MultiWave Hybrid Technology for Flexible Electronics Fabrication

Introduction

MultiWave Hybrid™ technology allows laser beams with different wavelengths to be combined into a single, coaxial beam (1). The individual laser beam wavelengths can be used together to create a number of unique material processing capabilities, or they can be used individually to create a multi-step material processing solution. The fabrication of flexible electronic circuits is an example of the later type of application.

Several processing steps are required to fabricate a flexible electronic circuit, and many of these steps can be accomplished by laser processing. These steps include selective removal of conductive layers to form circuit elements, and selective removal of insulting layers to creating vias to interconnect the circuit elements. Each of these laser processes requires a different wavelength, which generally requires separate laser systems. Multiwave Hybrid™ technology enables all processes to be run on a single laser system without any re-tooling or set-up. Laser marking and cutting of the polymer substrate round out the process capabilities for flexible circuit fabrication.

Selective Ablation of Insulating Layer

In the development of flexible electronics circuits, it is often necessary to create vias (or holes) through insulating polymer layers to make electrical contact with an underlying conductor layer. This is done for circuit repair, circuit testing and circuit customization. In one such application, vias must be created thorough a polyimide insulating layer to expose the underlying copper conductor. The best way to create these vias is by selective ablation (vaporization) using a CO_2 laser beam.

The 1.06μm wavelength CO_2 laser beam is readily absorbed by the polyimide layer, but it is almost completely reflected by the underlying copper layer. This is indicated in Figure 1, which compares the optical absorptivity spectra of copper and polyimide. The laser energy rapidly heats the polyimide that is directly in the path of the beam. The polyimide quickly melts and vaporizes, leaving a clean via through the polyimide layer all the way to the underlying copper surface. Since the copper surface reflects the 1.06μm wavelength, it is completely unaffected by the CO_2 laser beam.

(1) See the whitepaper entitled "Multiwave Hybrid™ Technology for Advanced Laser Material Processing" for an overview of this technology.

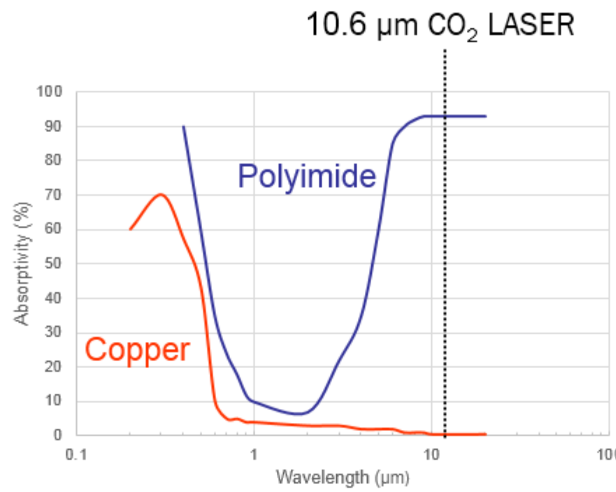


Figure 1. Optical absorptivity spectra for polyimide and copper.

Figure 2 show a series of 10 small vias that were created through a 125µm (0.005") thick polyimide layer to an underlying copper conductor (top image). Each via was created by a single laser pulse. A close-up of one of the vias shows that it is circular, and it extends all the way to the copper surface (bottom image).

