PCB Laser Technology for Rigid and Flex HDI – Via Formation, Structuring, Routing

Dr. Dieter J. Meier, Stephan H. Schmidt*
LPKF Laser & Electronics AG
Garbsen, Germany and Wilsonville, OR*

Abstract

A new versatile laser technology is available that is capable of working with both ridged and flexible boards using only one laser source. This system is based on a THG-UV laser (355 nm) and vector data software. This system can be used for drilling, cutting and structuring. Small and medium board manufacturers will be able to enter the HDI market with a minimum investment and a guaranty of high yields for each technology step. Various materials and combinations including glass fiber reinforced substrates can be drilled, cut and structured with the same equipment. This paper will introduce special applications in the area of micro via formation (minimum diameter of 30µm at 250 holes per second), laser direct structuring (minimum line widths of 0.8mil at 13.8 inches per second) and routing (compounds of various materials) and will discuss the technological benefits.

Introduction

The trend to further miniaturization continues. For rigid and flex circuits the industry predicts dimensions[1] that can't be produced economically with the current technology. Low yield and technical requirements that can't be matched require a technology change. High density interconnect (HDI) circuits require microvias with diameters of less that 40µm and tracks with less than 50µm width.

The well-established laser technology will definitely play a leading role in this technology change[2]. When choosing a laser system it is necessary to answer the following questions:

- Does the laser system's performance meet the demand for current and future generations of both flexible and rigid circuit board?
- Is the chosen laser technology capable to handle the selection of materials (metal layers, glass fiber, different substrates, adhesive, solder mask, galvano- and photo resists, etc.)?
- Which wavelength is best, considering the absorption ratio and ablation performance of the desired material?
- Is the performance of the laser including power, regulation and consistency wide enough to cover the range of desired material properly?
- Can the mechanical design of the system deliver the required accuracy and repeatability in the micrometer range?

An ideal concept would be an inexpensive system with only a single laser source, yet flexible enough to cover a broad range of applications on flexible and rigid boards. This would enable small and medium sized businesses to enter laser technology. For better return on investment, an ideal system would be versatile enough to drill holes but also structure circuitry as well as scribe and route boards.

Laser and System Concept

The laser source has been designed particularly for this application field. It is based on a Q-switched Nd:YAG Laser with a wavelength of 355 nm (UV). At this wavelength most of the metals (Cu, Ni, Au, Ag) that are to be ablated in printed circuit applications show absorption rates of more than 50%. Organic materials can also be accurately ablated. The high photon energy of UV lasers at 3.5-7eV[8] cracks the chemical bonding as the ablation process in the UV spectrum is partly photo-chemical and partly photo-thermal. These capabilities make a UV laser system the first choice for applications in the printed circuit board industry[7].

The system should only use a single laser source for budgetary reasons, but still have to provide an energy density (fluence) of more than $4J/cm^2$ that is needed for opening the Cu surface when drilling microvoia[4] holes or for structuring Sn layers[5]. The ablation process of organic material such as epoxy resins and polyimide requires only an energy density[6]of around $100mJ/cm^2$. To address this wide spectrum the laser would need a very precise and sophisticated energy control as the drilling of microvias requires a 2-step process. The first step opens the Cu with a high fluence and the second step removes the dielectric with low fluence. Another aspect in using one single laser source is the spot size. CO_2 lasers with their usual spot size of 70µm[9] can't drill state of the art microvias with less than 50µm in diameter directly. Instead it is necessary to use a pre-etched conformal mask on the board to limit the laser beam to the desired diameter[10]. UV lasers on the other hand typically have a spot size of approx. 20µm at a wavelength of 355nm. The frequency of the laser pulses is between 10 and 50kHz at a pulse length of less than 140ns. Detailed investigations of the resulting blind vias indicate that 140ns pulse length causes no Heat-Affected-Zone (HAZ) in the material. Fig. 1 shows blind vias in Cu with a diameter of 70µm. The substrate material is FR4.

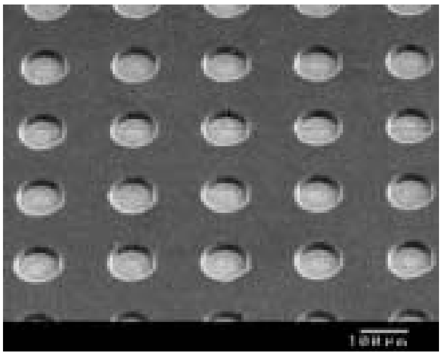

Fig. 1: Heat-Affected-Zone (HAZ) test pattern

Therefore both flex and rigid materials can be properly processed with this pulse length.

