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Laser Direct Structuring as an Innovative Alternative for Traditional Lithography

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Abstract:
The combination of high speed and accuracy laser beam deflection, the know-how on wet chemical processes for Printed Circuit Boards (PCB's), as well as CAD/CAM implementation for Laser direct Structuring (LS) of PCB's together with machine development and construction know-how, resulted in a total laser technology with a dedicated system (Figure 1), that offers an innovative alternative for the manufacturing of High Density Interconnection (HDI) technology.

The LS process can easily be integrated into standard PCB production lines, what is proven at a European PCB manufacturing site. The LS process uses a thin immersion Tin (Sn) as etch resist that is ablated by a focused laser beam. The laser beam contourizes the circuitry tracks and pads.

The movement of the laser beam is controlled by a high-speed controller, based on electronic CAD-layout data. This allows to achieve 50 µm space – line structures –and even smaller- without the need for clean room facilities, with acceptable yields (>70 –80%) and acceptable processing time.

Furthermore, the system has a highly flexible modular construction; a system set-up with a 532 nm (green) or 355 nm wavelength laser proofs to be an excellent structuring as well as µ-via drilling system and this from quality but also performance view point.

Introduction

At the moment, even for HDI boards, for most PCB manufacturers, 100 - 75 µm space-line technology is standard. To go below this imaginary line-space width, large efforts and investments are needed. This is caused by the necessity for clean rooms (2500 EUR/m²) and/or the need for glass master technology (which has on its turn an impact on the panel size – and thus throughput). Besides this, the achievement of acceptable yields is another critical issue.

Next generation electronic devices may require high density but just for one or two components, while at the same time keeping >90% of the PCB area in the conventional 100 µm space line technology. Chip sized packages (CSP) used in GSMs, cameras, pagers etc. ask for adaptation and innovation in PCB manufacturing processes, resulting in lower tolerances and finer lines/spaces. Here the use of laser structuring becomes justified: add locally - as pure drop-in process - fine structures by using laser technology, implemented in the standard PCB manufacturing line.

This is the so-called PHD process (Partial High Density). For small substrate dimensions like BGA/CSP or MCM substrates, the whole area can be laser structured within the field size of the laser optics.

The constructed Laser structuring system allows structuring for partial high-density areas (field size 50 x 50 mm²) or for full structuring PCB's or packages (like e.g. MCM or BGA packages).

Figure 1 - Microbeam â System

The impact for the electronic industry is clear: miniaturization of fan-out areas with high densities becomes possible, not only due to the realization of smaller space-lines but also to a major extent due to the better registration possibilities (with smaller absolute tolerance ranges).

Laser Structuring can have an important contribution to the reduction of the high registration tolerances in the PCB manufacturing compared to the conventional lithography.

Using the tin etch process and LS with a positioning accuracy of <10 µm in the laser scan area of 50x50 mm², there is almost no more need for a rest ring around the drilled vias, or in case of solder stop removal, around the solder pads. The electronic control of the laser beam positioning system is even able to locally scale the layout by adapting itself to the measured hole positions.

A reduction of the needed circuit area is one of the obvious advantages but it is still limited to the dimensions of the components to be mounted. Only high-density packages like BGA's, CSP's or Flip-Chips can take advantage of the miniaturization potential of the LS process.

Besides the fine line capability by using the well-known tin etch subtractive process, the LS process becomes also very attractive for coarse structures once the linear laser processing speed is high enough. This is scheduled in the machine roadmap for the next 2 to 3 years. In the meantime layouts have to be optimized and adapted for minimum LS-processing time. This can be proven with suited applications that have a high potential for going into large manufacturing volumes.

Another application is the removal of the cured solder stop mask in high density BGA, CSP or even Flip-Chip areas. Where conventional imaging is restricted to annular rings, exposed and developed free around the pads, LS can reduce this tolerance to < 10 µm.

The Laser System as Ideal Process Tool: Main Components

A dedicated laser processing system has been developed for fulfilling processing tasks under volume manufacturing conditions. The key components determining the speed of the system are the laser source itself, the deflection unit (galvo-head), the steering hard- and software and the mechanical periphery (like X-Y moving table).

Laser Source

A Nd:YVO4 (Vanadate laser) was selected as best suited laser source for the aimed applications. This laser has very short pulse widths (< 35 ns) even at high working pulse frequencies. Due to the nature of the process, a substantial pulse overlap (>60%) is required to obtain straight track edges (see Figures 2 and 3). For higher speeds higher frequencies are required. Therefore laser sources with pulse frequencies > 100 kHz are needed. These frequencies, combined with short pulse widths, are realizable with the Vanadate crystal.

