Trimming and Printing of Embedded Resistors Using Demand-Mode Ink-Jet Technology and Conductive Polymer

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Abstract
This paper presents a method both to enhance the yield of embedded resistor processes and to print embedded resistors using drop-on-demand ink-jet device capable of dispensing a precise volume of intrinsically conductive polymers (ICPs) onto plated or screen printed resistors. By controlling the volume of ICPs, and in tum its thickness, the resistance per square can be controlled and brought to the PWB industry tolerance. This method can be used as complementary to laser trimming method to enhance the overall yield of embedded passives processes.

Introduction

As automation, miniaturization, and overall system costs become critical in manufacturing of embedded passives, ink-jet printing methods are becoming increasingly attractive material micro-dispensing alternatives. The advantages provided by the ink-jet printing include precise control of dispensed volume and data driven, *in situ* processing.[1] Ink-jet being an additive and data driven process can be easily set up and modified for different embedded resistor form factors.

Two broad approaches are typically utilized for ink-jet printing of materials for manufacturing applications. In "Continuous, Charge and Deflect" ink-jet printing technology,[2] illustrated in Figure 1, fluid under pressure issues from an orifice, typically 50-60 µm in diameter, and breaks up into uniform drops by the amplification of capillary waves induced onto the jet, usually by an electromechanical device. The drops are electrically charged and deflected by the charging and the deflection field respectively, to their desired location, either the catcher or one of the several locations on the moving substrate.

This approach is suitable for high-speed coverage of relatively large areas since drops up to 0.5mm in diameter may be generated at rates up to 1 MHz.

A more widely used and simpler approach for smaller drop (20-100 µm), lower frequency (up to 20KHz) printing applications is the "Drop-on-Demand" (DOD) technology[3] shown in Figure 2.

