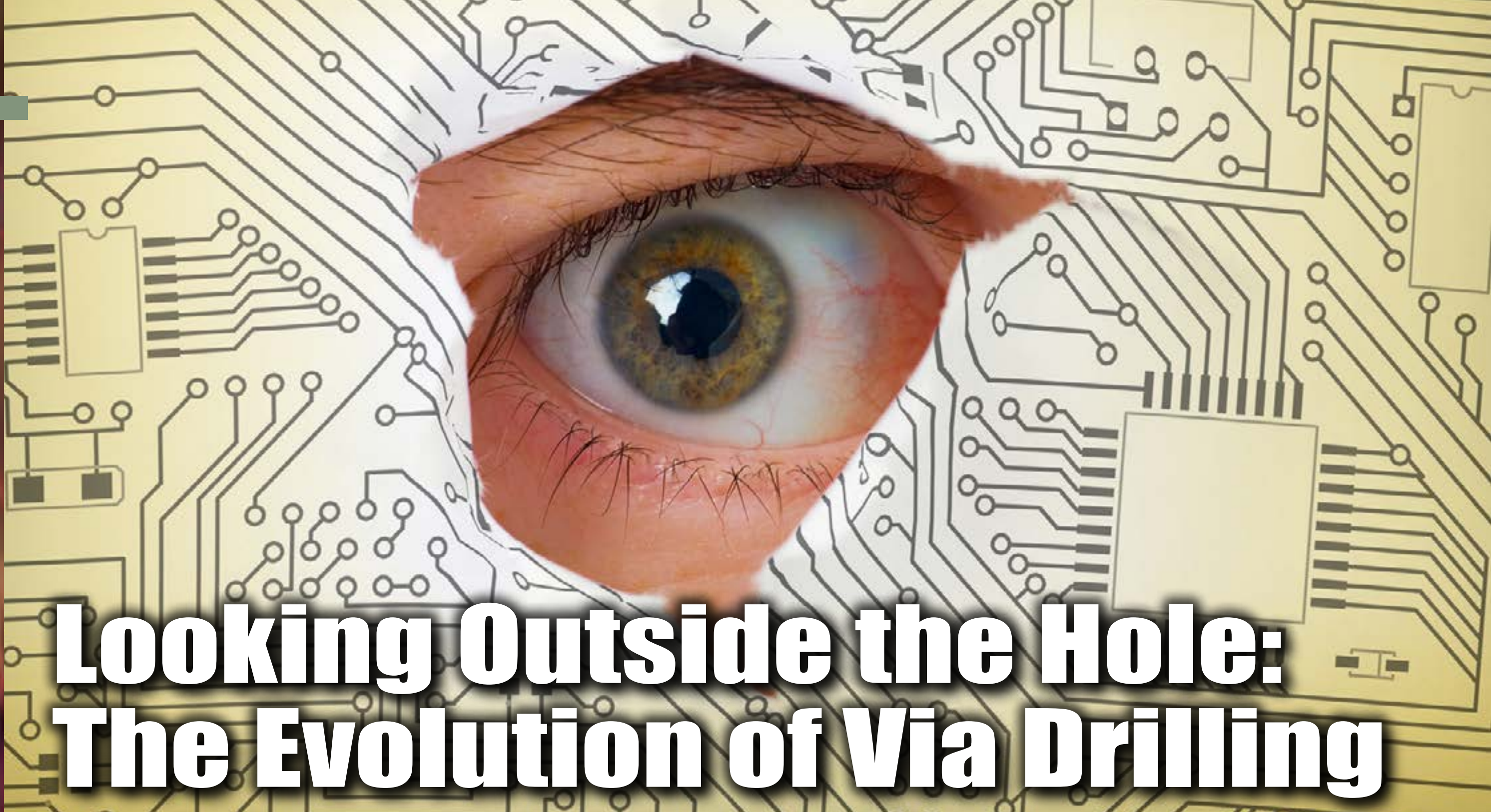

Looking Outside the Hole: The Evolution of Via Drilling

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SUMMARY: New developments in laser-based fabrication that are an extension of laser microvia drilling technology are helping to reduce feature sizes and facilitating the miniaturization of electronic devices.