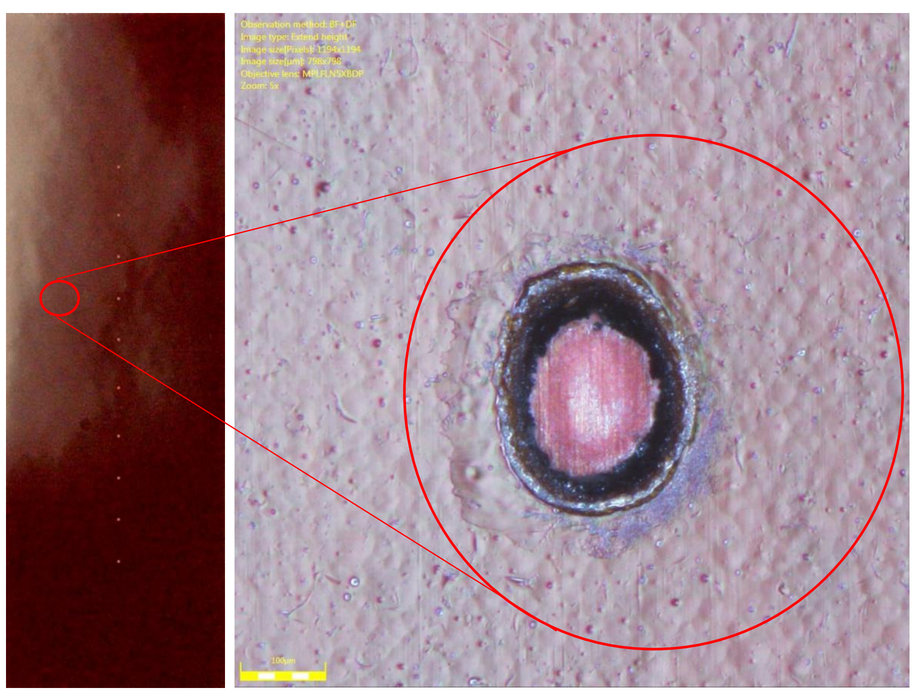


Figure 2. Ten vias through polyimide layer (left); Close up of an individual via revealing clean removal of polyimide to expose underlying copper (right).

Figure 3 is a 3-D microscope image that shows that the vias are cylindrical, with an average diameter of 125 μm (0.005”).

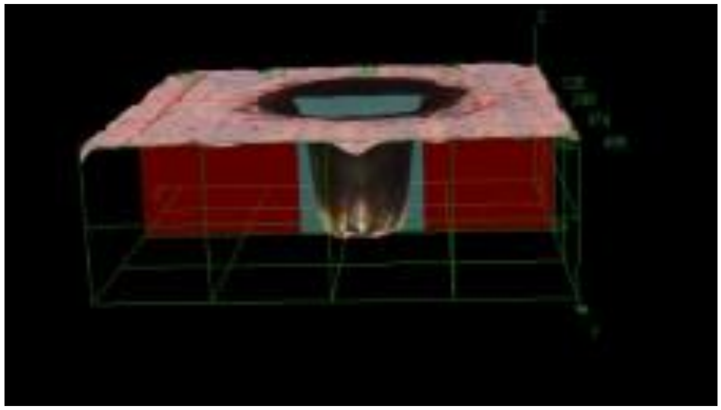


Figure 3. 3-D microscope image of a via created through a 125μm polyimide layer.

Selective ablation of an insulating layer is a valuable processing tool for the development, testing and customization of flexible electronics. A polyimide insulating layer was highlighted in this example, but similar selective ablation processes have been developed for other common insulting layers such as PET and PEN.

Selective Ablation of Conducting Layers

Selective ablation of conducting layers is another laser process that is valuable for flexible circuit fabrication. It is often necessary to cut an existing conductor trace on a flexible circuit for repair or for customization. Also, selective ablation of conducting layers can be a powerful rapid prototyping tool.

Conducting materials such as copper, silver and carbon can readily absorb the 1.06μm wavelength Yb-doped fiber laser beam. The laser energy rapidly heats the conducting material that is directly in the path of the beam, causing it to vaporize. This wavelength is also largely transparent to many insulating layers such as polyimide, PET and PEN. Heat generated by the ablation of the conductive layer can cause some surface melting of the insulating layer, but there is no ablation of the insulating material at this wavelength.

One common material system that is highly compatible with laser processing is a carbon conductor layer deposited on a PET substrate. Figure 4 shows a serpentine carbon conductor line that has been printed onto a PET substrate (top image). The middle image is the same carbon, with a vertical strip of the carbon conductor removed by selective laser ablation. A microscopic image of the laser-ablated area shows that the carbon has been completely removed with no damage to the underlying PET (bottom image).