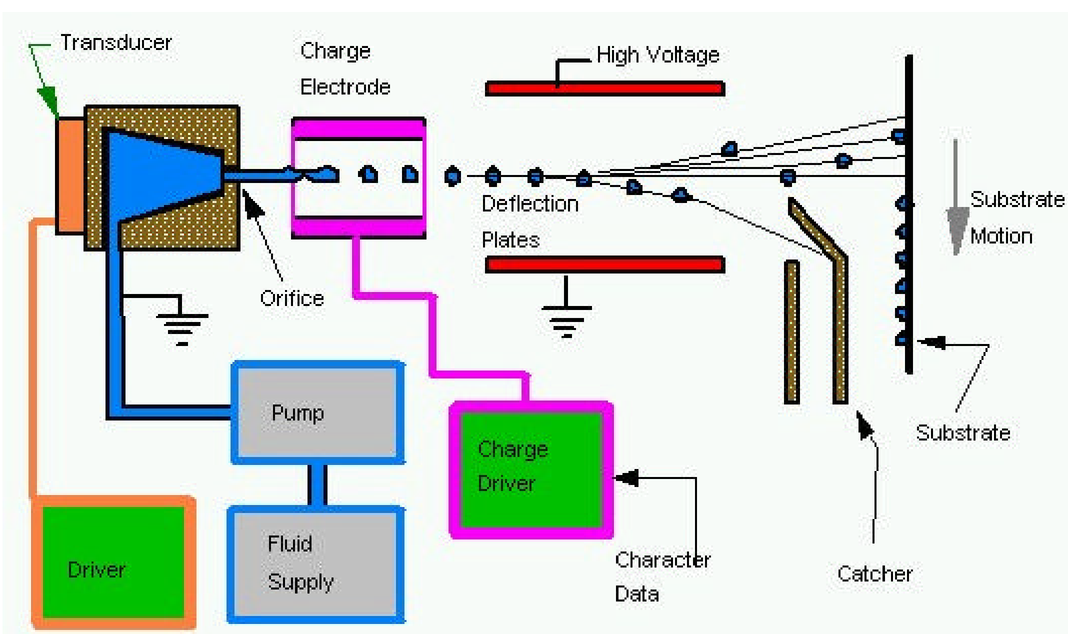

Figure 1 - Continuous, Charge and Deflect Ink-Jet System

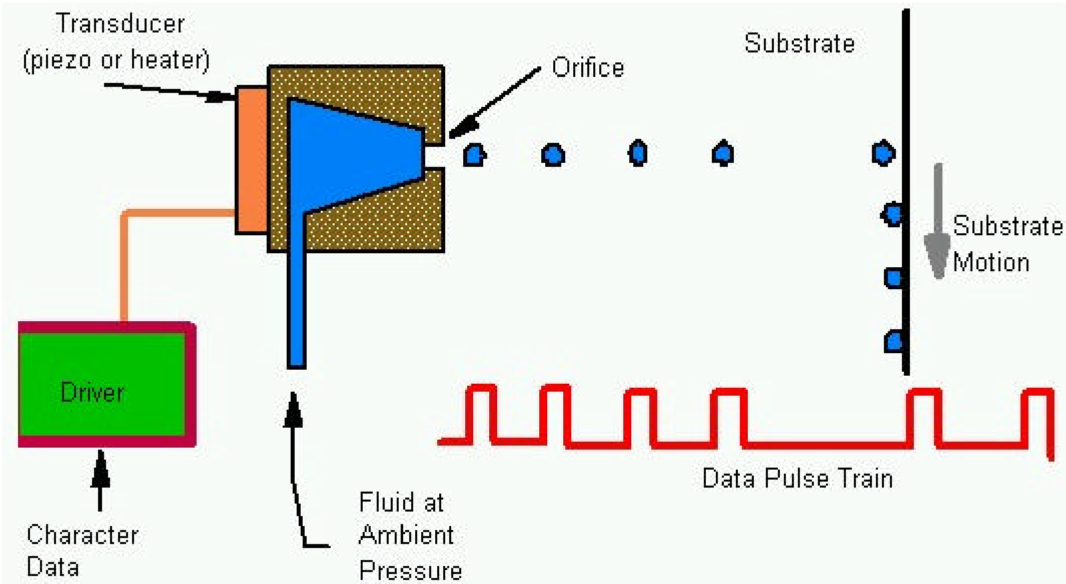

Figure 2 - Drop-on-Demand Ink-Jet Printing System

In DOD, a drop is only ejected from the device orifice when a voltage pulse is applied to a transducer. Since the fluid at ambient pressure in the device is coupled to the transducer, the acoustic waves generated by application of an electrical pulse eject a drop from the device orifice. The DOD device produces drops that are approximately equal to the orifice diameter of the drop generator.

Figure 3 shows a single jet glass device generating drop-on-demand at a rate of 2000 drops per second.

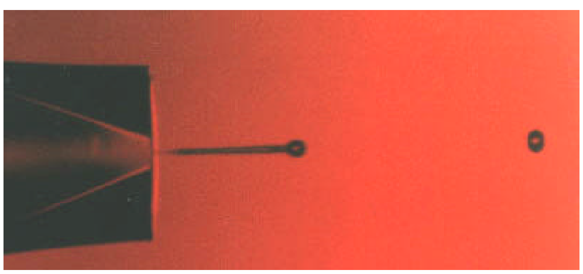
Figure 3 - 50-mm Drops of Issued from DOD Ink-Jet Device at 2 kHz

The photograph of drops shown in Figure 3 was made by illuminating the drops with an LED that was pulsed at the drop generation frequency. The camera exposure time was ~1 second, so that image represent thousands of events superimposed on each other. All the drops must be in the same position at the same time or the image would be fuzzy. This also illustrates the accuracy and repeatability of the drop-generating device.

Print Head and Jetting Platform

Two basic styles of print heads were used to print, and to trim Ni/P embedded resistors. Figure 4 and Figure 5 show those styles of piezoelectric jetting devices.

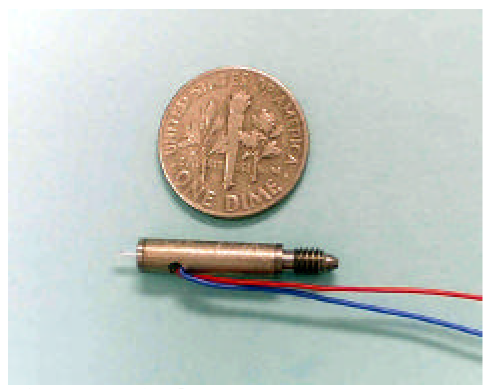
Figure 4 - Single-Jet, Room-Temperature Printhead


Figure 5 - Single-Jet, High-Temp Printhead (6-mm Diameter)

The jetting platform used to print and trim PWB panels is shown in Figure 6. Printed areas of 15 x 15 cm can be addressed at accuracies of 3-10µm and at rate up to 20 kHz onto a temperature-controlled platen. The system is enclosed to allow for environmental control. Vision capabilities include substrate/drop alignment, drop-formation setup and printed pattern inspection.

