August 2010

Fabricating Single and Double Layer Circuits with Laser-embedded Nanoparticle Conductors

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Potomac MesoSystems uses an entirely additive (in contrast to photolithographic/etching) process to fabricate very fine feature conductor patterns on a variety of organic substrates. This approach is enabled by new silver and copper nanoparticle pastes that allow high quality conductors to be deposited from paste and sintered at temperatures compatible with organic substrates. Laser patterning is used to fabricate fine-line conductor patterns on thin polymer substrates. If necessary, conductor patterns can be fabricated on both sides of the substrate and laser-drilled microvias filled with nanoparticle material used for interconnection of layers.

Figure 1 shows the simple "Mill & Fill™" process steps used for conductor fabrication. The embedded conductor technology described here was developed by Potomac Photonics, Inc. in 2001 with DARPA support under the MICE (Mesoscopic Integrated Conformal Electronics) program

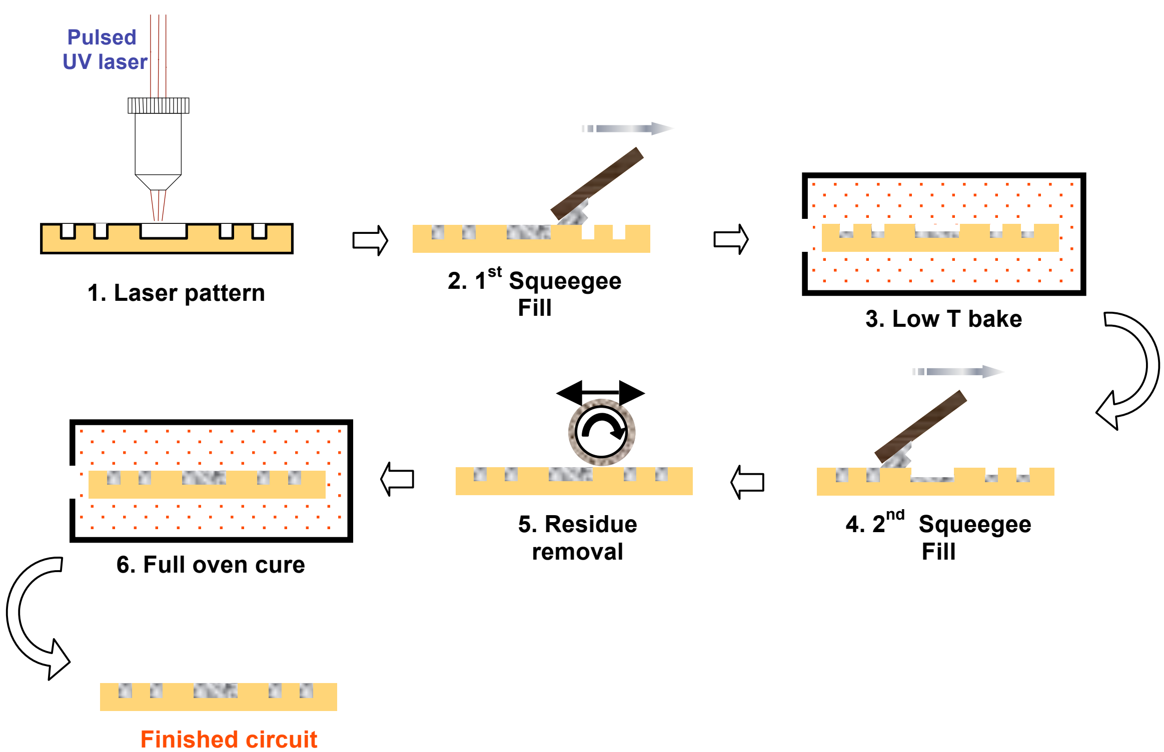

Fig. 1. Laser-embedded nanoparticle conductor process

The complete circuit assembly process begins with the conductor fabrication as shown in Fig. 1, followed by coverlay application, adhesive dispensing and component placement. The step-by-step process is outlined below.

1. The first fabrication step is laser ablation of channels and recesses that will define shapes of the conductors and vias that will be fabricated on both sides of the substrate. This is normally done with a high-repetition-rate uv laser system under CAD/CAM control that scans a focused beam over the substrate surface. Minimum trace widths are determined by the diameter of the focused beam and can be as small as a few microns. Trace thickness is controlled by the laser power and scan speed and can vary from a few microns to 2-3 times the trace thickness. Many current applications use traces with widths in the 12 – 20 micron range and similar thicknesses. Figure 2 shows a laser-ablated pattern in polyimide film.

