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Laser Direct Imaging of tracks on PCB covered with laser photoresist

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Abstract. The increasing demands for miniaturization and better functionality of electronic components and devices have a significant effect on the requirements facing the printed circuit board (PCB) industry. PCB manufactures are driving for producing high density interconnect (HDI) boards at significantly reduced cost and reduced implementation time. The interconnection complexity of the PCB is still growing and today calls for 50/50 μm or 25/25 μm technology are real. Existing technologies are unable to offer acceptable solution. Recently the Laser Direct Imaging (LDI) technology is considered as an answer for these challenges. LDI is a process of imaging electric circuits directly on PCB without the use of a phototool or mask. Our laboratory system for Laser Direct Imaging is designed for tracks and spaces on PCB with minimum width distance of 50/50 μm. In comparison with conventional photolithography method, this technology is much better for 50/50 μm track and spaces. In our research we used photoresist with resolution 50 μm, but in case of using laser photoresists with better resolution (e.g. 25 μm) it will be possible to image tracks in super-fine-line technology (25/25 μm). The comparison between two technology of creating mosaic pattern tracks on PCB proved that laser imaging is promising technology in high density interconnects patterns, which are widely use in multilayered PCB and similar applications.

Key words: Laser Direct Imaging (LDI), photoresist, printed circuit board (PCB), UV laser.

1. Introduction

Since many years electronics market calls for smaller and lighter and more reliable portable electronic devices. As challenges facing to electronic devices manufactures are going to be more critical, they create new, smaller housings of the integrated circuits. As a result, there are new, alternative designs of the multioutput circuits named CSP (Chip Scale Package). This construction leads to decreasing of induction and delay time of signal propagation as well as decreasing electromagnetic noise. There are new trends in this area:

- creating circuits housings with taped electric outputs situated on each four side with very small raster <0.5 mm,
- turning wire outputs into spherical contacts,
- turning the housings with outputs situated on its circumference into outputs situated at the whole bottom side as a net with very small raster,
- integrating a bared semiconductor structures directly on PCB using “flip-chip” technology.

Existing technologies are unable to offer acceptable solution and the inevitable results is reduced production efficiency and lower yields. For example, a R/C devices manufactures creates from year to year a smaller components such as 0402 (1 × 0.5 mm) or 0201 (0.5 × 0.25 mm) or 01005 (0.5 × 0.25 mm). During last five years an average tracks width in conventional PCB’s reduced from 200 μm to 100 μm. During next five years, the tracks width will reach 75 μm. So, conventional PCB’s will be manufactured in HDI (High Density Interconnects) technology where tracks and spaces of the electric circuits on PCB is 75/75 μm with 20 pads per cm^2 or even 50/50 μm in new technology fabrics.

Recently, major number of the PCB manufactures produces circuits board using masks to create circuits pattern on the photoresist (photochemical process). This technology unfortunately reached its limits due to creating high density interconnects on PCB. It is unable to create fine track on PCB below 150 μm of track width and spaces. This is a result of dramatically increasing number of losses.

Several new technologies have been developed and utilized in recent years to address this challenge. One particular solution based on the Laser Direct Imaging (LDI) has managed to prove itself, as the best and most comprehensive imaging solution for HDI boards [1]. LDI uses focused laser beam to direct expose PCB panel coated by photoresist, eliminating the use of phototools and exposure systems and avoiding all inherent problems, such as [2]:

- repeat defects from phototool handling and off-contact exposure,
- poor dimensional stability of the phototools (changes of size with temperature and humidity),

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- material changes of each panel between panels of the same batch.

LDI is carried out using a laser beam that is scanned across photoresist surface and switched on and off by means of a computer control system according to the electrical circuit pattern. It has been proved that LDI systems, which work in UV spectrum are most suitable for obtaining fine lines and spaces below 50 μm [1]. In order to be used in HDI board production, an LDI system should have the following capabilities [3]:

- high quality exposure of fine lines and spaces down to at least 50 microns and below if possible,
- good depth of focus ensuring imaging quality for high topography design. This is especially needed for uniform exposure of outer layers and Sequential Build Up applications (SBU),
- a system design that can accommodate various product types, materials, thicknesses, manufacturing technologies and production steps,
- a flexible, highly accurate registration system compatible with different manufacturing technologies and production steps,
- an ability to compensate dynamically for material dimension changes in order to overcome variance in panels form the same batch and to be able to achieve tight registration tolerance over the whole area of PCB panels.

