Fabrication of Passive Elements using Ink-Jet Technology

by
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Abstract

A novel process has been developed to print passive elements like resistors, capacitors and inductors using demand mode ink-jet technology. The process involves printing intrinsically conductive polymer, thermosetting resin system loaded with conductive particles, ferrite-powders in thermosetting resin matrix, or liquid metals using drop-on-demand printheads and a precision printing platform. The same printing technique can also be used to enhance the yield of current embedded resistor processes by trimming resistor down (reduce the resistance) using intrinsically conductive polymer.

Introduction

MicroJet technology is an emerging technology developed to meet the needs of next generation electronic and opto-electronic packaging solutions in a data-driven manner. It is based on piezoelectric demand-mode ink jet printing technology that is capable of generating and placing droplets of polymers, solder, organometallic and metal nanoparticle solutions, 25-125µm in diameter, at rates up to 4,000 per second. As performance, real estate and overall system costs become critical in manufacture of printed circuit boards, ink jet printing is becoming an increasingly attractive material deposition method. Ink jet based deposition is a low cost (no tooling required), noncontact, flexible & data driven (no masks or screens are required since the print pattern is created directly from CAD information and stored digitally), and environmentally friendly (it is an additive process with no chemical waste).

Ink Jet Technology

Two broad categories of ink jet printing technologies that are used in manufacturing are demand mode and, continuous, charge and deflect. In demand mode ink jet systems, a volumetric change in the fluid is induced either by the displacement of piezoelectric material that is coupled directly or indirectly to the fluid,[1] or by the formation of a vapor bubble in the ink, caused by the heating a resistive element.[2] The volumetric change causes pressure/velocity transients and these are directed so as to produce a drop that issues from an orifice.[3,4] A drop is created only when it is desired in demand mode printing systems and they generate drops that are approximately equal to the orifice diameter of the droplet generator. Figure 1 shows a single channel MicroJet device, fabricated by MicroFab, generating 50µm diameter drops of ethylene glycol at 2,000 per second.

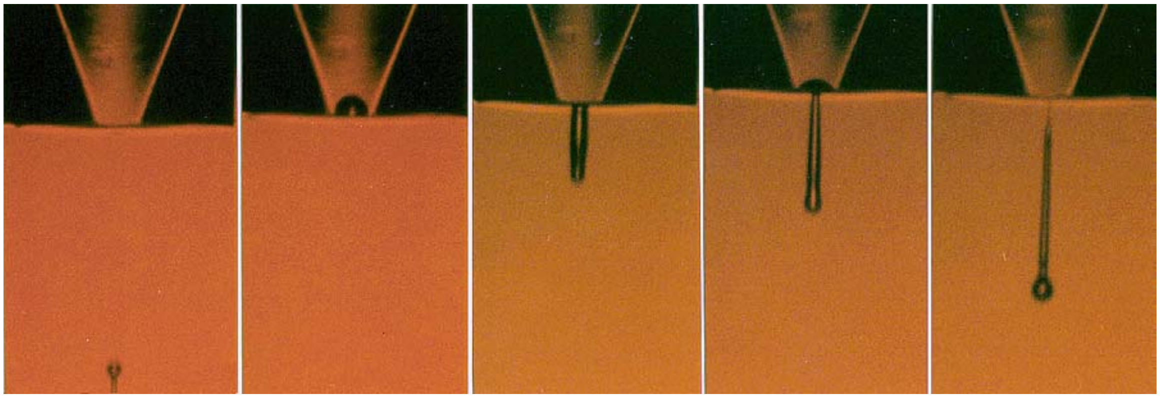

Figure 1 *Demand mode ink-jet glass device generating 50µm diameter drops at 2kHz.*

Demand mode Ink Jet Device

Many device configurations for drop-on-demand (DOD) dispensing have been demonstrated over the past two decades. One of the earliest configurations developed is also one that can be adapted to dispense a wide range of materials. In this configuration, an annular piezoelectric transducer is attached to a glass tube with an integrated orifice, as illustrated in Figure 2. Since glass is the only wetted material, this configuration can be used to dispense practically any material with acceptable fluid properties (<20 cP Newtonian viscosity).