This laser type is relatively new because of historical difficulties in manufacturing the Vanadate crystals with good quality. Thanks to the availability of diode pumping the crystal dimensions became a lot smaller compared to earlier rod crystals that had to be lamp pumped.

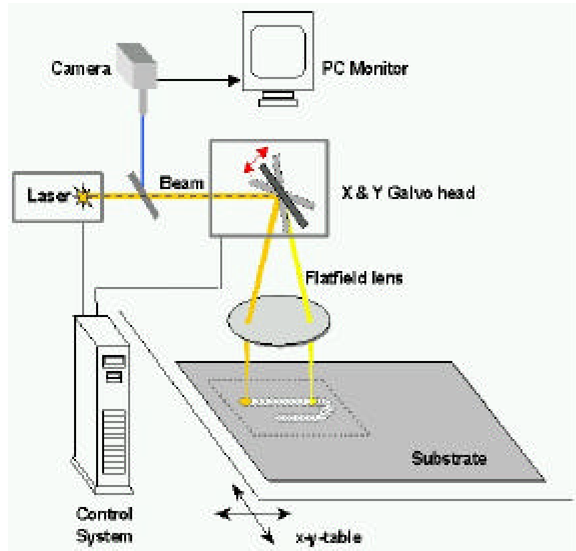


Figure 2 - Schematic Illustration of the Laser Structuring System, Showing Overlapping Pulses

As a benefit of the small pulse widths (compared to e.g. Nd:YAG lasers), the thermal load on the printed circuit board is reduced to a minimum: the shorter the laser beam impact is, the lesser thermal loading on the substrate can occur. The main reason is that a lot of ablation processes occur in the very first nanoseconds of a beam pulse; the rest of the pulse just couples in an extra amount of heat into the processed substrate. On many substrate materials, thermal load can cause delamination or cracking, which presents a quality problem at µ-via or through hole level in a PCB.

Together with the major laser source suppliers, the laser source is and will be further tuned to the application by increasing the available power and the working pulse frequency and decreasing the pulse width.

Besides the base wavelength of 1064 nm, the frequency doubled, tripled and quadrupled lasers are also considered. Although the speed is often directly proportional to the beam diameter and the available power or energy per pulse, to some materials a specific wavelength shows better absorption characteristics. For structuring the 532 nm laser has a better absorption on tin and copper and brings finer lines than the 1064 nm in a comparable working field.

The Deflection Unit

To achieve acceptable speeds, galvo-head providers try to offer deflection heads that function at high angular velocity with high positioning accuracy (and repeatability).

Momentarily, the working speed is imposed by the bottleneck of the system: it can be the laser source (power) the steering card (vector output rate) or the deflection head.

1200 mm/s at a resolution of 5 µm can be reached now. Very fast laser beam deflection (5 – 10 m/s) at high positioning accuracy (< 5 µm) is in development.

Hardware Steering Card (LDS Card)
The electronic hardware to monitor the laser pulse output, combined with laser beam positioning over the galvo-head is done by the LDS Card, a special developed printed circuit board with dedicated electronic components. Actually the vector output rate is reaching >700 kHz, which means that per second 700,000 vectors can be generated at a resolution of 3 µm (per vector); this means that a maximum laser beam positioning speed of 2100 mm/s is possible at given resolution (if the galvo heads could realize this).

With the hardware, suitable software for the preparation of the laser data together with the conversion to vector data is available. This card calculates during process all the transformations due to optical and geometric distortions along the beam pad and for position calibration and stretching.

The amount of generated laser data is minimized because they are only vector data.

The system allows standard Gerber or DXF Format Input for structuring. Also laser drilling on the same system can be done (with the respective drilling formats like e.g. Excellon).

High Positioning Accuracy
A very important property of the system is its ability to align and position within the galvo field size with very high precision. Table positions are reached over linear stages but within the galvo field size (50 x 50 mm²) the exact registration versus given targets (fiducials) is realized using a vision system that locates the targets by looking over the galvo mirrors (along the laser beam) and thus calibrating itself automatically for galvo drift failures, reaching accuracies for the overall laser system (350 x 350 mm²) of +/- 10 µm.

All this is necessary for solving the tolerance problems in succeeding process steps on different layers and for stitching different part pictures belonging to one PCB layout. The working area is 710 x 610 mm².

The Laser Process for Fine Line Structuring
The Laser Process
The laser ablation process is based upon local ablation of tin (Sn) from a copper surface; it provides a simple manner to realize line-space densities that reach dimensions of < 50 µm (or even < 30 µm), depending upon the copper thickness to be etched.