The major advantage of LDI technology can be observed in reduced steps in imaging conductive pattern on PCB, particularly using of the masks. Table 1 shows differences between conventional and LDI technology.

Table 1
Steps in conventional and laser method of creating conductive pattern on PCB

Conventional Method	LDI Method
Preparing computer data for imaging masks	Preparing computer data laser imaging
Imaging Masks	Preparing a Copper surface of PCB
Development of masks	Lamination of the photoresist
Conditioning of masks	Laser Direct Imaging with LDI system
Preparing a Copper surface of PCB	
Lamination of the photoresist	
Fitting masks on PCB and creating vacuum	
UV imaging in UV curing machine	

2. Experimental setup

Our system consists of three major components: the UV diode laser (λ = 375 nm), the telescope and the optical scanner XY (Fig. 1). The UV diode laser generates a laser beam at average output power of 9 mW. The optical scanner has built-in two high speed galvo drivers with mirrors, which allows to displace focused laser beam with maximum velocity of 1 m/s. The scanner head is connected to a computer through a PC card. To focus the laser beam, the F-Theta objective (f = 100 mm) is used. The working area of the scanner head is 6 cm $\times$ 6 cm. A computer controlled telescope can dynamically change the laser beam divergence, which allows to change a laser spot size over the working area of the scanner. A control program was developed to run the scanner head (X-Y) and the telescope (Z) according to the patterns consisted of tracks with different widths. This program operates on HPGL files, which are widely used in the commercial devices related with PCB industry. System for Laser Direct Imaging in presented version is equipped with stationary table, which could be leveled in two dimensions to obtain an ideal distance between imaged PCB and focusing lens. This is necessary for imaging fine thin tracks in all working area of optical scanner. The final tracks width can be also adjusted by one of the motorized telescope lens, which has ring with a scale. Those adjustment elements are used for system calibration.

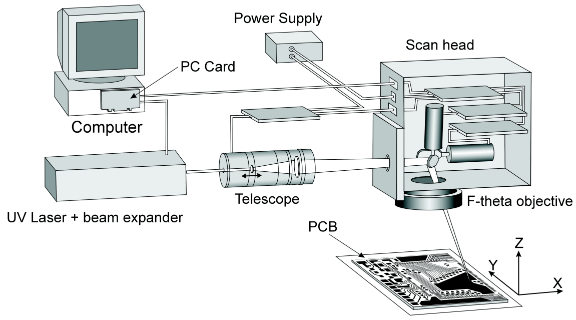

Fig. 1. Scheme of LDI system connections after Ref.4

The computer program has implemented two basic shape generators: multi-line generator and rectangle generator. Each generator can operate in two modes: “wobble” and “line by line”. The wobble mode is used to obtaining tracks with widths larger than the laser spot size. This is realized by joining two movements: linear movement along the specified vector and circular movement added to the linear. Changing the frequency and amplitude of circular movement one can obtain different tracks widths. This mode can be used only for tracks widths higher than 100 μm due to minimal amplitude of circular movement.

Second mode “line by line” can generate wide lines, which are combined with adherent lines. This method of imaging lines can be performed without any spaces between lines or with lines overlapping method. The degree of overlapping can be adjusted to obtain an optimum laser power distribution over the line surface.

At the moment, presented system for LDI allows to work in two dimensional area only. In the future a flat table will be changed to movable XYZ table, which expand all system capabilities. It will be possible to manufacture three dimensional shapes or elements made from special dry photoresists, which cure upon influence of UV laser beam radiation. 3D figures will be imaged layer by layer with micrometer resolution. This technique is suitable for small elements prototyping and can be used e.g. in medicine. In Fig. 2 a view of our laboratory system for LDI in present state is presented.

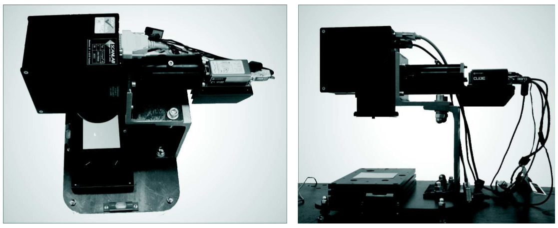

Fig. 2. A view of a real laboratory system for LDI

3. Results

During experiments of laser direct imaging on conventional photoresist KOLON, which photosensivity was 35–50 mJ/cm^2, we put a major impact on imaging tracks 50/50 μm. Tests were carried out on conventional photoresist to prove, that widely used conventional photoresist is suitable for LDI technology. The use of conventional phoresist is important for PCB manufactures, since the new LDI technology should be compatible to PCB's production process. During tests the velocity of imaging, frequency and, amplitude of circular movement, overlapping of the adherent lines and also average power of a laser beam were changed and optimal parameters for each operating modes of LDI system were found.