Figure 6 - Jetlab Printing Platform

Figure 7 is a photograph of a 12" x 18" panel mounted on the precision x-y motion system. During the printing operation the optics system next to the printhead is used for alignment.

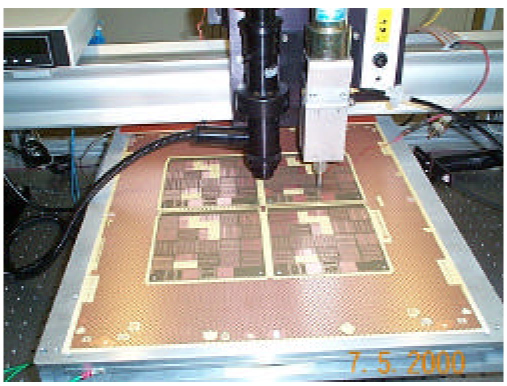

Figure 7 - Embedded Resistor Printing – A Close-Up

Material and Test Vehicle

Proprietary polyimide based conductive ink was used to print 100-ohm/square resistors and, a commercially available ICP was used to trim down Ni/P plated resistors. The test vehicle used for printing resistors has five array of arrays. There are four rows or columns of nine resistors in each array. Typically, the spacing between terminations varies for each row or column and so does the width of copper terminations. The sketch in Figure 8 shows typical configurations of resistors printed.[4]

The trimming of Ni/P plated resistors was performed on a test vehicle with resistor and copper termination sizes as shown in Figure 9.

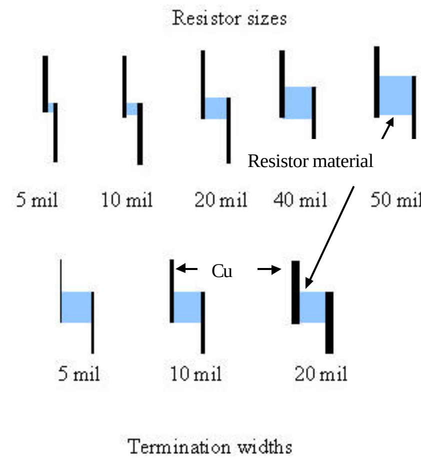

Figure 8 - Embedded Resistor and Copper Termination Sizes

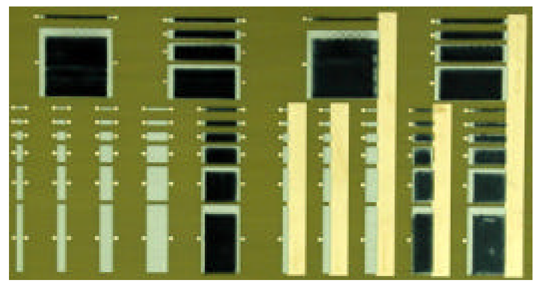

Figure 9 - Ni/P Plated Resistors Trimmed to 30 ohms/Square Using ICP

The resistor sizes trimmed during experiments were 20, 30, 50, 90, 170 and 330 mil long and the resistors trimmed were not square. Again, the reason for designing different sizes and, not using perfect square geometry was to verify the capability, reliability and stability of embedded resistor processes.

Embedded Resistor Printing and Trimming

We have trimmed Ni/P plated embedded resistors to 30 ohms/square nominal from 50 ohms/square nominal using ICP as exemplified in Table 1.

Table 1 Ni/P Plated Resistors Trimmed on an Average 32% (N=8 for each size) Using Intrinsically Conductive Polymer

	BEFORE TRIM		AFTER TRIM		
Resistor	Resistance	Ohm/sq	Resistance	Ohm/sq	**Change**
Size	Ohm		Ohm		**%**
320X90	24.0	45.2	17.2	32.4	**-28.3**
160X90	46.8	44.0	32.7	30.8	**-30.1**
80X90	98.1	46.2	65.1	30.6	**-33.6**
40X90	207.3	48.8	133.6	31.4	**-35.6**
20X90	534.0	62.8	359.0	42.2	**-32.8**

Also, we have demonstrated printing resistors as low as 100 ohms/square using proprietary polyimide-based inks as illustrated in Figure 10.

