

Best of Session Award

A High-Density, Resin-Coated-Foil (RCF) Substrate Utilizing Mask and Direct-Write UV Laser Photolithography

Scott Corbett*, Edward Swenson**, Jeff Strole*, Bill Beck*, John Yarno*, Thayer Hughes***

*MicroSound Systems, Inc., 34935 SE Douglas Street, Snoqualmie, WA 98065
Phone: 425-396-5707, Fax: 425-396-5861, corbetts@microsnd.com
<http://www.microsnd.com>

**ElectroScientific Industries, Inc., 13900 NW Science Park Drive, Portland, OR 97229
Phone: 503-641-4141, Fax: 503-643-4873, swensone@elcsci.com
<http://www.esi.com>

Abstract

This paper describes a novel circuit fabrication process using UV laser direct-write lithography in combination with conventional mask photolithography to produce a dense, multilayer, resin-coated-foil (RCF) build-up substrate. Using this process, a multilayer HDI substrate was produced featuring an FR4 layer with two RCF build-up layers. The top RCF circuit was patterned with a 10 x 10 array of pads at 250 micron pitch, fully connected through all layers of the substrate to a larger pitched periphery pad pattern, demonstrating a chip-scale package interconnect capability. The fine-line features of the top layer include 30 micron traces, which are patterned on conventional dry film negative photoresist using a tripled-YAG, UV laser drilling system (Electro Scientific Industries 5100) with highly attenuated output, after conventional mask exposure of larger trace features. This process allows fine-line features to be patterned in select areas of the HDI substrate, using the laser exposure process after conventional features are patterned using mask photolithography, significantly enhancing the ability to build dense multilayer circuits. An alternative approach, using the laser to subtractively ablate previously exposed photoresist, was also developed allowing a negative mask to produce traces as small as 10 microns. The demonstrated process is compatible with existing resist materials and circuit processing methods and adds only one process step of additional exposure or ablation of the resist. Both positive and negative circuit features can be patterned compatible with existing subtractive or additive processing methods. Further progress on new beam shaping optics allowing straight-wall, deep-aspect-ratio drilling should further enhance the direct-write resolution capability.

Keywords: RCCTM Foil, RCF, Laser, Flex Circuit, Substrate, Microvia, Direct-Write, Multi-layer, Polyimide, HDI

Introduction

High-density electronic substrates have been a key driver enabling a host of modern electronic appliances including laptop computers, cell phones and electronic pagers. A common method to extend the density capability of conventional FR4 circuit boards is to use "build-up layers" consisting of a high performance unfilled and metalized dielectrics. Material examples include Polyclad's CF 400 resin-coated-foil (RCF), Isola's resin-coated-copper (RCCTM) (both of which use B and C-stage epoxy as the dielectric) and Gould's ThincapTM material (which uses polyimide with epoxy adhesive as the dielectric base). As the dielectric is unfilled, these

materials are particularly amenable to laser drilling to produce microvias from 75-100 microns or even smaller, dramatically improving the routing density over conventional multilayer circuit boards. Additionally, with thinner metal layers and improved dielectric planarization, these materials can be patterned with finer trace and space features. Commonly, these high density substrates employ from 1-2 additional dielectric layers on the top and/or bottom of the conventional FR4 multilayer base substrate, with blind vias connecting the layers to the PC substrate. These circuits can be found increasingly in most modern portable electronic devices.

*** current affiliation: Enerdyne Solutions, Inc., North Bend, WA

Fabrication Process

Figure 1 shows a cross section of a typical build-up circuit featuring two RCF foil layers with blind vias

connecting the RCF layers to each other as well as to the FR4 layer.

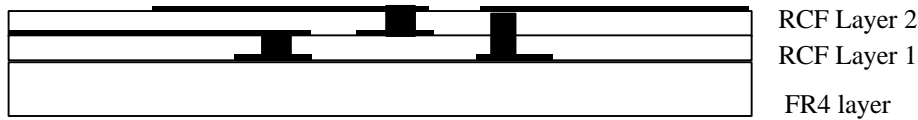


Figure 1 Via connections in two-layer RCF foil build-up circuit

The following sequential steps describe the fabrication of the build-up substrate:

1. Patterning of the top FR4 layer
2. Lamination of RCF 1 layer to FR4 layer
3. Blind via drilling through RCF foil layer 1 to FR4 layer
4. Via plating
5. Patterning of RCF Layer 1
6. Lamination of RCF Foil layer 2 to RCF Foil layer 1
7. Repeat of steps 3-6 for additional layers as appropriate

Vias can be created both with plasma etching techniques as well as with lasers. For laser drilling, both CO₂ and UV lasers can be used, however for microvias 75 microns or smaller, UV lasers are increasingly used. As the UV laser can ablate through metal as well as dielectric, the additional mask and etch steps required for the plasma etch or CO₂ laser (which cannot ablate through the copper layer) are avoided. In addition, 2 layer blind vias, as shown in Figure 1, which directly connect RCF layer 2 to the FR4 layer are easily accomplished.

Tripled-YAG lasers, in particular, can produce short high intensity pulses which cleanly ablate small vias with minimal heat affected zone (HAZ). Newer higher power versions include diode-pumped sources with improved non-linear crystals for harmonic generation.

Conventional Photolithography Limitations

While laser via drilling has improved the routing density of the build up layers, the pattern density is still ultimately constrained by the limits of conventional mask photolithography. Commonly, 50-75 micron traces and spaces can be patterned using collimated light sources and contact mask

lithography, with experimental efforts approaching 25 micron trace and space, however the fine-line features require considerable investment in specialty mask aligners, clean room areas, etc. Also, the dimensional stability of the add-on layers in the multilayer buildup process introduces another level of uncertainty, ultimately limiting the density of the circuit pattern using fixed dimensional masks.

New Direct-Write Technology

In recent years, direct-write imaging has been employed as a means to circumvent some of the traditional limitations of mask lithography. These systems commonly employ parallel sets of focused light beams driven by a raster system, which directly expose the photoresist under the area of the beam [1]. Early systems used visible light lasers, which required thicker and specialized resist. More recent systems employ UV lasers, which can expose conventional resist in the optimum window of 350-370 nm.

Using these systems, a computer generated "virtual mask" is translated directly into an exposed photoresist pattern on the circuit board. Other than replacing the traditional mask alignment and exposure process with the direct-write imager, other steps in the circuit board patterning process such as via drilling, plating, etching, etc. remain the same. While the space and trace patterning features are the same or slightly better than conventional mask exposure, the greatest advantage of this "maskless" process is the ability to adjust the scaling of the exposure pattern to the actual substrate.

As an example, in the build-up process, the underlying substrate is typically slightly distorted after the lamination press cycle. In the traditional process, this dimensional alteration, whether isotropic or anisotropic is compensated for by changing the mask pattern to the anticipated "warped" circuit pattern. Unfortunately, this process has certain limits, particularly as the trace and via size shrink, and

almost certainly requires one or more empirical process steps to optimize (requiring new artwork for each trial). The virtual mask process overcomes this limit by scaling the mask (using built-in fiducials on the underlying layer) to dimensionally compensate for any changes in the circuit pattern.

While the direct-write approach looks exciting from a new process development perspective, these systems have certain limitations, including high cost. They are also limited somewhat in throughput as the exposure process involves direct writing of individual, highly focused beams. Recent improvements in higher fluence beams and parallel raster scanning of multiple beams have increased the throughput, however the high cost of these systems has limited their general acceptance. In addition, these systems use a raster scanning approach which can create jagged trace patterns, particularly as the trace width approaches the bitmap resolution of the raster system. These small discontinuities are typically negligible at trace widths of 100 μm or larger but can become considerable for finer traces, potentially effecting the characteristic impedance of the trace.

Hybrid Direct-Write/Mask Technology

One might ask if the UV lasers so commonly used to drill vias in the build-up substrates might not also be appropriate for use as a direct-write tool, albeit at a much reduced fluence level. The wavelength output from these laser systems, typically a Q-switched tripled-YAG, is 355 nm, the same wavelength required for the resist exposure. The first concern with this approach might be the throughput, as only a single vector scanned beam is available for patterning of the photoresist. However, if the direct-write approach is combined with conventional mask photolithography, the best of both worlds can be achieved. In reality, the fine-line portion of most build-up circuits is commonly limited to areas of the circuit devoted to pad-array footprints required for chip-scale packages, where the density of the interconnect process is at a premium. Outside of the chip package arrays, large portions of the circuit do not require so-called high density interconnect (HDI) technology.

