Electrostatic Printing of Electronic Components for Novel, Inexpensive Electronics Products

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Abstract

New materials like organic light emitting diodes (OLED), organic semi-conducting materials, and electrically switchable display materials have created new markets for novel electronic products not possible 10 yrs ago. Even traditional electronic products like silicon chips on glass epoxy boards have become so complex that it is desired to print discrete passive components like resistors and capacitors.

Electrostatic printing of functional materials is an important manufacturing process for these new electronic products. The component's to be printed include:

1. Metal conductor interconnecting paths
2. Resistors
3. Capacitors
4. Inductors
5. Organic field effect transistors

The substrates of interest, mostly non-traditional, include PET or PEN, polysurface and paper.

Introduction

Electrostatic Printing of functional materials configured as liquid toners has been demonstrated on glass, metal and high temperature polyimide materials.[1] Here we focus on the manufacture of electronic components on inexpensive, flexible substrates for a range of new products not possible before.

The emerging markets for printed electronic products include:

1. Radio Frequency Identification Devices (RFID). These are tags or labels attached to consumer products, warehouse cartons, airline baggage etc. that allow addressing at a range of a few meters and respond with an appropriate radio frequency identifications message.
2. "Electronic Paper", flexible non-light emitting display panel for inexpensive, hand held personal digital products
3. Simple anti-theft labels and tags that absorb RF energy at a particular frequency
4. Smart Cards and Vehicle Toll Tags that contain a battery; a silicon chips. And an antenna printed on a flexible substrate.
5. And a host of other products yet to be invented

In all cases these products can be manufactured by existing photolithographic technologies but at a cost above that which the market will sustain. Electrostatic printing provides a low cost alternate below that presently available.

Substrates and Conductor Patterns

The core of any electronic product is its substrate and the interconnect wiring pattern (the "printed wiring board"). Traditionally this is a glass fiber /epoxy resin board or polyimide film (75 to 125 micron thick). Neither solution is appropriate for the next generation of low cost electronic products because of cost factors

The substrate is ideally paper or an inexpensive polymeric film of robust mechanical properties. The conductor patterns are ideally pure metal foil as in traditional printed wiring boards or flexible circuits which have copper layers from 8 to 35 microns thickness.

Table 1

Melting	Points	Working	Temp	Price
Au	1063°C	PET	125°C	$5/lb
Ag	960°C	PEN	150°C	$18/lb
Cu	1083°C	PES	185°C	$22/lb
Al	658°C	Cyclic Olefins	220°C	$30/lb
Zn	419°C	PI	350°C	$80lb
		Paper (card stock)	200°C*	$1.00-$1.50/lb

*Superior high temperature properties to PET films

Table 1 shows a list of usefully conductive metals, their melting points and interesting flexible materials, including paper; and their upper temperature limits. It is obvious that one cannot print particulate metal and thermally sinter it into a useful structure. A solution to this dilemma has been found by Parelec LLC of Rocky

Hill, NJ.[2] They coat a pure metal particle (in this case silver) with a metallo-organic decompostion products (MOD); which upon modest heating, decomposes to “atomic” silver that fuses the silver particle mass together. This material has been formulated into a liquid toner that has been successfully imaged and transferred to useful surfaces. Parelec calls these toners and inks Parmod ™ materials.

Table 2 Electronic Properties

A- Conductor resistivity (micro ohm•cm)	
Ag	1.63
Cu	1.69
Al	2.7
Parmod Ag Toner 220°C- 2 min	5
Parmod Ag Toner reduced temp	8 to 15
Silver filled inks	50 to 100

Table 2 shows the resistivities achieved by the Parmod toners versus the pure metals and silver filled (vinyl or epoxy) inks. With higher temperature processing (220° C) conductivity’s 30% of bulk silver are realized. With lower temperature processing, 10 to 20% of bulk conductivity has been achieved.

This latter achievement has enabled us to print silver toner on PET film with thermal processing at 125°C that yielded useful electrical conductivity compared to silk screened silver filled vinyl or epoxy inks.

