New Methods for Digital Fabrication of Printed Circuits

Peter H. Roth, Epic Research Inc., Quechee, Vermont, USA

Introduction and General Concepts

The printed circuit will continue to be the dominant component of electronic devices. Although more electronic functions are being reduced to integrated chips, it is totally unrealistic to expect designers of complex circuits to be limited or constrained by chip design. However changes in requirements, particularly reduced sizes and more complex architecture, are pushing manufacturers of printed circuits to new and ever more challenging demands. Other significant factors, affecting change in the manufacture of printed circuit boards (PCB's), are the demands for (RoHS) restriction of hazardous substances and elimination of leaded solder for surface mounting. These restrictions will become legally binding in July 2006 in the European market and will probably have to be met internationally.

Considering how revolutionary and disruptive these factors are to established methods of PCB manufacture, it is also an opportunity to consider alternative methods to produce complex boards. Today's technology involves many complicated steps, such as generation of photo masks, its subsequent removal, electroplating. generation of electrically conductive vias or through holes , etching to remove unwanted architecture, screen printing of solder mask and its removal, plus the elimination or recycling of many hazardous chemicals. With the discovery of and evolution of better electrically conductive polymers. some manufacturers have developed methods to integrate this new technology in the design of PCB's Development of electrically conductive inks, some using the new polymers, have led to the fabrication of circuits using ink jet printing.

Description of New Methods

We, at Epic Research have examined some of the new methods and have developed our own approach. The criteria we felt was essential to successful manufacture was high resolution architecture, simplicity and minimal new inventions to facilitate low cost implementation.

Two methods were selected, that showed great promise; one was the use of existing electrophotography, with newer toners, and use of current high resolution digital printing, such as flexography and offset to create sharp masks. Each of these technologies are well established and require nosignificant changes, and do not need to have masks removed, since the materials used are highly insulating and well bonded to surfaces. If established methods of manufacture are used, the two technologies serve as masks for electroplating, but must be subsequently removed to etch away unwanted copper. If printing is done on a non-conductive surface, then there has to be a way to deposit electrically conductive material over the open areas. This can only be done with electroless plating. since there are no ways to tie together all the circuit elements for conventional electroplating as a unified electrode. The key invention to make these systems work, was the design and development of a new, stable and well adhering catalytic surface to facilitate electroless metal deposition.

Why not use conductive polymers and print these directly and thereby eliminate masks?

<u>Specific Resistivity of Common Metals</u>		
Gold -Au -	2.10-2.44	microohms-cm.
Copper - Cu -	1.72-1.73	
Silver - Ag -	1.59	
Nickel - Ni -	7.6 - 7.8	
Aluminum - Al -	2.82	
Lead - Pb -	22 - 23	
Lead/Tin -(63/37) - (common solder)	22.4	
<u>Conductive Polvmers</u> -	<u>5 - 10 milliohms-cm</u>	

From the table it is immediately apparent that some of the best electrically conductive polymers, fall far short in electrical conductivity to common metals used in fabrication of PCB's. In addition, the need to solder to circuit elements precludes the use of polymers. Although newer methods to surface mount components to circuits use electrically conductive resins that can be cured thermally or chemically, these are expensive and require newer methods of fabrication that are not simple to execute. By staying with conventional metals, conductivity and soldering are maintained as normal elements of manufacture.

Electrophotography

Electrophotographic printers are capable of rapid and high resolution architecture. Newer, toners with narrower particle size distribution and smaller average particle size have moved this technology to achieve sharper images. Conventional thermal curing cycles. as designed into printers may set the toners, but are not adequate for a wet masking process. Experimentally, the set toner is porous and when subject to plating, will exhibit such porosity as to allow metal to deposit in masked areas. However by allowing a slightly higher temperature and somewhat longer curing cycle the toner elements flow together and form very impervious chemical barriers. Normal toner heat set cycles versus use of special cycles show up as increased gloss and density as measured.

	Before special Cure	After special cure
Gloss-	matte finish	high gloss
Density-	1.42 black	1.55 black
Plating-	porous	dense

Process Description

1. Catalytic fluid is coated on desired substrate.
2. Mask is printed over dried coating using a conventional electrophotographic printer. For rigid boards, such as FR-4 (resin */fiber glass. A* conventional printer was modified to act as a flat bed unit without heat set function.
3. Catalytic coating and toner are simultaneously set using elevated time/temperature conditions.
4. Coated substrate is electroless plated with copper, to desired conductivity.
5. Copper coated PCB is coated with a thin coating of electroless nickel to protect copper surface and maintain good surface soldering conditions.