The Sn ablation process, was first patented by Wittig in 1983 and became a public domain a few years later, so there is no restraint for using this process in industry. The process is reliable, well known and in use for prototyping applications. An extra advantage is the very thin etch resist that the immersion offers: 1 to 1.5 µm is much thinner than most conventional but also than special ED (Electro-Deposit) resists that have to fulfill this function.

Another alternative replaces the thin immersion Sn layer by organic resists, but in all cases, the thickness will always be bigger compared to immersion tin. Several major resist manufacturers offer resists that are suited for laser ablation.

The focused laser beam contourizes the track or pad layout and evaporates the thin tin layer from the underlying copper (Process details in Figure 3). Even from the copper a few microns could be removed. This free lying copper can then subsequently be etched (no acid etch possible due to the tin presence). This process has been proven to be effective for realizing circuitry on 3D (Molded Interconnection Devices) substrates.

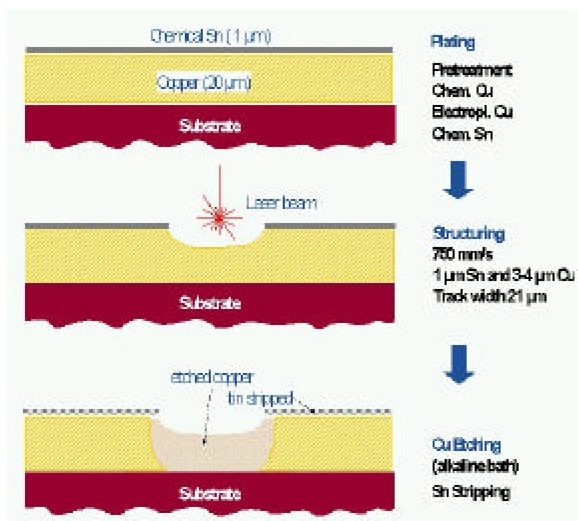


Figure 3 - Illustration of the Sn ablation LS Process

The process mainly used for PCB's is a subtractive one (see Figure 3). Achievable space-line widths are dependent upon the used laser, optics and the copper thickness. The relation between these parameters is shown in Figure 4.

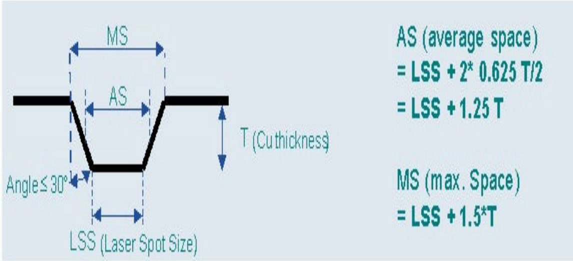


Figure 4 - Calculation Model Based Upon Practical Experience with the LS

Due to the modularity of the base laser system, other laser wavelengths and optics are possible. This results in achievable space widths as shown in Figure 5. These values of course do not only depend upon the used laser system and wavelength but also upon the etch bath quality.

Figure 5 gives a brief summary of the technology's potentials for fine line structuring. The smallest space that will remain after etching is taken is main criterium. As the standard laser system uses a 50x50 mm² scan field size, the laser spot size in focus is wavelength dependent. The smallest spot size in focus is 15 µm (UV), 22 µm (532 nm) and about 35 µm (1064 nm).

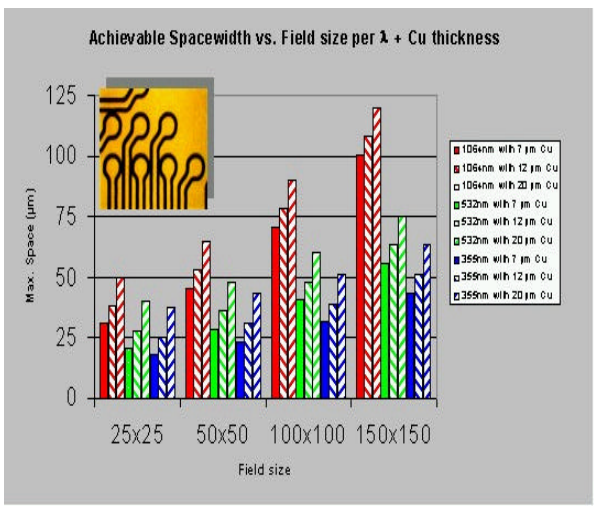


Figure 5 - Achievable Maximum Space (See Formula in Figure 4)

The best compromise between structuring speed (laser power) and smallest feature size (spot size) is the green (532 nm) wavelength. But every wavelength has its own proper advantages: using 1064 nm allows high speeds (but has a big spotsize), using the UV laser and thin copper, pitches of 25 to 30 µm become possible, but structuring speed must be offered.