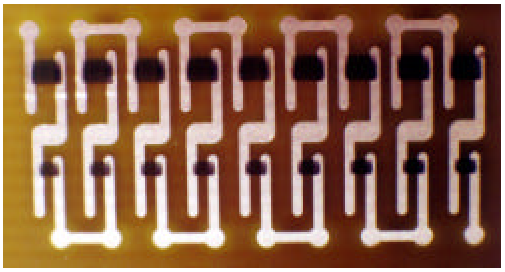

Figure 10 - 100-ohms/Square Resistors Printed on a PWB Board Using DOD Ink-Jet Device

The Figure 11 shows a cross-section of a plated resistor trimmed down using DOD ink jet device (as shown in Figure 4 and 5) and, ICP.

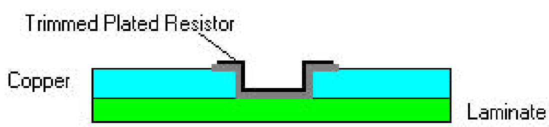

Figure 11 - Cross-Section of Ink Jet Trimmed Plated Resistor

Ink Jet Trimming Cost Model

Laser trimming (to increase the resistance) can be performed on embedded resistors fabricated with nominal value less than the application target value. But if the nominal value of embedded resistors is higher than application high spec limit ink-jet printing of a conductive "ink" to trim down (i.e., decrease the resistance of) embedded resistors is an attractive solution as illustrated in Figure 12 below.

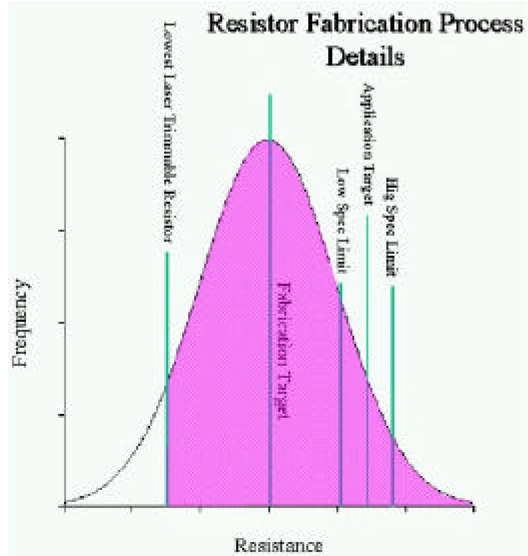

Figure 12 - An Example of a Typical Embedded Resistor Process for PWB

The alternative is to consider scrapping the whole board or even the panel. It is more economical, in most cases, to trim the resistors than to scrap a board or a panel as illustrated by an example in Figure 13.[5] For processes with a standard deviation greater than about 6% of application target, laser trimming and rework using ICP and ink jet device is more economical than scrapping the board. The example assumes design tolerance of 5%.