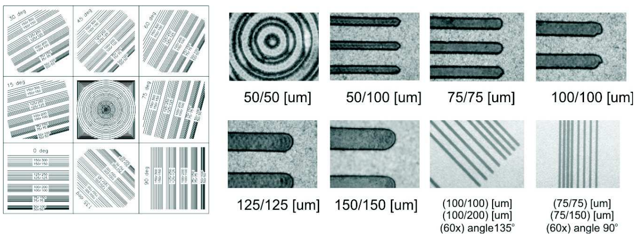

Fig. 3. Test pattern consisted of lines with different widths and angles and also circles inside

In Fig. 3 a standard test consisted of parallel lines with different widths around a central circular pattern are presented. The test was prepared to answer for the following problems:

- how the line width is dependent on angle of imaging,
- what is a quality of tracks when track widths and spaces are equal,
- what is a quality of tracks when spaces between tracks are two times wider than tracks widths.

The test shows also the quality of imaging of circles and track's angles. The experiments resulted in obtaining exact values of imaging process parameters. Imaging speed, was found to be optimal at 5 cm/s. Imaging with this speed produces fine tracks with smooth surface of photoresist lines without any irregulars at the track edges. Imaging with slower speed leads to much more irregular, rugged surface of line surface, which also resulted in bad edges. On the other hand, imaging with higher speed causes washing away of the tracks during development process, due to much smaller energy of laser radiation delivered to the photoresist surface.

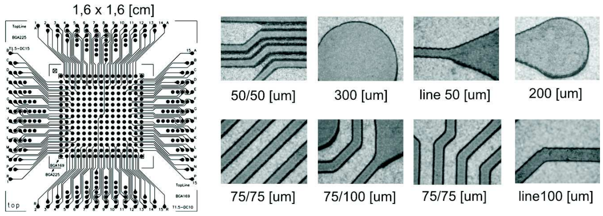

Fig. 4. Pattern BGA (Ball Grid Array) and magnified tracks on photoresist

In Fig. 4 the BGA pattern is presented. It consists of dots grid with tracks joining internal dots with external dots. This is an example of a real application of laser direct imaging technology. Such pattern is used for CSP technology (chip scale package) in electronic elements (processors or microcontrollers) with outputs on its back side. Dots were filled by adherent lines inside the circle, so the entire energy delivered inside the circle was resulted in smooth surface over the dots.

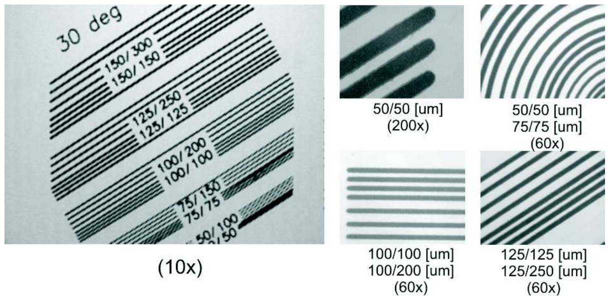

Fig. 5. Test pattern on PCB after etching process

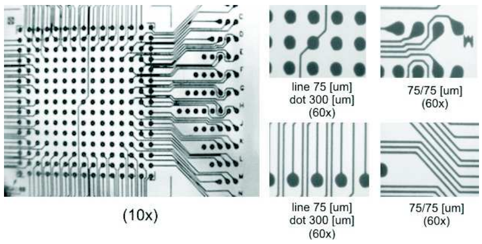

Fig. 6. BGA pattern on PCB after etching process

In Fig. 5 part of test pattern and magnified fragments are presented. The pictures were taken after the etching process of PCB. As one can see, lines with smooth borders and rounded endings are presented. This is due to the circular movement (wobble mode) during imaging process.

In Fig. 6 an examples of BGA pattern after etching process are presented. The widths of copper tracks on PCB are smaller than widths of photoresist tracks. This was caused by under-etching effect, which is observed during etching process.