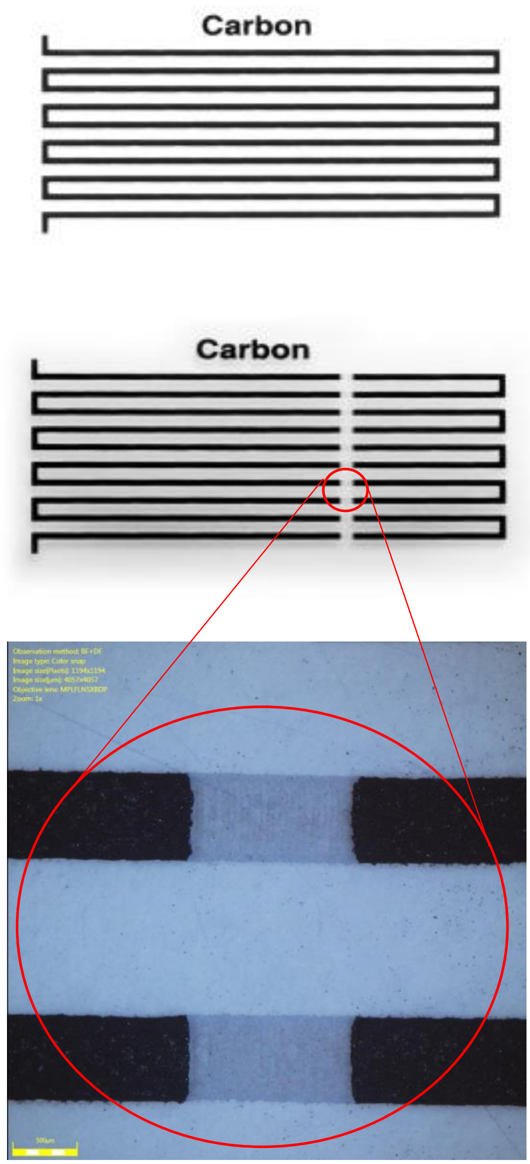


Figure 4. Carbon ink conductor printed onto PET to form a serpentine pattern (top image); after selective laser ablation of a vertical strip (middle image); microscopic image of laser ablated area (bottom image).

Laser Cutting and Laser Marking

In addition to selective laser ablation of insulating and conducting layers, laser cutting and laser marking is a valuable processes for flexible circuit fabrication. Laser cutting can be used to create intricate circuit shapes, without the need to fabricate special tooling. Laser marking creates indelible identification markings such as company logos, part numbers and QR codes.

Figure 5 shows a group of flexible circuit shapes that have been laser cut from a polyimide sheet using a 10.6 micron CO_2 laser. Figure 6 shows a serial number that has been marked on a polyimide part (top-left) using the same laser.

Figure 5. Laser cut polyimide sheet.

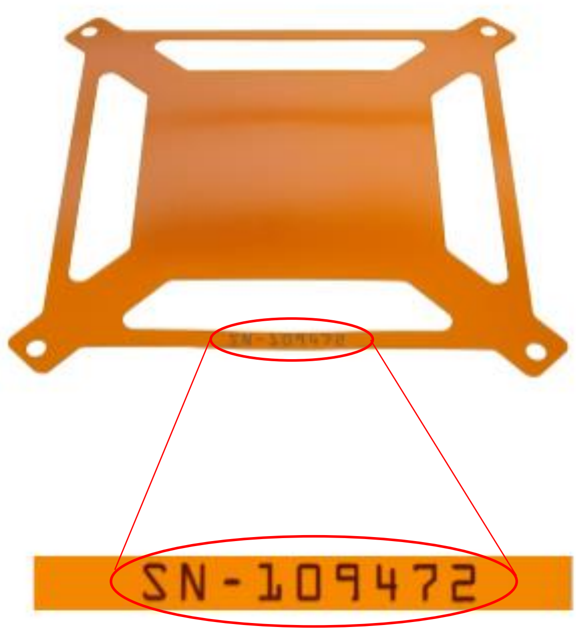


Figure 6. Laser marking on polyimide.

Circuits fabricated on PET and PEN substrates can also be laser cut and laser marked. The serial number on the left was created using a 10.6µm wavelength CO_2 laser. This mark is legible, but somewhat faint against the transparent material. The mark on the right was created with a 9.3µm wavelength CO_2 laser. This mark is much bolder and easier to read. This is especially important for machine readable marks, where the error rate can be high if the mark is not sufficiently bright and distinct.

Figure 7. Laser cut PET, with a serial number that was created using a 10.6µm CO_2 laser (left) and 9.3µm CO_2 (right).

The mark created by the 9.3µm laser is a surface mark, so there is no damage to the PET material. By contrast, the mark created by the 10.6µm laser is created by ablating PET, which can weaken the material. The reason for the difference in the two marks is highlighted in Figure 8, which shows that PET has a strong absorption peak at a about 9.3µm, while it absorbs weekly in the 10.6µm regime.

