend curves, the designer will be able to calculate and design a variety of options for a given desired value. This variety of solutions to the same problem makes designing thick-film resistors embedded into printed circuit boards more complex, but more versatile than the selection of surface mounted passive components. As shown in figure 2, the linearity of the polymer resistors is very good and repeatable. The linearity of these materials will be helpful when designing for particular resistance values.

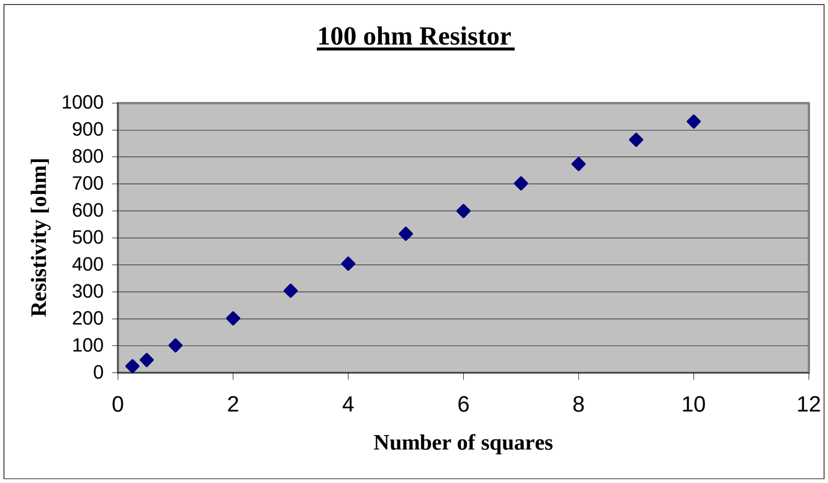


Figure 2 Linearity of 100 ohm polymer resistor

Processing

Embedding polymer resistors inside printed circuit boards can be achieved using standard processing equipment. Most PWB shops are already equipped with screen printers and curing ovens or furnaces which are necessary for the processing of polymer thick film resistors. To achieve tight tolerances on the order of <2%, a laser trimming system will be required.

These polymer resistor inks can be screen printed directly on the etched copper terminations. ½ oz. copper thickness is recommended for the best print resolution. For adhesion purposes, the copper surface should be free of oils, or other surface contaminations and minimal surface oxide. Anything that interferes with the interface of the copper and resistor may also cause unexpected resistance values. A standard micro etch process that cleans the copper surface is sufficient to promote good adhesion and prevent any negative effects on resistance. Because the polymer resistor can maintain good resistance stability, it can be printed directly onto the copper terminations; immersion silver treatment on the termination pads is not required.

Once the surface cleaning is complete, the screen printing and curing process can be performed. Using a standard screen printer with a vision system for registration purposes, the polymer resistor is applied to a cured thickness of 15 to 20 microns. The rheology of the paste enables good paste transfer, which leaves a resistor print with consistent, straight side walls. This characteristic, along with good thickness control, makes a 20 percent as printed tolerance achievable. This is accomplished using standard stainless steel mesh screens with a backside emulsion buildup versus a metal stencil.

Curing the polymer resistor can be carried out in a box oven, an IR furnace, or a conventional belt furnace. Figure 3 steps through a typical box oven profile, which is a two step temperature profile recommended for optimum resistor stabilities. The matrix will cross-link at 170°C but a heat bump is recommended for optimal performance. Infrared curing furnaces will enable faster cure cycles[2].

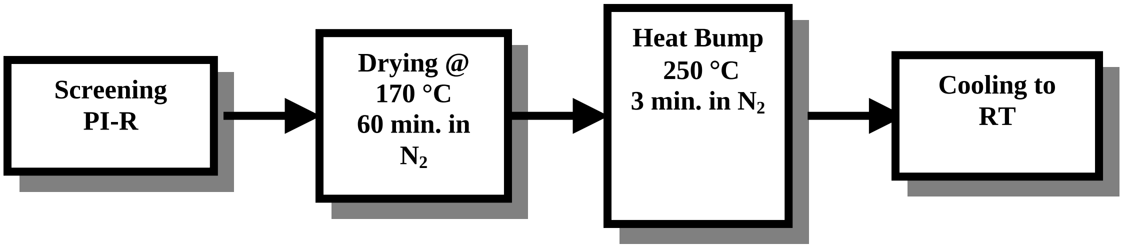
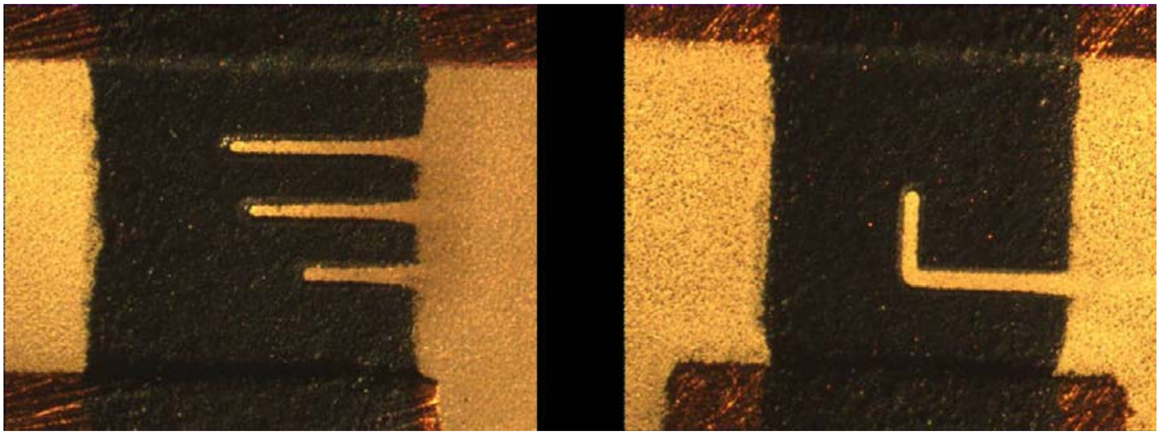