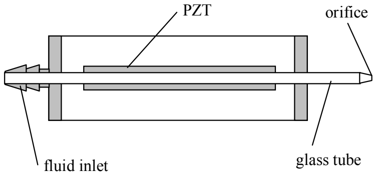

Figure 2 *Single channel drop-on-demand dispensing device configuration*

Figure 3 and Figure 4 show this type of jetting device in a metal housing with fluid fittings. The device in Figure 3 is designed for operation up to 240^{o} C, through the selection of appropriate piezoelectric and adhesive materials. It has operated for several hours at 320^{o} C. The devices in Figure 4 are designed for operation below 100^{o}C.

These types of devices have been used to dispense materials as diverse as aqueous dispersions and solutions, molten solder, polymers, organometallic and metal nanoparticle solutions. They have been used at operating temperature ranging from ambient to 340^{o}C.

Figure 4 *Single channel drop-on-demand dispensing device; $T<240^{o}C$.*

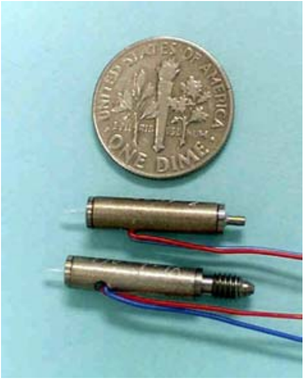

Figure 3*. Single channel drop-on-demand dispensing device; drop-on-demand, dispensing devices; $T<100^{o}C$.*

Multiple devices of the type described above can be mounted into a mechanical assembly to form an array. This type of an array of devices may be used to increase throughput or to dispense multiple fluids, as shown in Figure 5.

Resistor Printing and Trimming

Ink jet printing of embedded resistors has been successfully demonstrated using both filled polymer and conductive polyimide ink as part of an ongoing NIST/ATP project. Figure 7 below shows one of the 4-up 18”x12” embedded resistor test vehicle panel printed using proprietary polyimide ink. Resistors ranging from 100Ω to several MΩ/square have been created using materials with low resistivity. Printed resistors ranged in size from 125µm to several mm long.

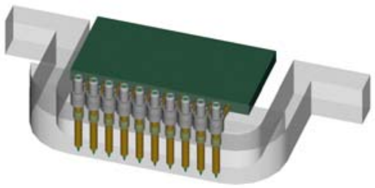

Figure 5 *Ink-jet dispenser array consisting of single channel devices mounted in a fixture.*

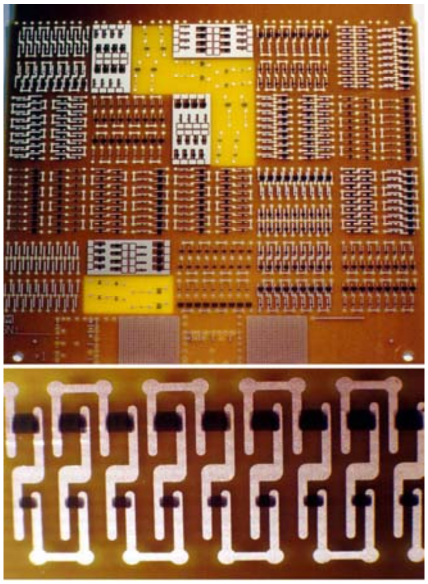

Figure 6 Ink jet printed embedded resistor using conductive polymer*; 100 ohm/sq.*

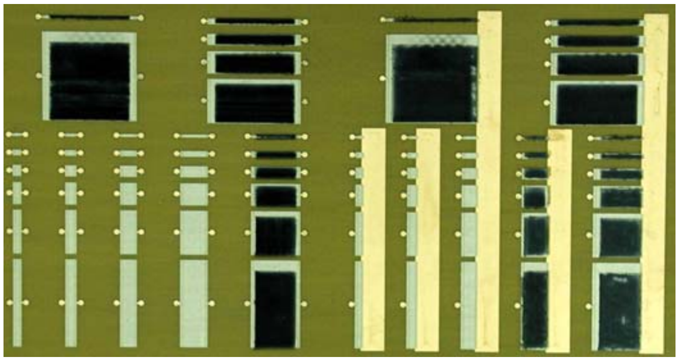

Figure 7 *A portion of inner layer of a multi-layer PWB resistor panel trimmed using DOD ink jet technology.*