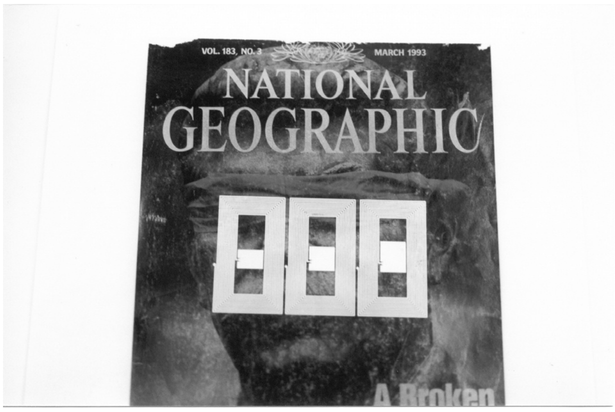

Figure 1. Silver inks Printed on Paper

Figure 1 shows the silver inks printed on paper actually the cover of a National Geographic Magazine with high temperature thermal processing at 220°C.

Figure 2 shows the silver printed on a coated PET film with thermal processing at 125°c. The coating plays an important role in the thermal sintering of the silver toner. Referring back to Table 2A, we note that the low temperature processed silver toner is still 3 to 6x more conductive than silver filled inks. The Parmod toners contain NO resin so this conductivity advantage is to be expected and with further chemistry improvements, better results can be expected.

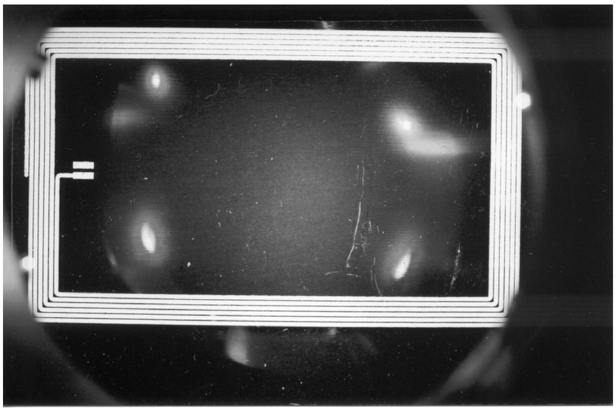

Figure 2. Silver Printed on a Coated PET Film

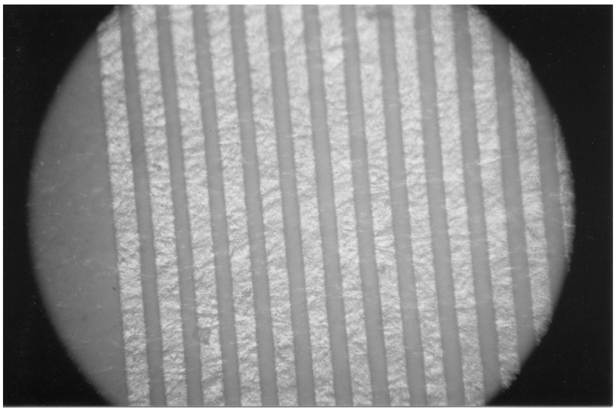

Figure 3. Photomicrograph of Silver Toner

Figure 3 shows a photo micrograph of silver toner printed on a “smooth”, coated food packaging grade of paper. The lines are 100 microns wide with spaces of 80 microns. Note the paper fibers, nominally 12 microns is diameter. The cured silver toner is 1 to 2 microns thick so this encourages us that the toner spreads as a uniform coating over a rather rough surfaces; and still is electrically continuous.

Printing Passive Components

This is a need to print passive components like resistors, capacitors and inductors to make a complete electronic product. A Pentium II mother board contains 1270 passive components, most of them pull-up or pull-down resistors.

One approach is too print a palladium catalyst toner and then electroless plate it with nickel metal through very high value resistors are not possible. Parelec has developed an ITO based ink that thermally cures to sheet resistances of interest.[3] This material can certainly be made into a liquid toner.

In a similar manner Kydd has formulate a $BaTiO_3$ ink as a high dielectric constant capacitor (a ferro-electric) materials.[3] Figure IV shows a nest of electronic components printed on glass. The square structures on the upper left are 9mmx9mm and 5mm by 5mm capacitors. They are three layer devices, a bottom layer of Parmod silver metal, a Barium titinate layer (silk screened ink in this care) and a top layer of silver. Capacities of 2 to 5 nanofarad/cm^2 have been achieved. This barium titinate ink can also be made into a toner.