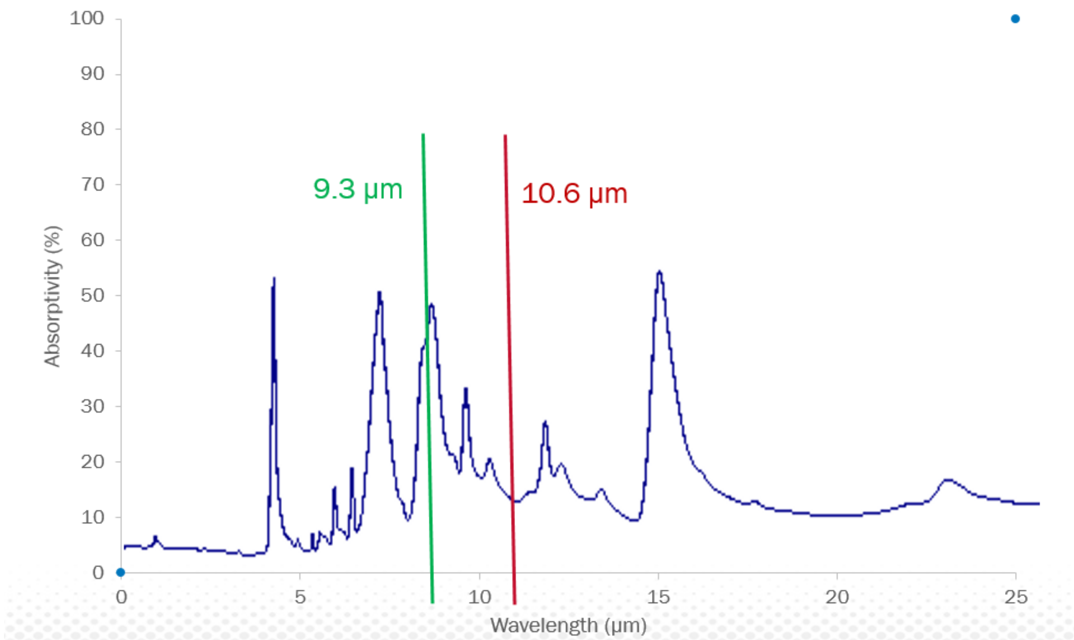
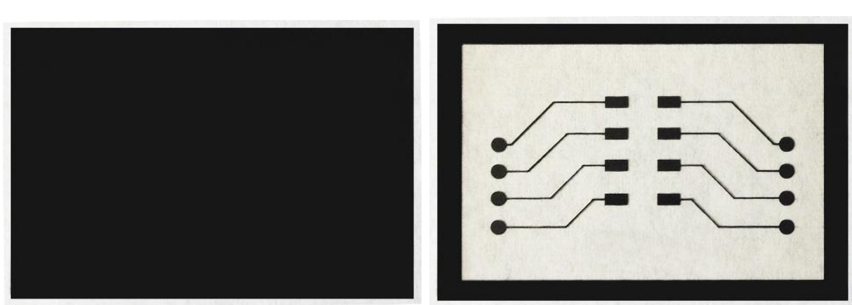


Figure 8. Optical absorptivity spectrum for PET showing a strong absorption peak at about 9.3µm.

Rapid Prototyping using MultiWave Hybrid Technology

The process described above can comprise a powerful set of processing tools for producing flexible electronic circuits. This is depicted in Figure 9, which steps through a multi-step fabrication process. Step one is the starting material, which is carbon ink that has been silk screened onto a PET substrate. Step two is the selective ablation of the carbon ink to form the conductive traces. This is done using a 1.06µm wavelength laser beam. Step 3 is marking the PET substrate using a 9.3µm wavelength laser beam. Step 4 is cutting the PET substrate with a 10.6µm wavelength beam to release the finished flexible circuit from the substrate sheet.



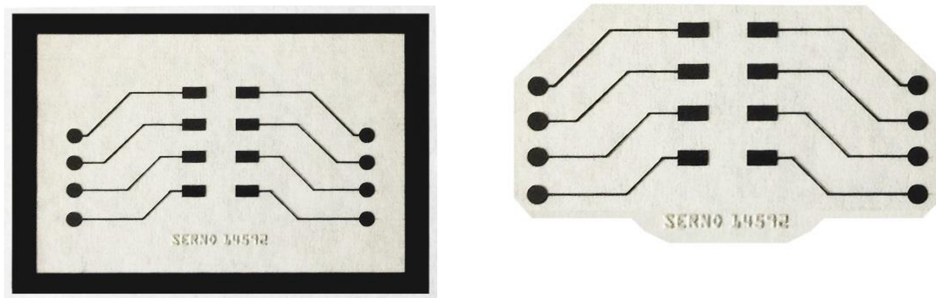


Figure 9. Multi-step manufacturing process showing: 1) Carbon ink silk screened onto a PET substrate (top left); 2) Selective laser ablation of carbon ink to form the conducting traces (top right); 3) Marking the PET substrate (bottom left); 4) Cutting the PET substrate (bottom right).

Summary

Laser materials processing is a versatile method for fabricating flexible electronic circuits. MultiWave Hybrid technology provides a broad range of materials compatibility. A number of individual processing steps including selective laser ablation of the conducting and insulting layers, and laser marking and cutting of polymer substrates have been demonstrated. These steps can be combined to create a powerful tool set for fabricating flexible electronic circuits.