Fig. 2 shows the basic principal of such a system[11,15]. The laser beam is positioned with a computer-controlled scanner / mirror system and focused through a telecentic lens that allows the beam to maintain a right angle to the drilled material. This scanning process allows the software to generate a vector pattern and it compensates for both material and layout deviation. The scanning area measures 55 x 55 mm (2.2” square).

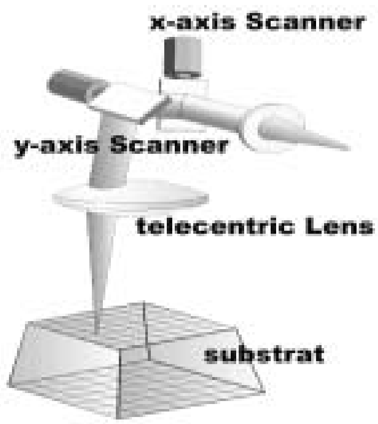

Fig. 2: Scanner concept

This system is compatible with a CAM software[12] that imports all common data formats such as Gerber™ RS-274S and RS 274X, Excellon™ I and II, Sieb & Meier™, DXF™, Barco™ DPF, HP-GL and ODB++™ among others.

The mechanical design is based on a rigid granite construction precisely polished to a surface accuracy of less than 3µm. The table rests on air bearings and driven by linear motors. The positioning accuracy is controlled with glass scales that guaranty a repeatability of ±1µm. An optical sensor integrated in the table itself compensates for the optical distortion and long-term drift based on an accurate alignment of the laser position at various mirror locations. The software creates an array of correction data based on the alignment that is overlaid on the entire scanning area. The calibration for the drift compensation takes about 1 minute and can be done while a work process is executed. Any variation in the substrate itself, such as inaccuracies in the positioning caused by deviation of the fiducials, is detected by a high-resolution CCD camera and compensated for by the control software.

Inconsistent planarity is compensated by surface sensing with a resolution of 1µm that controls the topography of the board, which allows the control software to adjust the laser focus.

The substrate fixture is based on a vacuum unit with a honeycomb design. Eventually emitted gases will be extracted and filtered through an active-charcoal system. The laser system is covered and compliant with laser safety class I.

Laser Drilling

A wide variety of material can be laser drilled but the speed and therefore the throughput of the drilling process depends on the material properties. In general there are two main ways to maximize the throughput: 1) Reduction of the Cu layer thickness to 5µm (1/8 oz.) to allow the removal of the copper (step 1 of the drilling process) with high fluence and 2) to develop substrate material that has good laser ablation characteristics (step 2 of the drilling process). DuPont, for instance, developed a material called THERMOUNT[14] that contains non-woven aramid fibers. The manufacturer claims this material is easier to ablate with laser technology, than material with woven glass reinforcement. Other new developments of dielectric substrates that can be more easily ablated by laser utilize so called “Hotmelts”[17].

For HDI application some special build-up and connectivity techniques have been established that use RCC (resin coated copper). Those are thin Cu foils (min. 5µm), which are covered with an epoxy resin system and are usually laminated on both sides on rigid substrates. Fig. 3 shows blind vias, which were formed into this material. The diameter of these holes is 30µm. With this material a speed of up to 250 holes per second could be achieved.

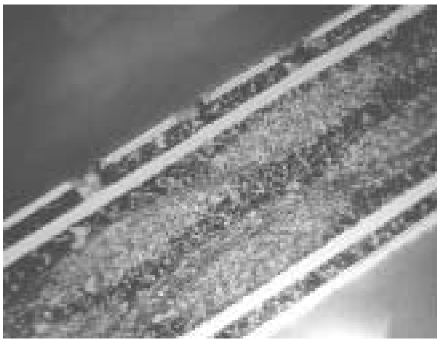

Fig. 3: Cross section of blind vias in RCC

The resin layer thickness is 50µm. Interesting to mention is, that the residue (smear) by the ablation process on the hole's wall is so insignificant that the plating process could be performed using only the common cleaning chemicals[15]. This also supports the use of a UV laser versus a CO_2 laser for this application. If the laser parameters are optimized, it is to expect the smallest HAZ and little debris and recast. The Cu surface in the hole's bottom is slightly textured by the laser, producing good adhesion capabilities for the following plating process, as shown to Fig. 4.

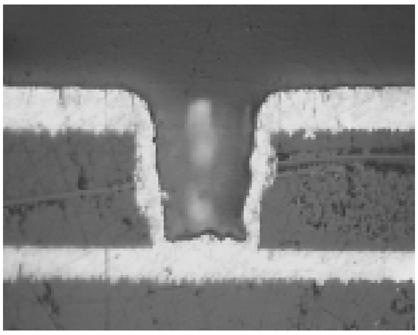

Fig. 4: Cross section of metalized blind-vias in glass reinforced FR4

After opening the Cu layer with high fluence, both the resin and the glass fibers will be ablated and vias can be plated, as shown in Fig. 4. It shows blind vias in an FR4 inner layer with 17,5µm (1/2 oz.) Cu. The drilling speed was determined here with 100 holes per second.