Related to Laser Wavelength, Galvo Field Size and Copper Thickness

An example of fine lines in 18 µm of copper is shown in Figures 6 and 7.

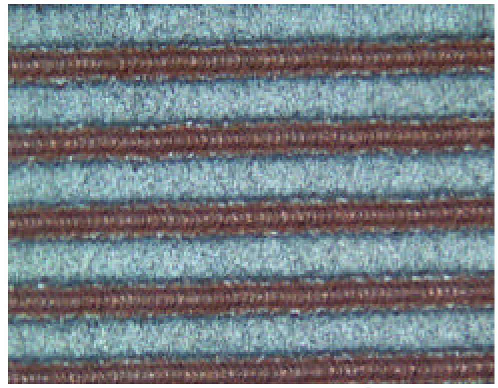


Figure 6 - Laser Structured Lines (Sn ablated from Cu)

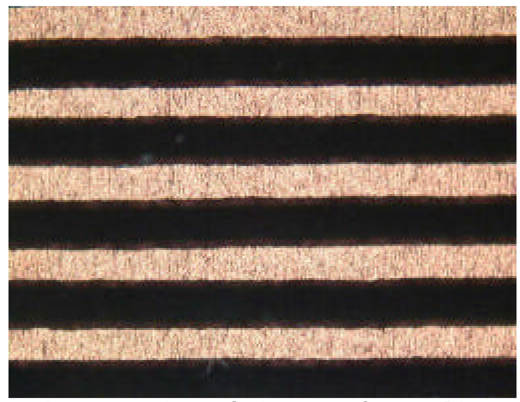
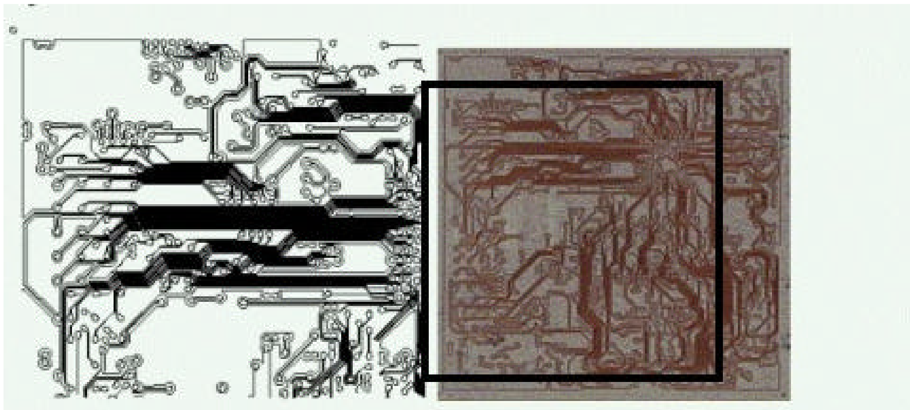


Figure 7 - Lines of Figure 6 after Etching nd Tin Stripping

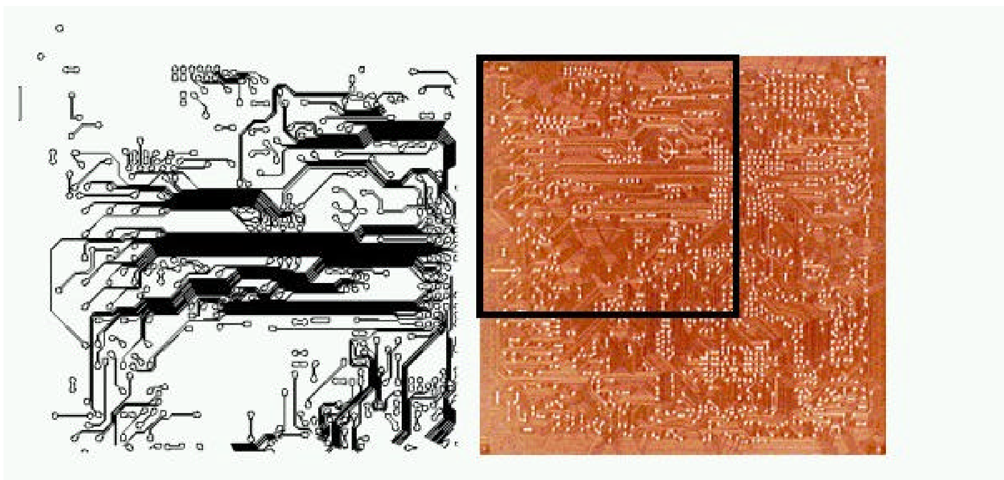
The Process of Optimizing the Layout for Laser Direct Structuring

The laser structuring process is very well suited for so-called "max copper" applications. The focused laser beam only has to contourize the tracks and pads and leaves all other copper planes unaffected. Concurrent engineering has to help the customer (the developer of the board – NOT the manufacturer) to optimize his design. From the EMI shielding viewpoint this max copper design is better known as "line in plane design" and must ground all planes to avoid the presence of floating copper planes that could interfere with the functionality or signal integrity of the board.