Board is now ready for any further manufacturing requirements such as surface mounting or printing of identifying components.

We have successfully soldered the new non-lead solders to these boards, which require higher temperatures and newer fluxes. Both however are compatible.

Using Conventional Printing

The preferred process which we have developed, uses conventional printing, technology, such as offset lithography. This method allows architecture resolution of better then +/- 3 microns on conventional presses for the generation of the mask. Choice of ink is very important to facilitate well *cured, highly* insulating coatings.

Process Description

1. Catalytic layer is coated on desired substrate.
2. Mask is printed on conventional press. If rigid board is used, then sheet fed, flat bed press must be used.
3. Both catalyst and ink are cured at elevated temperatures.
4. Copper is electroless plated to desired conductivity.
5. A thin coating of nickel is electroless plated to protect the copper surface and maintain solderability.

In most respects the two processes are similar, electrophotography and printing. However, printing produces superior resolution and a mask that is inherently non-porous as printed.

With the development of the current catalyst as an aqueous ink, suitable for direct printing, it would be possible. to eliminate one step, the printed mask. However at this stage of development this puts serious limitations on the conventional printing presses that are used to handling solvent based or hydrophobic inks. It may also be more economical to coat the catalytic layer as a uniform thin, conventional coating and deliver the substrate ready for printing of mask, on demand and to whatever pattern is needed.

The catalytic coating fluid is a proprietary, patented material. It is stable both as a fluid and as a coated, cured layer. It has the property of reducing conventional electroless compositions such as copper, nickel and other metals.

The choice of protecting copper surfaces with nickel, rather then electroless tin, is primarily based on cost, stability and environmental toxicity factors. Commercial electroless catalysts were evaluated and found unusable in this process;

1. for resistance to fluids and subsequent adhesion.
2. incorrect pH characteristics.
3. poor reducing rates in commercial chemistries and poor crystallographic characteristics of plated metals. (too grainy)

Very complex, high resolution PCB's have been demonstrated by the described process and very little disruptive technology is needed to greatly simplify the commercial manufacturing process. Many toxic chemistries have been eliminated, making the process more environmentally suitable for today's demanding requirements. The promise of further improvements in the direct printing of PCB's, will require the development of new inks, using very conductive nanoparticles. Although some of these have been described, they are not ready for commercial fabrication. Manufacturing techniques and reduced costs will have to be solved to make these developments feasible. This may take years or may be abandoned as one sees the real issues evolve; none of this is entirely predictable.

A final note on the use of the stable catalytic fluid-, is its use as an inkjet material to print patterns directly. Once printed and cured the process is similar to the one described. It would seem to be much easier to develop a usable ink to function in conventional or high resolution ink jet printers, then to develop an aqueous ink for offset lithography, with its much more demanding characteristics. Ink jet printing is especially suited to making a small number of prototypes or circuit development, with out investing in long printing runs. However for mass production, it is hard to image a lower cost process then conventional offset printing, and for the printer it is an opportunity to utilize excess press capacity in a high value operation.

Conclusion

A description of our new PCB process is not complete without showing samples of complex circuits made by these techniques. Furthermore it is important to show by actual example the high electrical conductivities, routinely achieved as well as solderability of the resulting layers. Samples are available to show interested parties separate from the presentation of this paper.

References

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Author Biography

Peter H. Roth is president of a small technology consulting firm that contracts with clients to solve practical development or manufacturing problems in areas of imaging, coating, electrical conducting polymers and system analysis. He has training in chemical engineering from City University of NY., and graduate degrees in physical chemistry and solid state physics from Northeastern University, Boston. His experience covers more than 40 years with Polaroid Corp. in the design, development and reduction to commercial manufacture of complex imaging systems for both the amateur and industrial and medical imaging. After leaving Polaroid Mr. Roth started a small consulting business and is an operating partner *and director in a small electronics firm that develops proprietary technology for the fabrication of complex electronic printed circuits.*

His clients are both large and small companies that required rapid, economical solutions to special problems. He has done work involving complex coatings, biotechnology development, electrical coating formations, electrophotochromic system, complex polymer formulation, solving wetting phenomena in fluids and designing fluids requiring complex rheological properties. He has numerous Us and European patents and papers on colloid chemistry, image stability, design and stable image receptor surfaces. In all areas of activity special emphasis is placed on developing practical and economical solutions rather than impractical abstractions.