Laser Structuring

The uses of lasers for the structuring of metallic or polymer surfaces intersperses itself more and more. In the beginning only Sn layers [18] over Cu foils were structured and turned into conductor tracks after etching and stripping. As a result of the decrease in the spot size (down to 20µm) another possibility arises, that allows ablation of lacquers and photo resists directly (Direct Write UV Laser Photolithography)[19] as an alternative to the traditional photo lithography.

Fig. 5 shows a structured printed circuit board developed with UV laser. The minimum track clearance is 30µm. The maximum structuring speed depending on the material, can reach up to 300mm per second on a work area of 640 x 560mm² (25.2" x22") with a total thickness of up to 50mm (2").

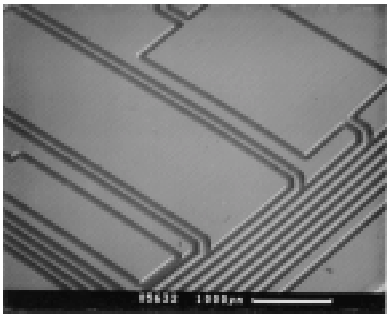

Fig. 5: Direct circuitry structuring using Laser and Sn resist technology.

As previously mentioned, polymere materials and layers can be ablated, without damaging the substrate material. This is accomplished with the accurate energy control of the laser. This offers further application possibilities with the decrease in the Packaging pitch (Wafer Level Packages, CSP, µBGA®). The photolithographic structuring of solder masks presently can handle apertures as small as 150-200µm. Also here laser ablation allows further integration and smaller apertures. Fig. 6 shows the opening of a solder mask (manufacturer: Lackwerke Peters / Germany) with the developed laser system. With a resist thickness of 25µm an ablation speed of 60mm per second could be achieved. The opening width here was 100µm, however elements can eventually be as small as 50µm. The Cu underneath could be plated after a usual cleaning process with Ni / Au without problems. This technology can also be used for HDI applications to open PI or PET based cover coats or cover layers.

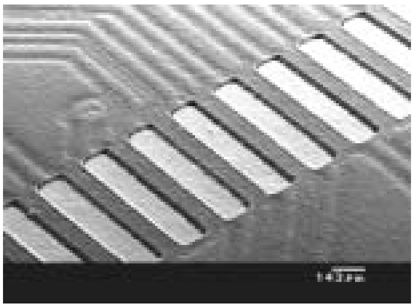

Fig. 6: Solder mask structured with laser

Investigations of conductive material (Ag based) embedded into polymer substrates to create conductive structures, found that the UV laser system can successfully be used here. In Fig. 7 such structures are shown. A special polymer system on epoxy resin base with a layer thickness of 15µm could be structured at a speed of up to 300mm per second. The minimum structure width was obtained with 25µm.

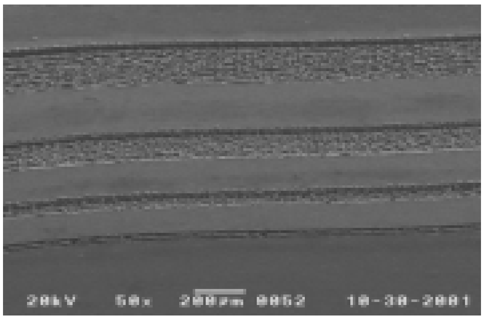

Fig. 7: Laser scribed tracks for Ag-Paste

Laser Routing

The freely programmable and flexible mode of operation make UV lasers particularly suitable for precision cutting of HDI applications[11,21] (depanelization, singulation). With the developed laser the most different material combinations could successfully be processed. Fig. 8 shows an HDI multilayer with 6 layers of different materials (FR4 / polyimide / epoxy resin and acrylate resin). The cutting velocity was 10mm per seconds. Delamination did not occur.

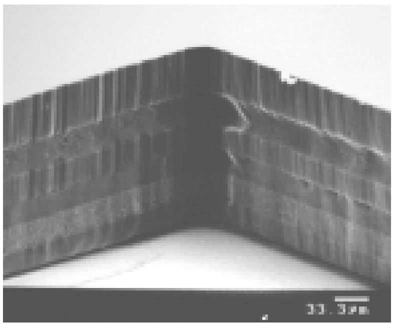

Fig. 8: Multilayer build-up, laser routed

In addition, glass-fiber reinforced FR4 could be processed with UV laser, as represented in Fig.9. The edges are clean and don't need any post processing, as usually would be required with mechanical routing or punching or when cutting with CO_2 laser.