There are two possible approaches using the laser tool. At high fluence levels (although still significantly reduced from levels required for via drilling), the laser pulse has sufficient energy to completely ablate the photoresist material applied to the substrate surface without damaging the underlying metal layer. If a conventional subtractive

etch process is used to pattern the copper, the laser ablation process can be used to remove (ablate) portions of the resist corresponding to unmetalized spaces in the finished pattern (negative mask). This step can be performed after conventional mask exposure of the resist pattern. Fine-line regions where the direct-writing patterning is performed are first exposed and cross-linked through appropriate open portions of the mask, followed by subtractive ablation of the photoresist using the laser. The registration and patterning of the fine-line region can be reoptimized and scaled by the software of the laser scanner to fit within the exact footprint of the space required. Other than the additional step of laser patterning after resist exposure through the mask, all other process steps in the circuit fabrication remain the same.

The second approach entails using the laser at even more reduced fluence levels to expose but not ablate the resist. Typical fluence levels for conventional film resist exposure are in the range of $30\text{mJ}/\text{cm}^2$, which the laser can achieve when highly attenuated. In this process the circuit image is first patterned on the negative resist using a conventional negative mask (exposed regions of photoresist correspond to metal trace patterns in the circuit), with the exception that the fine-line region is left unexposed by leaving the region opaque in the mask. After mask exposure, individual fine-line regions of the resist are exposed directly with the laser (corresponding to eventual traces). The pattern is then developed out conventionally, leaving through-mask and laser exposed resist regions where traces will be patterned. As above, all other process steps in the fabrication process remain conventional.

In theory, this technique can also be used with additive circuit patterning methods, whereby traces are formed from a plate-up process in portions where the resist is removed, using a positive mask to pattern the circuit.

Experimental Results

Process development of the laser direct-write process was initially completed on polyimide flex circuit substrates using conventional 20 micron thick, film photoresist. Process results were then applied to complete a functional two-layer RCF foil build-up circuit as described later.

Resist Ablation with Laser

In the first experiment, we used the resist ablation method to pattern pre-metalized polyimide sheets. Standard 20 micron (0.8 mil) dry-film resist

was laminated to 5 μm metalized, 50 micron (2 mil) polyimide (Gould Electronics, Inc.) using a hot-roll laminator. The resist material was then flood exposed to 350 nm UV light to cross-link the material over the entire surface. 10 micron spaces were ablated in the dry film resist using standard Gaussian optics on an Electro-Scientific Industries (ESI) 5100 laser drilling system, emitting a wavelength of 355nm. Approximately 10 micron wide spaces were patterned at 30 micron centers. After ablation, the parts were briefly cleaned by plasma etching to remove residual laser debris.

Figures 2a and 2b below show the ablated resist (30 μm pitch between ablation lines). The lines patterned below represent one laser beam width.

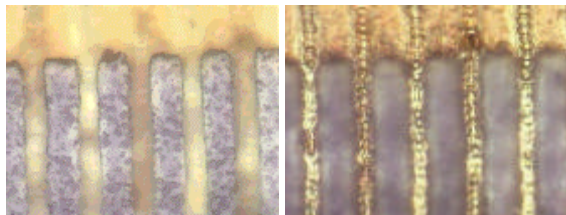


Figure 2a. Ablation of dry film resist. Microscope focused on top of resist. Space approximately 12 μm . Blue region is remaining resist after laser ablation. Figure 2b. Microscope focused on bottom of resist/copper interface. Space approximately 8 μm .

Due to the Gaussian beam shape and the ablation dynamics, the laser patterned the resist with a tapered space, approximately 12 microns on the top surface of the resist and 8 μm at the bottom of the resist as shown in Figure 3 below.

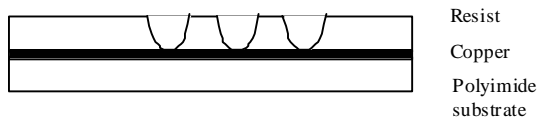


Figure 3. Diagram of ablated photoresist showing tapered ablation channel.

New developments have been made to improve the beam shape such that straighter edge walls can be ablated [4], however, the work reported here was done with the traditional Gaussian beam. We hope to report future work using the new beam shaping optics.