By doing this, the total laser track length is minimized and throughput maximized. This max copper design (Figures 8 and 9) is a world apart compared to the standard copper removal version. If the copper planes had to be removed, the time consumption for the non-max copper design is a factor 5 to 10 higher as is shown in the examples in Figures 10 and 11.



Figures 8 and 9 - Part of Layout (left = black square right) and Laser Structured PCB with “Max Copper” Design



Figures 10 and 11 - Part of Layout (left = black square right) and Laser Structured PCB with “Non- Max Copper” Design

Another practical example shows how the reduction of line-space dimensions drastically increases the total copper surface area and thus reduces the area that has to be laser ablated.

The layout engineer reduces the spaces between tracks and pads and their respective adjacent copper planes to 50 µm. The nominal line widths are preferably 50 µm too, as long as the copper thickness allows it (see Figure 5).

An example of a standard layout (100 µm line / 130 µm space) compared to a laser optimized layout (50 / 50 µm line-space) shows a drastic reduction of the area to be lasered (all white areas have to be lasered). Often not only reducing the widths of the lines and spaces but sometimes minor layout changes help to come to maximum laser throughput. (See Figures 12 and 13)

A copper area of 655 mm² was the standard layout, (Figure 12) which resulted in 936 mm² (Figure 13) after changing the original linewidths of 120 µm and space widths of 100 µm to 50 µm both and after a few minor layout changes. This resulted in a laser time reduction between 30 and 50 %.

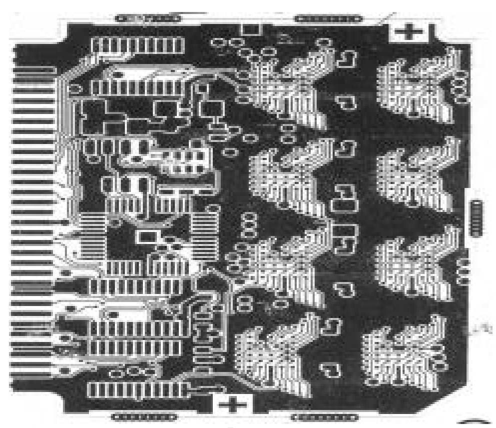


Figure 12 - Example Layout / 100/120 µm Line/Space Standard Layout : 655 mm²

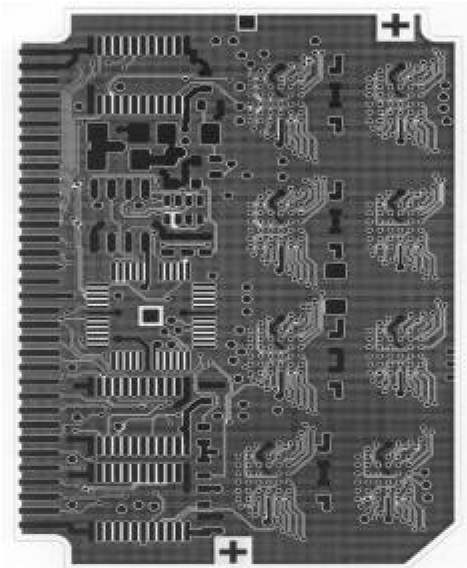


Figure 13 - Example Layout / 50/50 µm Line/Space Optimized Layout: 936 mm²

The Laser Process for Solder Stop Ablation

The introduction of CSP (Chip sized Packages) or even Flip Chip on Board becomes a reality today. This imposes high requirements on the use of the solder mask in the high-density area. Conventional exposure and development, followed by curing the solder stop cannot guarantee a clearance < 50 µm on a panel of e.g. 510 x 610 mm.

An accurate laser evaporation of the solder resist reduces the solder stop clearance position accuracy to ≤ 10 µm. The green (532 nm) wavelength is best suited for ablating at high speeds a solder mask of conventional thickness from copper pads; speeds of > 100 pads per second (diameter 250 µm per pad) are achieved. At the high removal speeds the PCB material just aside of the pad, is lightly affected by the laser beam and cannot avoid hitting it. Pressure Cooker tests (160h, 121°C, 100% r.h) and thermal cycle tests (-55°C /+125°C, 1000 test cycles) did not affect the reliability of the laser-exposed pads.