In Fig. 7 examples of:

- dots with diameter varied between 100–500 μm,
- squares of increasing diameter patterns with tracks density between 50/50 μm – 150/150 μm,
- printed coil on PCB with 100 μm tracks width.

These examples show capabilities of control program for LDI system. In this case, dots were imaged by means of spiral movement starting from central point of dots. Separate lines in increasing square patterns (multi-square patterns) were imaged using "line by line" method. The coil printed on PCB was imaged using "wobble" method.

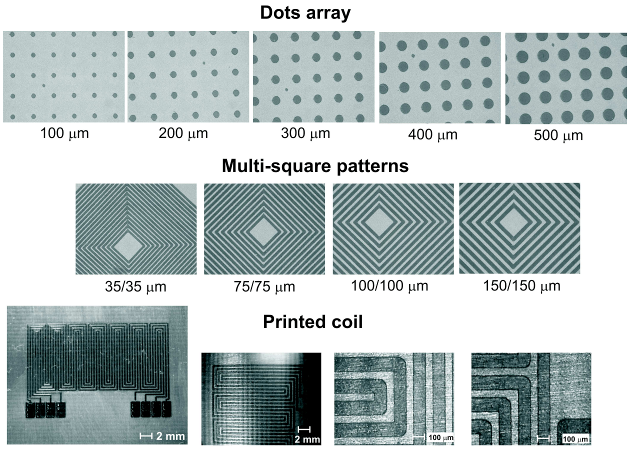

Fig. 7. Examples of different patterns on PCB, which show capabilities of control program for LDI system

In Fig. 8 four examples of tracks mosaic on PCB are presented. These examples were prepared using another function of control program – imaging from bitmap. These examples were published over the internet in PDF (Portable Data File) files, so the initial conversion into bitmap (BMP) file format was performed. This method of imaging tracks on PCB consist in separate imaging each pixel of the bitmap file. Using the presented system it is possible to obtain density of interconnects at 100/100 μm.

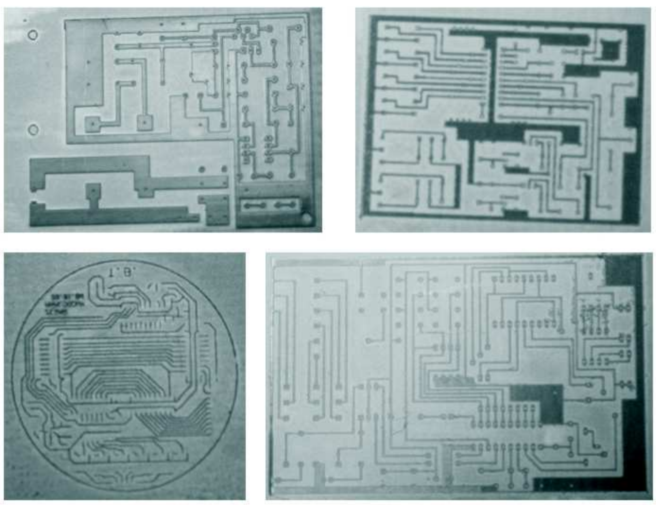

Fig. 8. Examples of bitmap imaging method of LDI system

4. Conclusions

Our recent results of the laser direct imaging using laboratory system for LDI proved that this technology is promising solution for high density patterns of the circuits on PCB. We obtained good results in imaging of the PCB covered by conventional photoresist which UV-sensitivity was 55 mJ/cm^2. We obtained 50/50 μm tracks and spaces density on photoresist layer, therefore the presented system can be suitable for super fine line technology. To check various shapes which can be present in a real PCB patterns we have developed a special test patterns: "Lines" and "BGA".

When portable equipment becomes more powerfull also complexity of the tracks on PCB is growing. The newest trend in PCB manufacturing is multilayered PCB's where even 100 layers can be developed. This multilayered technology is used today in computer motherboards. This allows to simplify all architecture of connections on motherboard PCB which has a significant impact on reduced overall costs. This is one of the solutions for high densities of interconnects and CSP technologies.

At now, our system for LDI is designed for imaging of the circuitry patterns on PCB covered by photoresist on area 6×6 cm, but we plan to wide up this area using a computer controlled XY table. It will allow to turn this system into a commercial system, where computer motherboard size PCB's are manufactured. This system can be also adapted as a system for stereo lithography in liquid photoresists. This improvement will allow to produce shapes with high precision and resolution of the elements. It will find application in medicine and other related fields where high precision and complexity of shapes are required.

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