A DOD ink jet printing process has developed whereby Ni/P plated resistors are trimmed down by printing conductive polymer onto plated resistors and, subsequently curing the printed polymer at $<200^{o}$C. Figure 7 above shows a section of PWB inner layer panel trimmed down using conductive polymer. Table 1 shows results of trimming Ni/P plated resistors by printing conductive polymer. Notice an average 32% reduction in the resistance for different size resistors.

Table 1 *Ni/P plated resistors trimmed an average 32% (N=8 for each size) using intrinsically conductive polymer*

	BEFORE TRIM		AFTER TRIM		
Resistor	Resistance	Ohm/sq	Resistance	Ohm/sq	Change
mils	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**

Emulator Trimming

As part of the continuing effort to trim resistors, a 15-up emulator panel size 18”x24” was trimmed using conductive polymer.

Results of trimming are presented in Table 2 below. Figure 8 shows a portion of a Ni/P plated OEM emulator trimmed by ink-jet printing conductive polymer.

***Table 2** Embedded Ni/P plated resistors trimmed (N=6)*

Resistor Size	Average	Standard	Average	Standard
milxmil	Ohm/Sq.	Deviation	Ohm/Sq.	Deviation
40x20	37.0	1.8	33.2	2.7
50x20	35.7	1.2	30.7	2.7
120x20	39.8	1.7	32.9	2.4
220x10	32.8	4.5	27.1	2.4

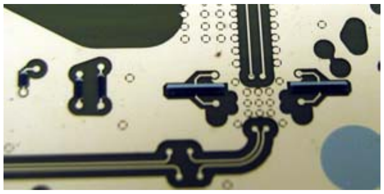

***Figure 8** A portion of an OEM emulator resistor panel trimmed down by ink jet printing*

Capacitors and Inductors

By creating local 3-D structures, capacitors and inductors can be formed (not necessarily planar) using ink jet printing techniques. One of the methods of creating these types of structures is shown schematically in Figure 9 and Figure 10. For a capacitor, the bottom electrode, dielectric, and top electrode layers are laid down successively, and may be repeated to form multilayer capacitors. Both the area and the thickness of the dielectric could be varied to achieve a range of capacitance values.

For an inductor, a center electrode, ferrite layer, and conductor coil are printed. The inductance could be varied by changing the number of turns of the printed coil. The challenge is in the materials required to make capacitors and inductors of practical value. Both organometallic and metal nanoparticle (e.g., silver, gold or copper) solution have been jetted but postprocessing temperatures are usually high. Finally, most high-capacitance (e.g., $Ba_{1-x}Ca_xTi_{1-y}Zr_yO_3$) and high-inductance materials (e.g., Ni-Zn or Mg-Zn-ferrite powder) are ceramics that are sintered at high temperature.

Despite these difficulties, progress has been made in development of suitable materials and ink jet printing methods in last few years for ink jet printing of capacitors and inductors.

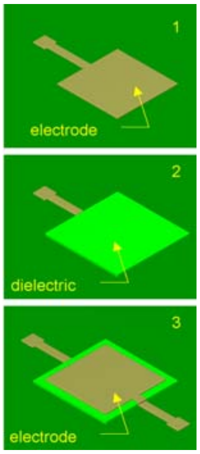

***Figure 9** Steps for*

direct-write capacitor fabrication.

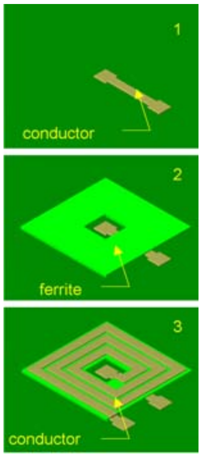

***Figure 10** Steps for*

direct-write of inductors.