The next pictures (Figures 14-17) show how pads of 100 µm, that were laser cleaned from solder stop resist, look like after a 1000 hour thermal cycling tests: The solder resist shows slight discoloration (normal), has no damages (i.e. rips) and shows no changes in comparison to the printed circuit board before testing.

The laser and optics are adapted to get a favorable taper for the applying the solder paste in the next production step.

An additional advantage of the smaller clearance is the ability of getting more lines between adjacent solder pads by gaining extra space between them.

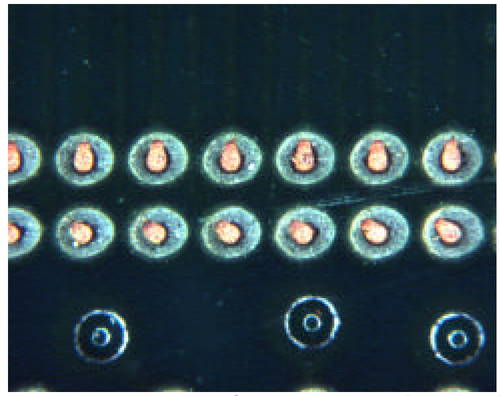


Figure 14 - Top View of Laser Exposed Pads after Thermal Cycling

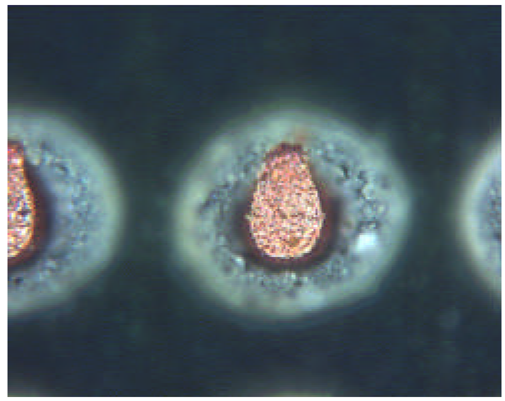


Figure 15 - Exposed Pad (Detail of Figure 14)

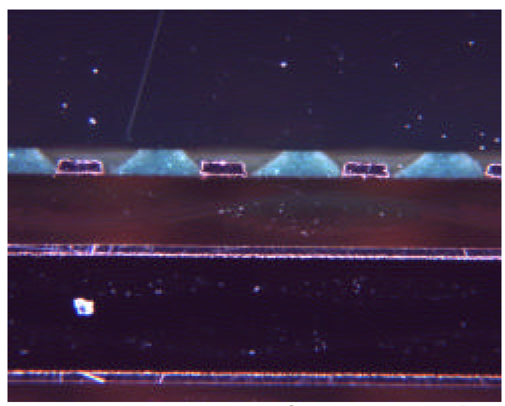


Figure 16 - Cross Section of Laser Exposed Pads in Solder Mask

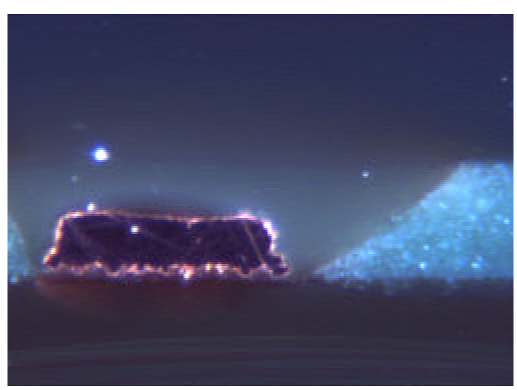


Figure 17 - Detail of Figure 16

Practical Examples in Manufacturing HDI Products using Laser Structuring

Test Board for Process Evaluation

To illustrate the possibilities, opportunities and limitations of this technology, there is no better way than implementing it under manufacturing conditions.

Together with a PWB manufacturing site in Karlsruhe, Germany, test structures in PHD technology were implemented on a standard SBU (Sequential Build Up) board (23.5 x 17 cm). Aim was to drop in the laser structuring technology into the conventional manufacturing line (no clean room is available). The 3 implemented components on board from were a µ-BGA 48 pins, grid 0.8 mm, a CSP – 192 pins, grid 0.5 mm and a flip Chip – 96 pins, grid 0.2 mm. The assembled board with cross section through one of the test structures is shown in Figures 18 and 19.

Evaluation on Flying Probe electrical tester and cross sections showed no LS relevant failures.