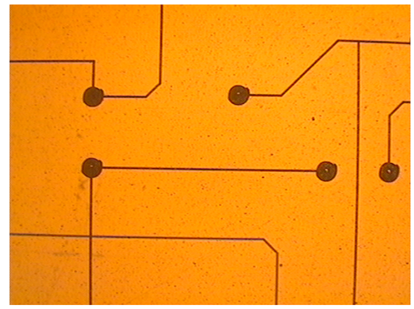

Fig. 2. Laser-ablated channels and pads in a 2 mil polyimide. The channels are 15 microns wide and 12 microns deep.

2. In the second step a squeegee process like that used for stencil printing is used to fill the laser-ablated features with nanoparticle paste material. Nanoparticle silver material is normally used. Nanoparticle copper materials are also available, but require more complex curing processes.

3. The filled substrate is baked at low temperature for a few minutes to remove solvents. Solvent evaporation results in shrinkage of the uncured nanoparticle material to 60-80% of its original volume.

4. A second fill step "tops off" the nanoparticle material in the laser-ablated features to compensate for much of the shrinkage in the first fill.

5. Nanoparticle paste residue on the substrate is removed prior to final curing of the conductive material. This can be accomplished with a variety of simple chemical or mechanical processes.

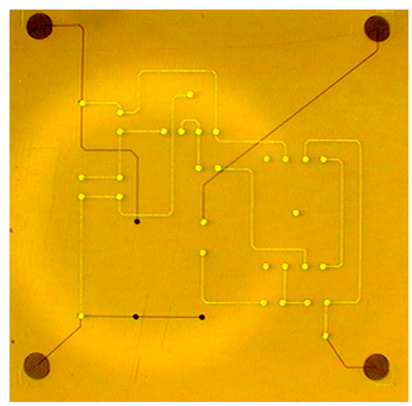

Fig. 3. Silver conductor pattern on 2 mil polyimide substrate after curing. Dark lines and pads correspond to features on the backside.

6. Final curing of the paste material is carried out in ambient air at temperatures of 150 – 200 deg C. Cure times range from 5 to 30 minutes, with higher temperatures and longer cure times resulting in improved electrical conductivity. For nanosilver pastes cured under optimum conditions, resistivity of the nanoparticle material can be as low

as 3 times that of bulk silver. Figure 3 shows a nanoparticle silver-filled conductor pattern.

The above approach to miniature circuit fabrication has significant benefits when compared with more conventional alternatives:

A. **Conductor routing is simplified by use of narrow, embedded traces.** Figure 4 shows a cross-sectional sketch of a conductor formed by the Mill&Fill™ process as it is routed beneath a passive component. Use of narrow embedded conductors allows multiple traces to be routed under even small discrete passives and between narrowly spaced pads. This minimizes the need for vias, reducing the number of routing layers required for complex circuitry and minimizing overall fabrication cost.

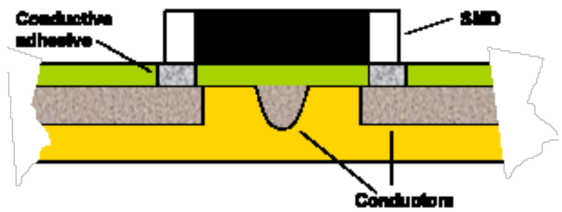

Fig. 4. Embedded conductor routed under surface mount component

B. **High aspect ratio conductors easily can be produced.** In contrast to jet or pen dispensing, conductor cross-sections can be relatively large. This reduces trace resistance and increases current-carrying capacity.

C. **Process chemistry is simplified and waste is minimized.** The additive, direct-write nature of the process eliminates the etchants, solvents, resists, masks, and baths associated with copper photolithography.

D. **Capital equipment and space requirements are reduced.** Key capital equipment items are reduced to a scanned laser system, paste applicator, adhesive dispenser, and pick and place unit.

E. **Adaptable to small batch or high volume production.** Software-controlled Direct write processes for circuit definition, dispensing, allow rapid design changes and cost effective small batch processing. However, modern laser equipment allows direct scale-up to high-throughput cost-effective manufacturing.

Substrate materials are limited only by their compatibility with laser machining and adhesion with suitable coverlay materials. In addition to the polyimide substrates above, the Mill&Fill™ technique has been used produce circuits on ABF (Ajinomoto Buildup Film) and alumina. Liquid crystal polymer, various resins and thin film epoxies are also candidates

The single and double layer processes shown here provide a simple, low-cost route to manufacturing of fine-feature miniature circuits. They also serve as a starting point for producing high-density, modular 3D packages and a variety of miniature electronic systems. Examples of these are available at the Potomac MesoSystems website.