Figure 3 PI-R Oven Curing

After the curing process is complete, the panel is ready for subsequent processing. Prior to the next lamination step, laser trimming can be performed if tight tolerances are required. With hot and cold TCR's (temperature coefficient of resistance) within 0+/-200 ppm, laser trimming speeds more associated with ceramic thick film resistors can be used. A standard L cut or double and triple plunge cuts are used to trim these resistors to a <1 percent tolerance. Figure 4 shows the 10 and 1000 ohm resistors with clean laser trim kerfs. The power setting, Q rate, and byte size must be adjusted to give clean cuts without damaging the FR4 substrate. While different settings may be required for various laser trimming equipment, the parameters are easily obtained with minimal test runs.



10 Ohm with triple plunge laser trim

1000 Ohm with standard L-cut

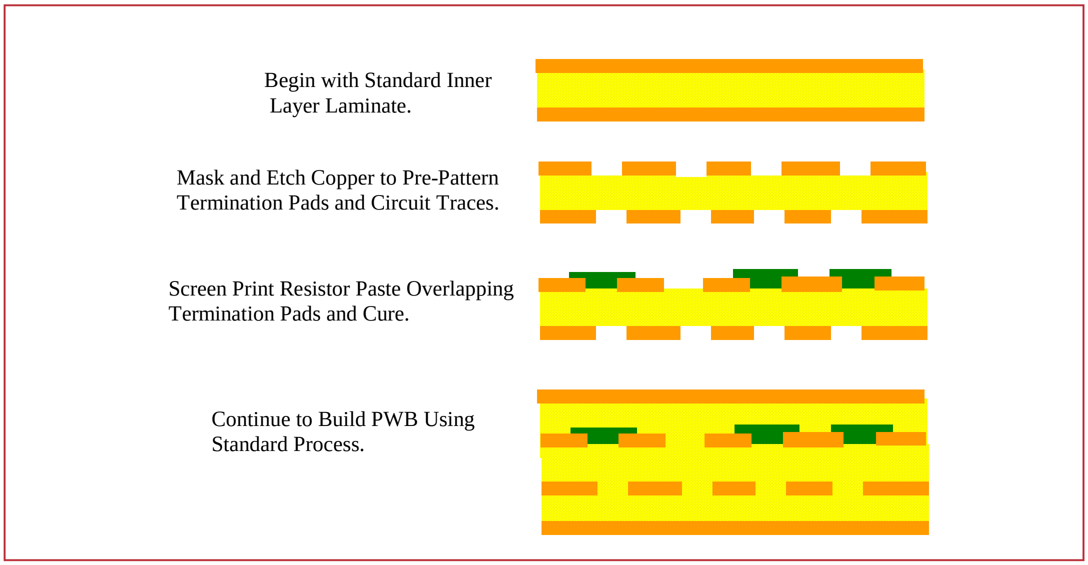
Figure 4 Laser Trim

The trimmed resistors are now ready to be embedded into the PWB. Oxide alternatives can be used to promote adhesion without adverse effects to the resistor material. If standard black oxide is to be applied, it is recommended that the resistors be encapsulated after trimming but prior to the black oxide treatment. Typical lamination pressures up to 500 psi can be used to laminate the inner layer containing the resistors to the remaining board layers. The panel continues through any other required PWB process steps as normal to create the finished product.

Alternative Processing

For process and performance improvements, a reverse lamination process can be used. Rather than screen printing on an etched inner layer as described earlier, the resistor ink would be printed onto 1 oz. copper foil. The cured foil is then laminated component side down to single sided FR4, using FR4 prepreg. The standard print, expose, develop, etch, and strip process is carried out to create the resistor terminations[3].

There are several benefits to this reverse lamination process: printing on a flat surface (foil versus etched inner layer) gives better print quality, which produces tighter CV's; more aggressive cure schedules can be used, which promotes better stability after subsequent heat excursions; and adhesion is improved by printing on treated side of foil, which gives better electrical contact giving better performance and reliability. Figures 5 and 6 compare the process steps for the traditional and reverse lamination processes.