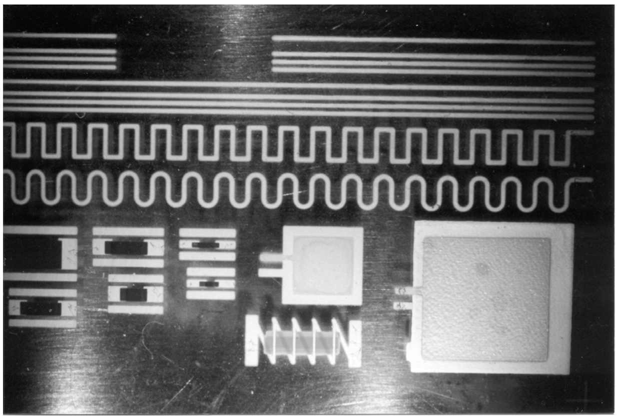

Figure 4. Nest of Electronic Components Printed on Glass

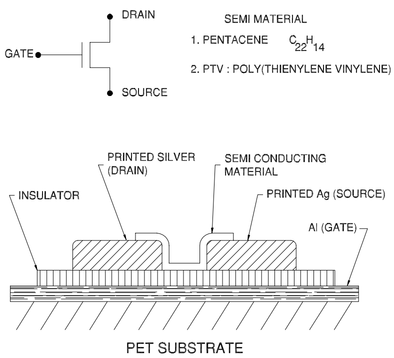

Figure 5. Cross section of a Printed Field Effect Transistor

Printing of Transistors

Figure V shows the cross section of a printed field effect transistor. It consists of a PET film substrate, an Al gater layer, an insulator, the printed Ag source drain/electrodes and finally the organ semi material, usually pentecene. Figure VI shows an example of this transistor structure before the top pentecene is applied.

Inexpensive Display Products

Two forms are working on electrophoretic display technologies. Xerox PARC and E ink of Cambridge, Mass. These are basically micro encapsulated liquid toners that can be uniformly coated on a transparent conductive film. (ITO coated polyester). Next s flexible back electrode structure is laminated to the micro capsules. Voltages on these electrodes cause the toner particles to move thereby changing the color of the display.

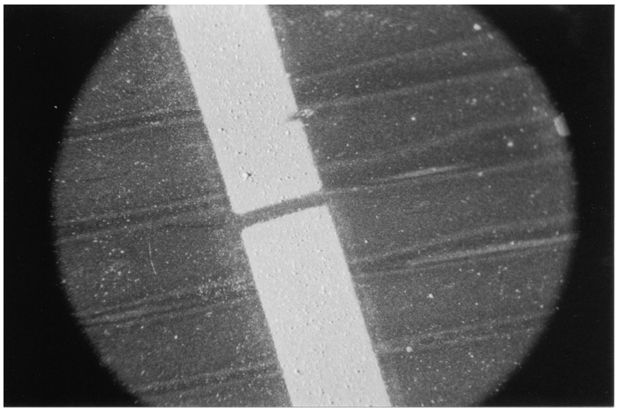

Figure 6. A Field Effect Transistor Substrate of PET Film with Silver Electrodes.

Conclusions

The development of new materials like organic semiconductor and electrophoretic display micro capsules, along with functional toners to print metals, resistors and capacitors has made the manufacture of electronic products at very low cost possible.

References

1. Detig, "Electrostatic Printing of Functional Materials…", Proc. NIP-14, pg. 184-186, October 1998.
2. Kydd, et.al., US# 6, 153, 348, November 28, 2000.
3. Detig, Kydd, Richard; Electrostatic Printing of Microstructures. Proc. NIP-15, pg. 293-296, October 1999.

Biography

Robert H. Detig founded Electrox Corporation in 1992 to apply electrographic imaging technology as a manufacturing tool for various industries. He has some of the basic patents relating to the polymeric electrostatic printing plate. He has extensive experience in all aspects of the electrographic imaging process going back to his early years at Xerox. He pioneered the concept of functional toners made of high density materials like metals and glasses to be used in manufacturing process.

He was awarded a PhD in Electrical Engineering from Carnegie Mellon University in Pittsburgh, Pennsylvania.