After ablation, the parts were etched to remove the copper in the region where the photoresist had been ablated by the laser, followed by stripping of the photoresist. Figure 4 below shows the resultant

part. The area corresponding to the 10 micron ablated region of the photoresist resulted in 20 microns of etched space. The widening of the etched region is due to a combination of factors including space widening after plasma etching and the isotropic copper etch characteristics. As can be seen, traces as fine as 10 μm at 30 μm pitch were achieved using the ablative approach.

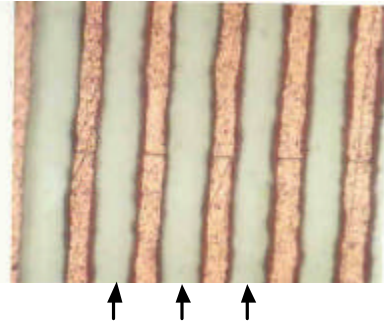


Figure 4. Detail of etched part. Arrows show region corresponding to ablated photoresist (originally 10 microns) resulting in 20 micron space and 10 micron trace.

Resist Exposure with UV laser

Experimental work was also performed to assess the feasibility of directly developing the resist with the UV laser. Exposure experiments were performed on dry-film 20 micron (0.8 mil) photoresist, which was laminated to 50 micron (2 mil) polyimide substrates using a hot-roll laminator. The laser beam output was attenuated to yield a fluence low enough to expose the photoresist without ablating or damaging the material and the resist was directly exposed with the laser.

After exposure, the photoresist was subsequently stripped, yielding a mask pattern where the laser exposure was performed. The pictures below show initial results of 25 micron (1 mil) exposure lines on the resist at 75 micron spacing.

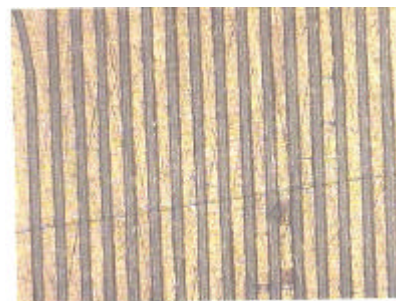


Figure 5. 25 micron trace @ 75 micron pitch after direct-write laser exposure and stripping of resist (before copper etching).

Design of RCF Build-up Circuit Utilizing Combined Mask and Laser Lithography

As a practical application of the laser direct-write process technology, we developed a multi-layer RCF build-up circuit design, featuring a dense 250 micron, 10 x 10 pad grid array (PGA) interconnect pattern on the top surface. The top layer of the circuit, which contains fine trace features in the vicinity of the PGA, was designed to be patterned both with mask exposure and direct-write exposure techniques. The circuit features 3 layers, an FR4 layer, and two additive dielectric/foil layers (Polyclad CF 400, C25T/B35T) with blind via interconnects similar to the cross-section shown in Figure 1, using process steps as described earlier. The dense 10 x 10 matrix is brought out to a larger perimeter array of pads, on the top layer of the circuit, such as required for an HDI substrate for direct-chip or chip-scale package attach. Figure 6 below shows a schematic of the top circuit pattern.

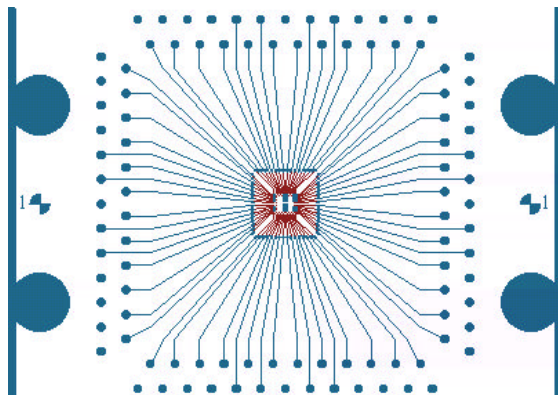
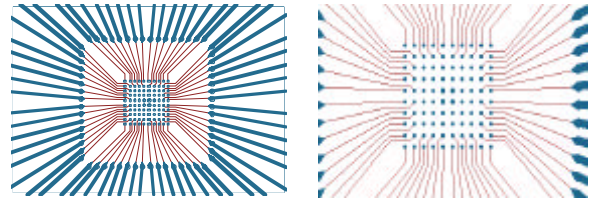


Figure 6. Top view of RCF foil build up circuit pattern schematic, showing periphery array connecting 10 x 10 250 micron pitch PGA array (top RCF Foil 2 layer). Blue portion is patterned using exposure mask, red (inner) portion is patterned with laser direct-write.