Baseball, it is said, is only a game. True. And the Grand Canyon is only a hole in Arizona. Not all holes, or games, are created equal.
George Will

Introduction

In the world of electronics, less is often more when it comes to device fabrication and product developers are continually looking for ways to shrink their products. There is pressure in many industries to pack more components, such as microcontrollers, wireless communication, and power delivery into an ever-decreasing footprint. However, conventional PCB technology is often limited to features greater than 50 microns, which severely impedes the ability to increase component density on a given device. New developments in laser-based fabrication that are an extension of laser microvia drilling technology are helping to reduce these dimensions and facilitating the miniaturization of electronic devices.

The Importance of Hole and Trace Sizes

Most readers will readily agree that interconnect circuit vias and traces are critical to the miniaturization of electronic devices. As vias and traces get smaller, component packing density can be increased, interconnect circuits can be made with fewer layers, and more features can be more easily integrated into small devices. The primary function of vias is the electrical interconnection of conductive traces between different layers of the device substrate. Precisely drilled holes allow designers to build more complex devices with a much smaller footprint. In addition to small holes and traces, another limiting factor has always been the ability to fill via holes with conductive material. New miniaturization processes are capable of addressing these issues and enable the manufacturing of next-generation electronic products, such as implantable medical devices, wireless communication and microfluidic devices.

Evolution of Via Drilling Techniques

Over the past three decades, there have been dramatic advances in methods for drilling via holes. The two most widely used techniques for drilling small holes in the PCB industry are mechanical drilling and laser drilling.

There have been major advances in mechanical drilling technology that have significantly decreased the diameter of drill bits while increasing their tool life. High-speed spindles, which are critical to small-hole drilling, can now achieve maximum speeds of 350,000+ revolutions per minute. Additionally, new drill bits coated with strong nanomaterials, such as diamond, have helped push the diameter of mechanically drilled holes to less than 50 microns.

Lasers have been used to drill holes in PCBs for more than three decades, but laser drilling continues to evolve quickly. The ability to focus a coherent low-divergence beam to create a hole is extremely useful and allows for enormous future advances. The most widely used laser for drilling holes in PCBs is the CO_2 laser. However, as hole diameters have been pushed below 50 microns, the popularity of diode-pumped solid-state YAG lasers has increased. In fact, holes as small as 1-2 microns with sub-micron tolerances can be achieved using this technology.

More recently, the availability of higher-power lasers has led to much faster drilling rates because the beam can split into several cutting heads to allow drilling multiple panels at once. Other advancements include extremely high-peak-power pulsed lasers that drill holes with better resolution and virtually no debris. These lasers, which can drill almost any material with the appropriate wavelength selection, will become even more important as newer and more advanced PCB materials are introduced into the market.

Moving Forward

The argument can be made that small-hole drilling is outpacing other elements of the PCB manufacturing process and until these areas are addressed there will be limitations to how small these holes need to be. One solution to this problem may be the use of highly evolved laser hole drilling technology and equipment to shrink other features of an interconnect circuit.

A technology currently under development that implements this technique is called mill and fill, which combines hole drilling and trace fabrication into one process. In this process, high-throughput laser equipment very similar to UV laser via drillers is used to not only drill microvias in a thin substrate, but also make narrow channels that can be filled with conductive material to form traces. These features are often smaller than 10 microns, and, ultimately, feature width and depth is limited only by the focusability of the laser beam. Using a simple squeegee technique, they can be filled with conductive nanoparticle silver pastes that cure at moderate temperatures to create intricate, high-conductivity interconnect structures for miniature electronic packages. In addition to size reduction, there are many benefits to this process over conventional PCB manufacturing, including the ability to build devices with a flexible form factor, lower capital investment, minimal use of consumables and minimal waste byproducts.

Example: Construction of a Miniature Microcontroller:

A promising application of this laser-based miniaturization technology is the fabrication of miniature application-specific integrated modules (ASIMs) that bring together a group of very small packaged components. Figure 1 shows a small, 10 mm x 10 mm ASIM that integrates a Texas Instruments MSP430 microcontroller, a microchip voltage regulator, an NXF dual inverter, and all associated passives.

The double-sided interconnect for these devices utilize silver traces fabricated with the mill and fill approach. A solid-state UV laser, similar to those often used in laser via drilling

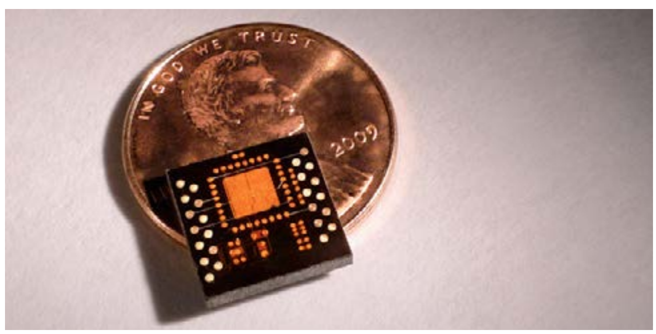

Figure 1: Microcontroller module with voltage regulator, invertor, and passives. Interconnection traces are 12 microns wide and not visible at this magnification.