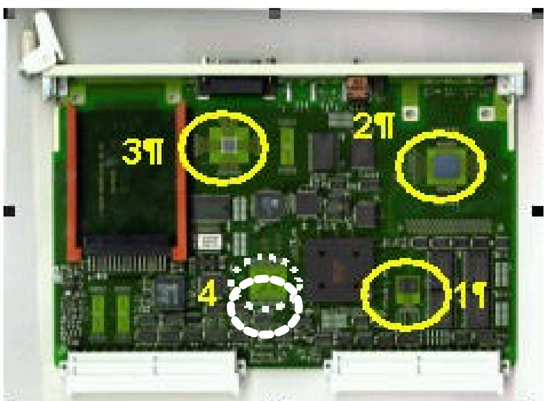


Figure 18 - Test Board in SBU Technology, Assembled (left) with (1) CSP 48 I/O - (2) CSP 192 I/O (3) FC 96 I/O and (4) Fine Line Tests Structures

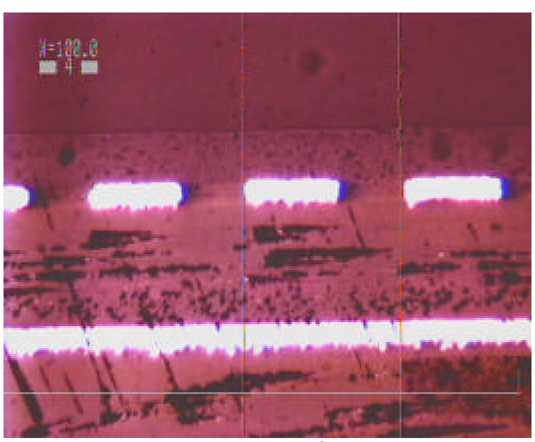


Figure 19 - Cross Sections of 50 µm Space Line Test Structures

MCM-BGA Substrate with Flip Chip Components for Automotive Use

An actual product example, completely realized in laser structuring technology, is an MCM substrate in high Tg FR4-05 material (Tg = 160 °C) for automotive industrial purposes.

It has 5 flip-chip components; line spaces of 50 µm, contains 6 layers and is finished with Ni-Au. Total thickness is 0.8 mm. The boards are manufactured in 7 rows of 6 boards (see Figures 22 and 23).

The first pass yield was > 75 % (electrical test results).

The pictures in Figures 20 and 21 below illustrate the laser structuring process and the final substrate.

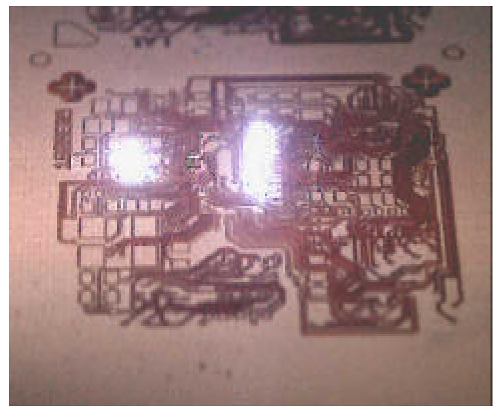


Figure 20 - Laser Structuring in Progress

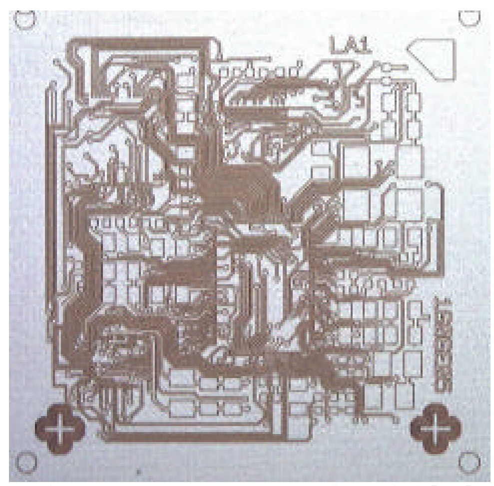


Figure 21 - Laser Structuring Finished

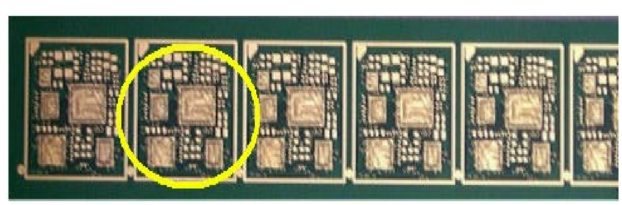


Figure 22 - Part of Production Panel (Each MCM = 27x27 mm)

