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Laser Direct Imaging system for high density interconnects on PCB

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. This article shows an alternative method for creating electric circuit patterns on PCB in high density interconnects technology. In this article a prototype system for laser direct imaging as well as results of imaging examples are presented.*

Streszczenie. *Nowoczesne urządzenia elektroniczne są budowane z coraz mniejszych i sprawniejszych układów elektronicznych. W niniejszym artykule przedstawiono laboratoryjne urządzenie do bezpośredniego naświetlania ścieżek elektrycznych na PCB pokrytym fotopolimerem wykorzystując w tym celu technologię LDI (Laser Direct Imaging). W niniejszym artykule przedstawiono prototyp urządzenia do bezpośredniego naświetlania laserowego jak również przykładowe wyniki naświetlania ścieżek na płytkach drukowanych. (**Urządzenie do bezpośredniego naświetlania ścieżek elektrycznych na obwodach drukowanych**).*

Keywords: Laser Direct Imaging (LDI), photoresist, Printed Circuit Board (PCB), UV laser.
Słowa kluczowe: Bezpośrednie naświetlanie laserowe, fotopolimery, płytki drukowane, laser UV.

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 in PCB manufacturing are unable to offer acceptable solution to this challenges 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 x 0.5 mm) or 0201 (0.5 x 0.25 mm) or 01005 (0.5 x 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. Therefore, 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 [1].

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 [2]. 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),
- material changes of each panel and 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 have been proved that LDI systems, which works in UV spectrum are most suitable for obtaining fine lines and spaces below 50 μm [2]. The major advantage of LDI technology can be observed in reduced steps in imaging conductive pattern on PCB, particularly using of the masks. The table 1 show differences between conventional and LDI technologies.

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 for 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 of a Copper surface of PCB	
Lamination of the photoresist	
Fitting masks on PCB and creating vacuum	
UV imaging in UV curing machine	

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.

Experimental setup

Presented LDI system is consisted of three major components: the diode UV laser, the telescope and the optical XY scanner. The 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 scan 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 scan head is 6 cm x 6 cm. A computer controlled telescope can dynamically change the laser beam divergence, which allows changing laser spot size in working area. A control program was developed to run the scan head (X-Y) and the telescope (Z) according to 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 its initial state was equipped with stable table, which can be level in two dimensions to obtain an ideal distance between imaging 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. This can be used for system calibration. The computer program has implemented fine lines as well as rectangles generators operated in two modes: “wobble” and ”line by line”. The wobble mode is used to obtain tracks with width larger than spot size. This is realized by joining two movements: linear along 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” allows achieve wide lines, which are combined with adherent sub-lines, which can be imaged one by one without any spaces or with overlapping. The degree of overlapping can be set up to obtain an optimum laser power distribution on line surface. The schema of laboratory system for LDI is shown in Fig. 1.

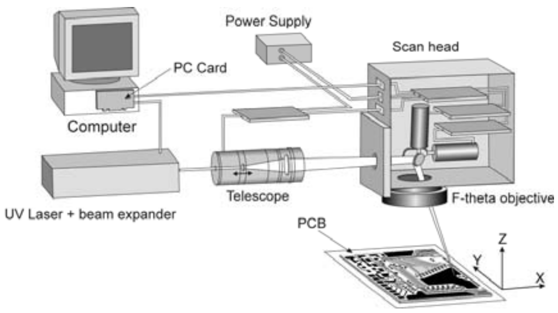

Fig. 1. Schema of LDI system connections [4]

System for LDI allows to imaging only in two dimensional area. 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. It is mean, that it will be suitable for rapid prototyping of small parts used e.g. in medicine.

Results

During experiments of laser direct imaging on conventional photoresist KOLON, which photosensivity was 35- 50 mJ/cm^2 [5], we put a major impact on imaging tracks of 50/50 μm. We were carrying out tests on conventional photoresist to prove, that LDI technology can operate also in widely used conventional photoresist. This is important for PCB manufactures to adapt new LDI technology to their PCB’s production process. During testes we have been changing speed, frequency and amplitude of circular movement, overlapping of the adherent lines and also average power of a laser beam. This lead us to specify a suitable parameters for any modes of LDI system and photoresists used during tests.