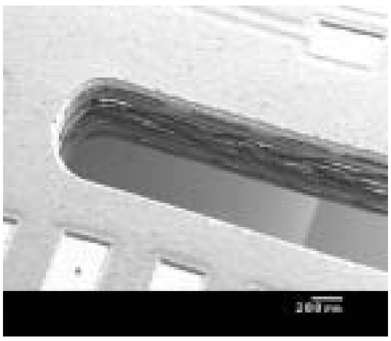

Fig. 9: FR4, laser cut

The cutting velocities, which can be reached, are material dependent and are typically within a range of 50mm to 500mm per second.

Summary

The presented laser technology was developed for a broad application field including, drilling, structuring, and cutting. It enables, in particular, small and medium-size companies to enter the HDI technology. Since only a single UV laser source is used, this system is very economical. The laser source was developed exclusively for this system, in order to achieve maximum performance at low maintenance cost and superior uptime. An arc lamp pumped laser is used, which allows the users to change lamps independently. The lamp life is specified with 300 hours working time and the calibration of the system requires a minimum expenditure of time.

Such a system is well suited for prototyping, since it both drills and structures. It also represents an alternative to photolithography. Since it operates in the UV spectrum at 355nm, the possible material range extends from flex to rigid PCBs including polymer materials such as solder masks, cover coats, galvano resists to name a few.

References

1. IPC, The National Technology Roadmap for Electronic Interconnections 2000/2001
2. Cutting Edge Manufacturing- Applying Lasers in Electronics Production, PRISMARK Partners LLC, Dec. 2001
3. “When is the Right Time to Buy a Laser Tool“, Schaeffer, R.D., CircuiTree, Feb. 2002, 56
4. “Improvements in High Speed Laser Microvia Formation, Using Solid State Nd:YAG UV Lasers“, Cable, A., IPC Printed Circuit Expo 1997 , Technical Paper p. 17-7, San Jose, 1997
5. “Current Alternatives to Direct Imaging/ Patterning (Part II)“, Vaucher, Ch., CircuiTree, 46, July 2001
6. UV-Lasers, Effects & Applications in Material Science, Duley, W.W.,Cambridge University Press 1996
7. “UV Laser Drilling of Multilayer Blind Vias“, Raman, S., Schreiner A.F. IPC Printed Circuit Expo 1998 , Technical Paper p. 17-1-1, Long Beach, 1998
8. Excimer Laser Ablation and Etching, by J. Brannon, American Vacuum Society Monograph, 1993
9. “Research for innovative PCB technology and experience with laser tool“, Krabe, D. Scheel, W., Glaw, V. , Printed Circuit Europe, Jan.-Febr. 1998, p. 9-13

10. ”CO_2-Lasers for Microvia Drilling and other PCB and Flex Applications“, Schaeffer, R., CircuiTree, September 2001, p. 90

11. ”Laser Processing of Flex“, Venkat, S., PC FAB 2001, p. 28-34

12. CircuitCAM- LPKF Laser & Electronics AG, Software

13. “Copper Foil for HDI Applications“, Cheskis, H.,et al., IPC Printed Circuit Expo 2001, Technical Paper p. 13-2-1, Anaheim 2001

14. “Empfehlungen zur Herstellung von Löchern mittels Laserablation in Leiterplatten und Multilayern, die mit THERMOUNT nichtgewebten Aramid verstärkt sind“ Powell, D., Weinhold, M., Dec. 1993

15. “Ultraviolet laser system and method for forming vias in multi- layered targets“ US-Patent 5.593606, 1997-01-14

16. “Thermal Reliabily of Laser Ablated Microvias and Standard Through- Hole Technologies“, Young, T., Polakovic, F.; IPC Printed Circuit Expo 2001, Technical Paper, Long Beach 1999

17. “A Novel SBU Dielectric and Coating System“, Wall, C., PCFAB 2000, p. 36-44

18. “Direkte Laserstrukturierung-50µm-Strukturen mit mindestens 80% Ausbeute“, Krause, J., PLUS-Produktion von Leiterplatten und Systemen 3/2000, 395-398

19. “A High-Density, Resin-Coated-Foil (RCF) Substrate Utilizing Mask and Direct Write UV Laser Photography“, Corbett, S. et al., International Conference on High-Density Interconnect and System Packaging 2001, Copenhagen

20. “Microvias Using a Conductive Paste to Replace Electroless Plating“, Gandhi, P. et al., IPC Printed Circuit Expo 2001, Technical Paper, p. 13-3-1, Anaheim 2001

21. “Solid State Lasers-Provide Manufacturing Solutions for Flex Circuits“, Venkat, S., CircuiTree November 2001, p. 46-53