Figure 11 shows 150µm ferrite spots and, Figure 12 illustrates 250µm silver nanoparticle lines ink-jet printed onto a ferrite nanoparticle layer, which was also ink-jet printed.

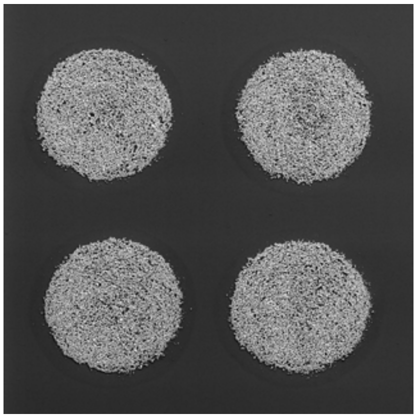

Figure 11 *150µm spots of ferrite particles Ink jet printed.*

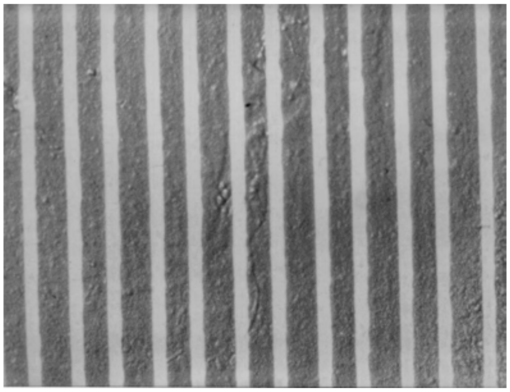

Figure 12 *250µm Silver line printed on ferrite; both using DOD ink jet device*

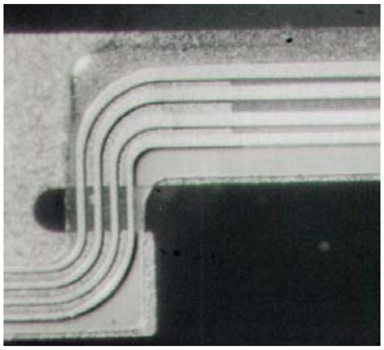

Figure 13 *A portion of head flexture circuit with UV-curing dielectric printed along 50µm wide gold leads.*

Figure 13 shows dielectric material printed onto head flexture circuit.

Figure 14 shows a test vehicle with pads printed with eutectic solder. Ink-jet printing of solder balls as small as 25µm on 35µm pitch has been demonstrated as shown in Figure 15.

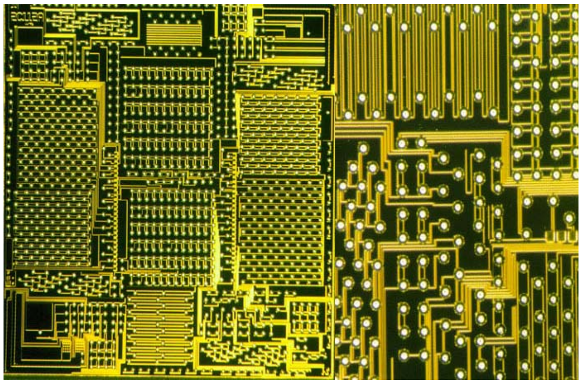

Figure 14 *IC test vehicle with 1440 pads, bumped with Sn63/Pb37 solder using Microjet technology. Ball size is 70µm.*

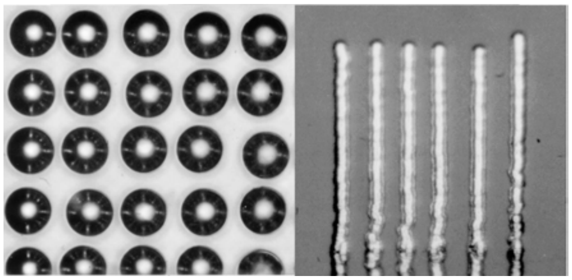

Figure 15 *25µm diameter bumps of solder on 35µm centers and 25µm towers printed on 50µm centers*

Acknowledgement

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