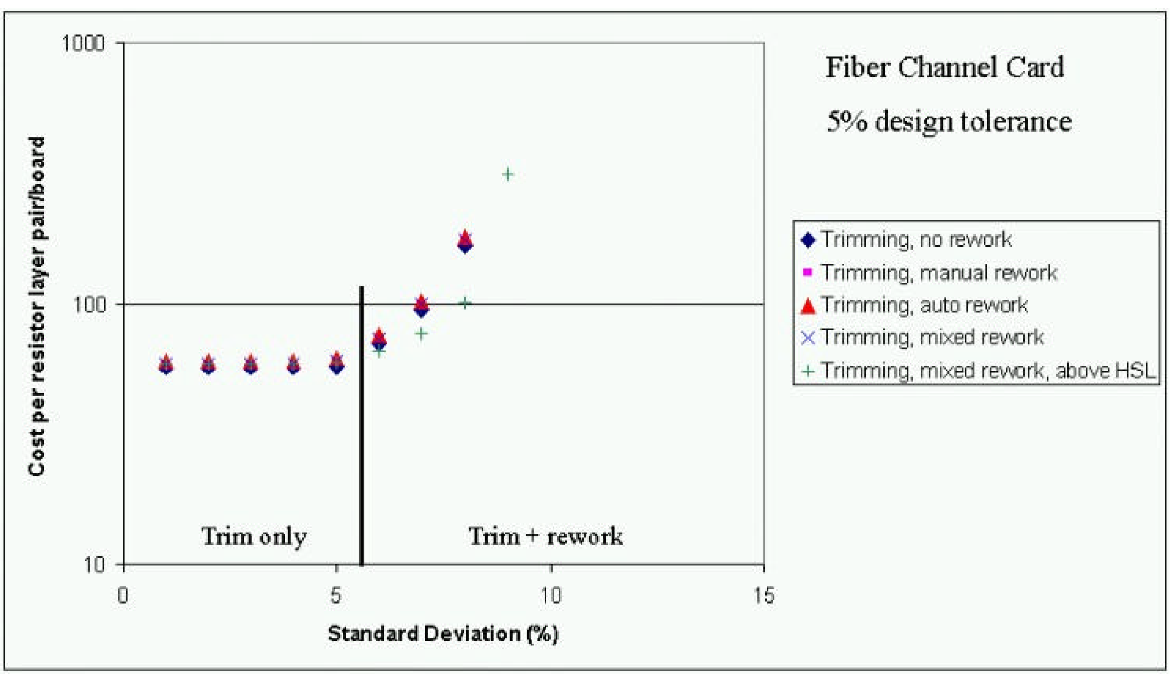

Figure 13 - An Example Where Rework Using Ink-Jet Printing of Conductive Polymer could be Economical

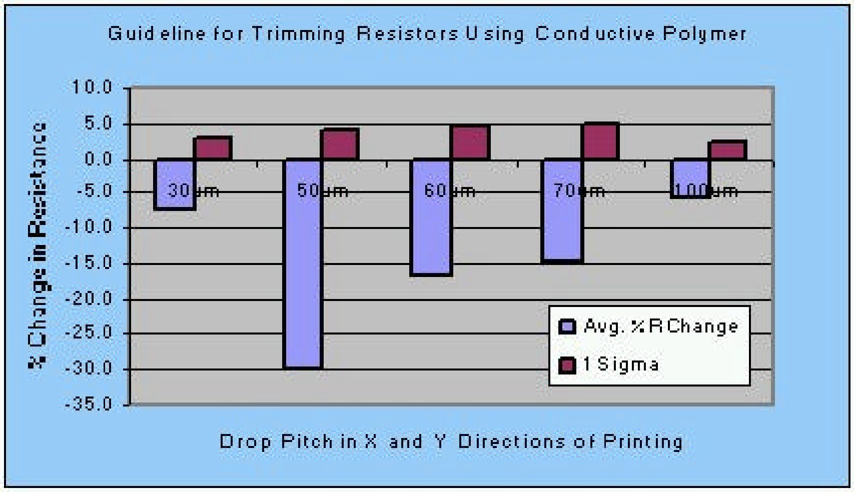

Figure 14 - Guideline for Resistance Reduction by Varying Drop Pitch in X and Y Direction of Printing

Results

Before trimming resistors down, all the resistors on each board of a 4up panel were measured using Fluke 70 III digital multimeter. Ni/P plated resistors were then trimmed down by printing a pre-programmed pattern using a digital file created in csv or txt format.

One of salient features of the DOD ink-jet printing technology is its ability to create practically, any shape or pattern using digital input that can be readily modified as needed.

As a result of numerous experiments conducted over time using ICP, we came up with a printing guideline for trimming Ni/P plated resistors down. The Figure 14 above shows the trimming guideline.

We have demonstrated trimming (i.e., reduce the resistance) of plated resistors in the range of 5-30%, to-date, from their original plated values as shown in Figure 14. By varying the drop pitch in x and y directions of printing and the number of drops per location the amount of conductive material being deposited can be controlled and hence the thickness of the conductive layer formed.

Conclusion

Although notable progress has been made in the development of new materials and improvements in the area of embedded resistors for PWB, the processes still have high enough variation to move them from a niche market to a wide spread use in the PWB industry. Ink-jet printing of conductive material to repair out-of-spec resistors in upper tail of the normal distribution and to repair laser over-trimming (see Figure 12 and Figure13) is cost effective. And it holds the promise of moving embedded passive technology from a niche market to mass production. The successful demonstration of trimming (i.e., reduce the resistance) of plated resistors in the range of 5-30%, to-date, from their nominal plated values testifies to that promise.

Acknowledgement

The authors wish to acknowledge all the 14 members of the NCMS/Advanced Embedded Passives Technology (AEPT) Consortium under support of the U.S. Department of Commerce, National Institute of Standards and Technology, Advanced Technology Program, Cooperative Agreement Number 70NANB8H4025. Details are at http://aept.ncms.org/

Special appreciation goes to MacDermid for supplying the Ni/P plated panels, Merix for building trimmed panels into boards and University of Maryland/CALCE for building the cost model for the technique outlined in this paper.

References

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