The fine feature traces on the top layer, to be performed by laser direct-write patterning after exposure of the larger features of the pattern using conventional mask photolithography are shown below in Figure 7. After combined mask and laser exposure the part is processed conventionally using subtractive etching methods.



Figures 7a,b. Further details of center of circuit showing 10 x 10, 250 micron pitch PGA array and (inner) laser-write portion in red. Regions which are mask-exposed are shown in blue.

The figures below show the trace pattern schematic on the other layers of the build-up circuit. Trace patterning on layers 1 and 2 as well as the large feature traces on layer 3 are imaged using conventional mask photolithography. Blind via drilling using the UV laser followed by plating is used to provide connection between layers (Figure 1).

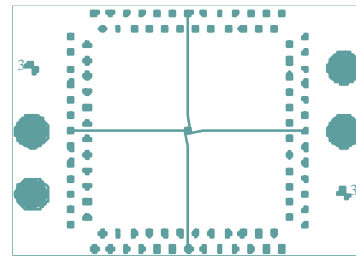


Figure 8a. FR4 layer circuit pattern (bottom layer).

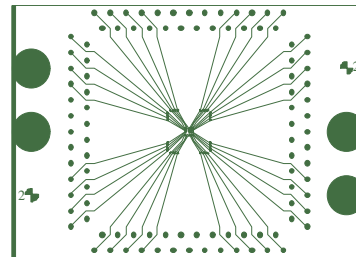


Figure 8b. RCF foil layer 1 circuit pattern.

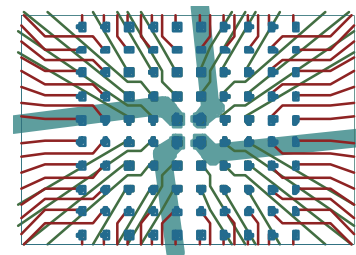


Figure 8c. Detail of center array portion showing superposition of all three trace layers.

Fabrication of Circuit

The RCF build-up circuit was fabricated using the steps described previously. FR4 layer-1 and RCF foil layer-1 were processed using conventional mask exposure and subtractive etching, using laser drilled blind vias to connect RCF layer-1 to FR4 layer-1. Top RCF layer-2 was first processed with conventional mask exposure, followed by laser direct-write exposure of the fine-line portions. Blind vias connected the top layer to the two underlying layers.

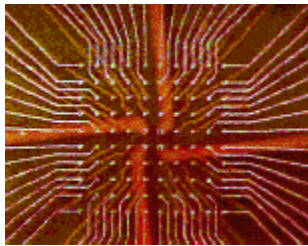


Figure 9a. Completed circuit showing detail of laser direct-write line region. Layers 1 and 2 are visible through the top layer.

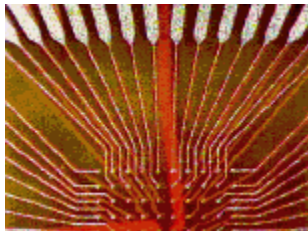


Figure 9b. Detail showing portion of large trace patterned with mask and small trace patterned using laser direct-write.

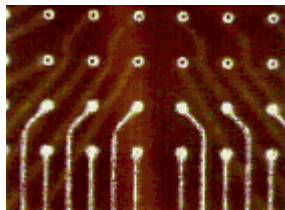


Figure 9c. Detail of direct-write line showing 30 micron traces.

Conclusion

We have demonstrated a combined mask and laser direct-write photolithography process that takes advantage of an industry standard laser drilling tool (the ESI 5100). By utilizing the laser in an attenuated state to directly expose or ablate

photoresist, fine-line features can be aligned and patterned on the substrate in addition to features patterned using conventional mask techniques, significantly enhancing the ability to build dense multilayer circuits. Traces as small as 10 microns were patterned using the subtractive patterning technique and as small as 30 microns using the exposure method.

Importantly, the process is compatible with existing resist materials and circuit processing methods. The laser direct-write step adds only one process step of additional exposure or ablation of the resist. Both positive and negative circuit features can be patterned compatible with existing subtractive or additive processing methods. Further progress on new beam shaping optics allowing straight-wall, deep-aspect-ratio drilling should further enhance the direct-write resolution capability [4].

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