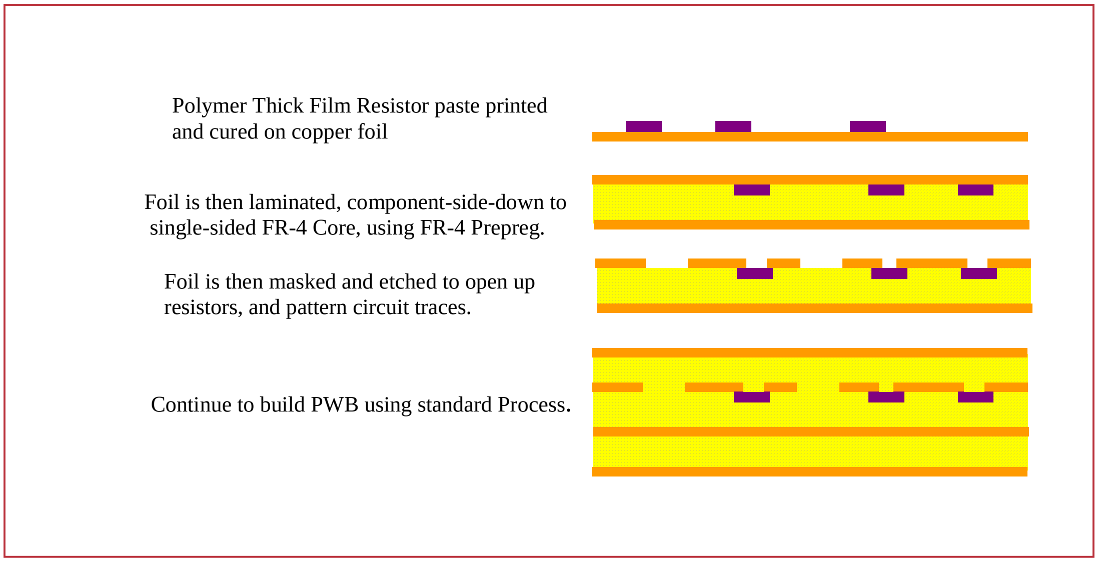
Begin with Standard Inner Layer Laminate.

Mask and Etch Copper to Pre-Pattern Termination Pads and Circuit Traces.

Screen Print Resistor Paste Overlapping Termination Pads and Cure.

Continue to Build PWB Using Standard Process.

Figure 5 Traditional Lamination Process



Polymer Thick Film Resistor paste printed and cured on copper foil

Foil is then laminated, component-side-down to single-sided FR-4 Core, using FR-4 Prepreg.

Foil is then masked and etched to open up resistors, and pattern circuit traces.

Continue to build PWB using standard Process.

Figure 6 Reverse Lamination Process

Performance

Once successfully embedded into the PWB, the polymer resistors show good reliability performance under various test protocol. As stated previously in Table 1, the embedded resistors must withstand many environmental and mechanical stresses. Table 2 summarizes a few of the environmental tests passed to date. Good results have been obtained on resistor sizes ranging from 0.25 to 10 squares (20 to 100 mils in length and 20 to 80 mils in width). Printing parameters are being developed to optimize printing of smaller resistors.

Table 3 shows the typical electrical properties obtained with the various paste values. The paste is formulated to meet a +/- 10% resitivity specification. The TCR values are also maintained to within +/-200ppm/ ^{o}C so that laser trimming parameters can be predicted.

Table 2 Reliability Summary

Ω/Sq.	R (Ω)	ESD Goal <1%	Δ R Lam % Goal < 5%	85/85 Goal < 5%	TCT Goal < 5%
10	10.1	0%	4.10%	3.70%	-1.10%
100	103	-0.10%	1.80%	2.20%	-0.46%
1000	729	-0.30%	0.18%	2.60%	-1.20%

Table 3 Electrical Properties

Property	Unit	Paste		
		10 ohm	100 ohm	1000 ohm
Resistance	ohm	10.1	103	929
HTCR (25 To 125^{o}C)	ppm/^{o}C	182	153	51
CTCR (-55 to 25^{o}C)	ppm/^{o}C	16	-52	-126
Noise	dB	-10	-6.1	-1.3

Conclusion

This polymer resistor technology is a new material that will improve the process of embedding resistors by eliminating the need for special termination treatment, such as immersion silver; speed up the laser trim process with tighter TCR's; and increase the reliability performance with a stable binder system.

The ohm values currently available for testing show good adhesion to a clean copper surface. This eliminates the need for silver immersion, which presents a cost savings as well as reduces concerns of silver migration. Up to two times the standard polymer laser trimming speeds have proven successful. Thus far, environmental and mechanical testing has also been successful. Continuing to test and formulate higher resistivity values will prove these compositions have a future in the embedded passives market.

Acknowledgements

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