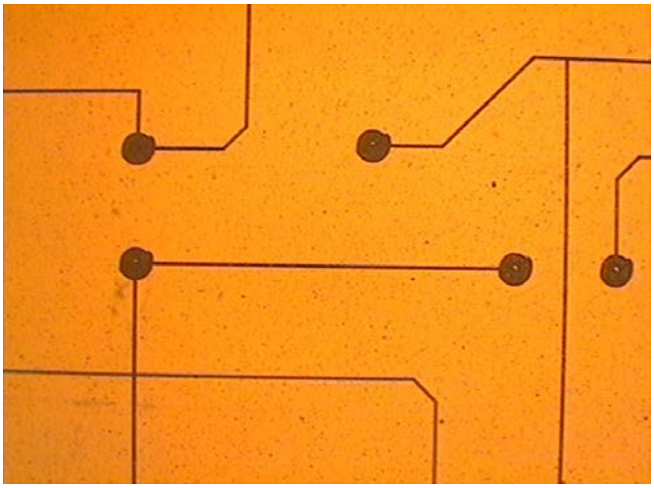

Figure 2a: Twelve-micron traces with pads and in-pad vias in 2-mil polyimide substrate.

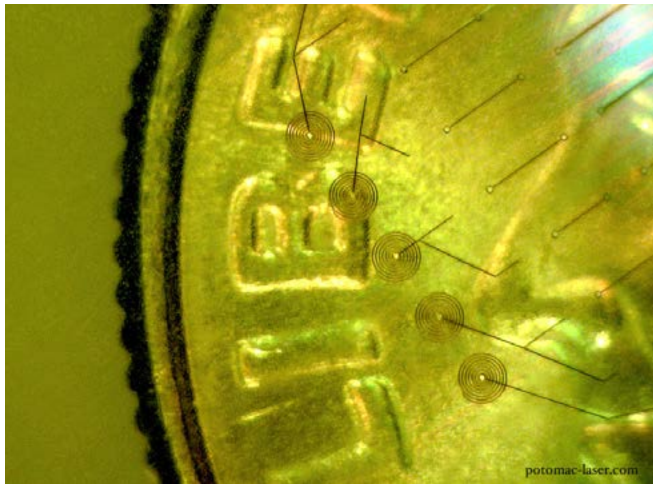

Figure 2b: Vias and 12-micron spaces.

systems, was employed to produce vias and channel patterns with trace/space dimensions of 12 microns in a thin polyimide substrate like that shown in Figure 2. Depth of the conductive traces is also about 12 microns. Although polyimide was used as the substrate in this example, other substrate materials, including liquid crystal polymer, Ajinomoto buildup film, resin coated copper, and polished alumina have been used in similar demonstrations.

Other advantages to this type of laser processing include the ability to pattern conformal surfaces and 3D objects. As device form factors shift from standard 2D panels to more complex configurations, these capabilities will become more critical. Figure 3 shows a small diameter polyimide tube with 10 micron vias and traces that have been filled with conductive silver.

Simultaneous nanoparticle silver paste filling of the fine-feature channels and vias was carried out with a squeegee process. Silver particles of submicron dimensions sinter together at temperatures that decrease with particle size. As particle dimensions enter the submicron range, sintering temperatures can decrease to as little as 100 – 200°C. This allows the nanoparticle silver pastes used to fill laser-formed channels and vias to be converted to sintered silver solids at temperatures compatible with many organic substrates. Resistivity of the sintered silver material is typically about three times that of solid bulk copper, but the overall resistance of the thin traces is reduced by their relatively large cross-section.

A proprietary assembly technique utilizing conductive epoxies and encapsulation materials brought together the various circuit components to produce the functional system with exposed silver contact pads shown in Figure 1. Standard parts placement and encapsulation equipment were used in the assembly processes. None of the fabrication steps required tempera-

Figure 3: Medical device fabricated in polyimide tubing with 10 micron vias and traces that have been filled with silver nanoparticle conductive material.