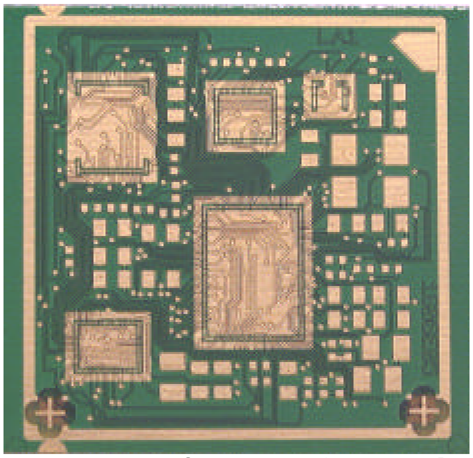


Figure 23 - MCM for Automotive, Completely Laser Structured (Yellow Circle of Figure 22)

PSGA: 3D Structured Substrate

Another example of direct structuring using the ablation of immersion tin, is the 3D structuring on PSGA substrates. These substrates are molded LCP substrates, that are fully copper plated and subsequently covered with immersion Sn, laser structured and etched. The picture below shows the advantages of laser direct structuring: due to the 3D features, conventional resist lamination and photo imaging is not possible anymore and the Laser direct structuring is the only way to realize this new type of chip package. The laser focal depth even allows to make connections over the edge as shown in Figure 24.

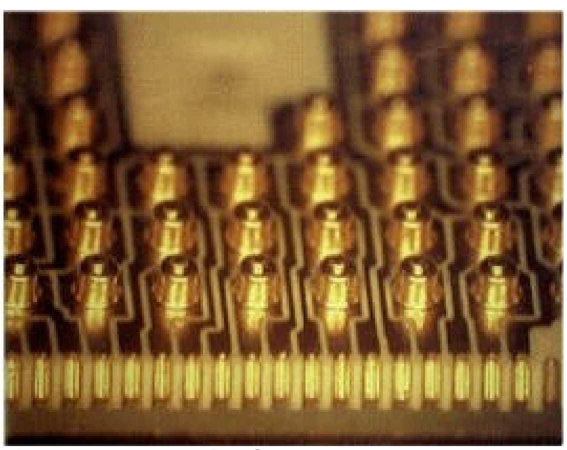


Figure 24 - Example of 3D Laser Structuring on a PSGA –The Laser Tracks are Going Over the Edge

Advantages of the LS Process and System

- The LS process with the tin resist etch step is a reliable process that enables to manufacture fine lines and spaces at low cost. This technology fits very well to most of the present process competence in (HDI) PCB production. This is the answer to the miniaturization push from the microelectronics industry with their chip-sized packages.
- With the LS technology the big tolerance problems of the PCB-manufacturing can significantly be reduced. The miniaturization potential of the LS-process cannot be neglected.
- The LS process does not need clean room conditions.
- The LS process can work without mask fabrication (e.g. glass masters) and handling, only electronic data are needed.
- The LS process makes the full automation of the PCB process sequence more possible.
- The ability of this technology to realize structures between 3D features on e.g. molded substrates like Polymer Stud Grid Arrays (PSGA), a new innovative package technology.
- The flexible modular concept of the laser system allows the use for other applications like e.g. drilling, trimming of resistors, soldering, etc….
- Compared to conventional imaging with all the required wet chemistry for resist development and stripping (that are not always aqueous solutions), the laser direct imaging process is a very environmentally friendly process.

Practical Utility

The above listed advantages clearly illustrate the practical utility for the electronic industry. With LS a new and innovative technology with a therefore developed laser system exists with a large market potential with high grow rates worldwide, especially due to the machines capability to perform µ-via drilling at high speed and quality.

Even more important than the machine market will be the influence for the electronic market. With LS there is an answer to the enormous microelectronics push for further miniaturization and cheaper packaging, as well on chip substrate- as on PCB-level. LS bridges the gap between chip-sized packages and chip-sized electronics. The laser becomes the most important manufacturing tool in the electronics industry for chips, packages, connectors, PCB's, MID and MEMS.

Another important problem is the positional accuracy of the solder stop mask in High Density areas. Here the same laser system offers the ability of removing the solder stop from critical pads with very high accuracy.

LS will bring new and innovative products alive like e.g. applications for chip packaging on other substrates like the PSGA.

Conclusion

As high density on PCB's becomes an absolute must for high performance applications, the introduction of micro-via boards in Sequential Build Up (SBU) technology offers a step in the right direction.

With the addition of the Laser Structuring (LS) process to the SBU technology, a reliable improvement in technology has been achieved to locally provide 50 µm space and line structures, and smaller, with high position accuracy and to achieve, without need for clean room conditions, yields that are comparable to those of the SBU technology itself.

Acknowledgments

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