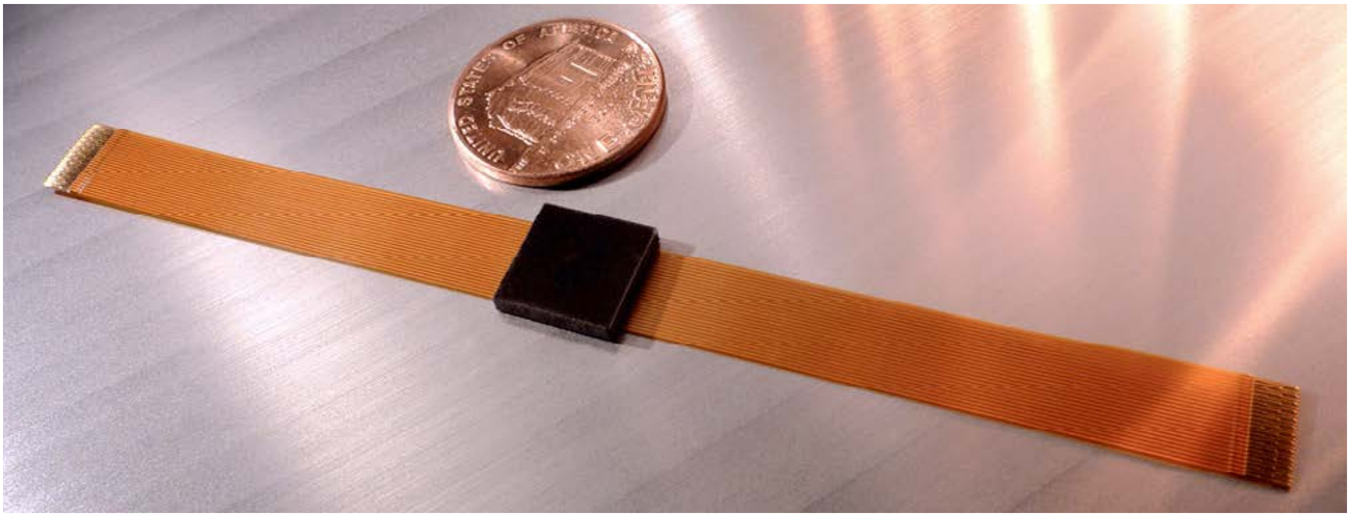

Figure 5: A 10 mm x 10 mm laser-fabricated module attached to a 25-conductor flex cable.

tures exceeding 180°C or produced a significant amount of waste byproducts. The entire structure is completely lead-free.

After fabrication, the application-specific modules can be used as stand-alone systems or can be attached to rigid circuit boards or flex circuit assemblies. Conductive epoxies are again used to make the connection between silver and copper pads. Use of standard underfill techniques results in a very robust structure in which all module components and conductors are encapsulated and protected from the ambient atmosphere. Figure 4 shows a module like that of Figure 1 attached to a wireless sensor board that utilizes a second similar module containing motion sensors. Figure 5 shows a similar module attached to a high-density flex cable, effectively making it a “smart” interconnection device.

Years of continuous improvement of UV solid-state laser via drilling equipment has resulted in high-power laser sources and high-speed beam delivery systems that are capable of very high throughput and precision in PCB fabrication. Combining these with nanoparticle materials technology now provides an opportunity to shrink other circuit features. This could be the next step in the relentless march toward miniaturization. **PCB**

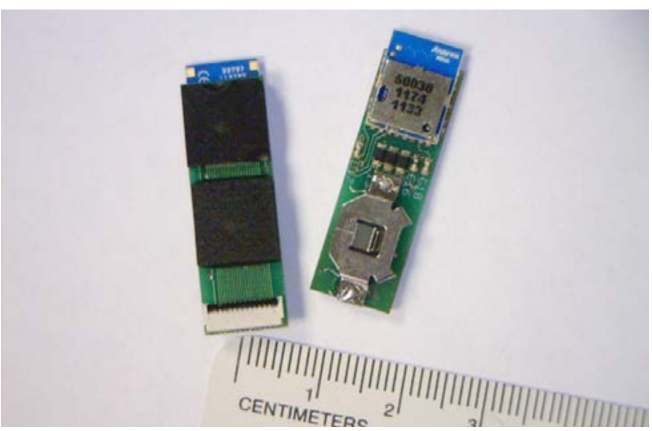

Figure 4: Top and bottom views of a wireless motion sensor. The two miniature laser-fabricated modules are shown on the left.

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