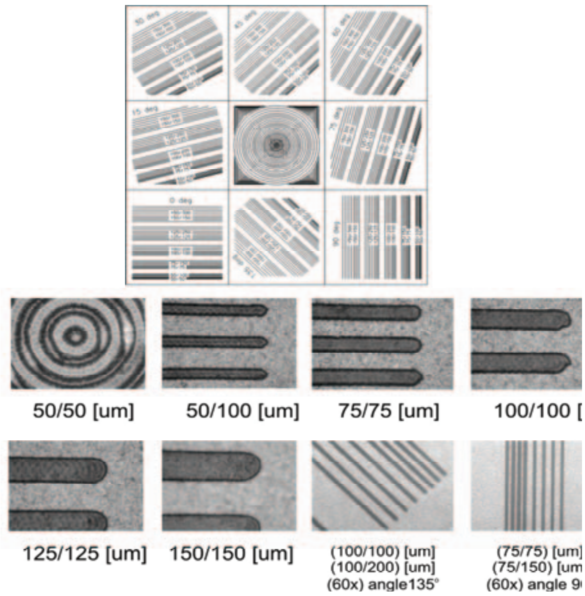

Fig. 2. Test pattern consisted of lines with different widths and angles and also circles inside

In Fig. 2 a standard test consisted of parallel lines with different widths around a central circular pattern are presented. This test was prepared to answer the following problems: if line width is dependent of the angle of imaging, how the tracks with equal width and spaces look and how the tracks with spaces two times wider looks. It also shows, how the circles and the right angles of lines look. Our tests resulted in obtaining of working parameters values. We found out that the imaging velocity of 5 cm/s should be set to obtain the best results with presented system. Imaging with this speed produces fine lines with smooth surface of photoresist lines without any irregulars at the edges of lines. We also observed that imaging with slower speed leads to much more irregular, rugged surface of line surface, what resulted in bad edges. On the other hand, imaging with higher speed causes washing away of tracks during development process, due to too small energy of laser beam, which is delivered to photoresist surface.

In Fig. 3 a BGA pattern is presented. It consists of dots grid with tracks joining internal dots with external. This is an example of a real application of laser direct imaging technology. This pattern is used for electronic elements (processors or microcontrollers) with outputs on its back side – CSP technology (Chip Scale Package). Dots were filled by adherent lines inside the circle, so the entire energy delivered in this place resulted in smooth surface of dots.

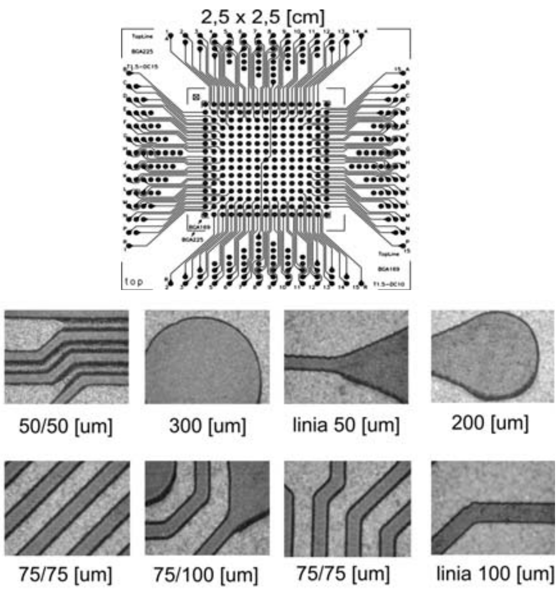

Fig. 3. Pattern BGA (Ball Grid Array) and tracks on photoresist

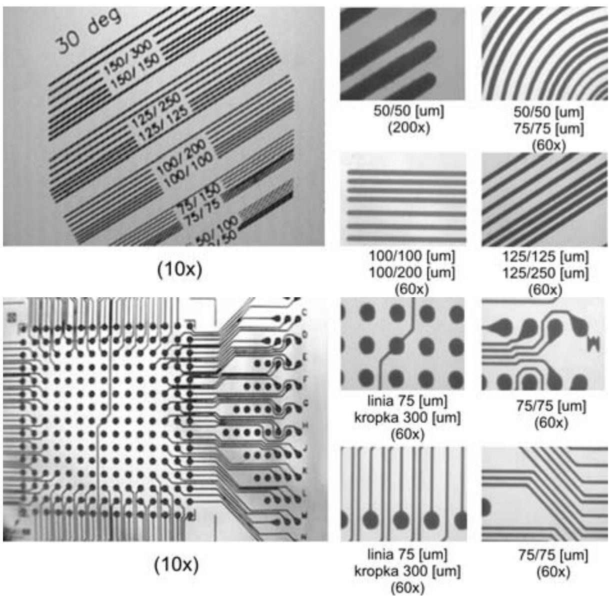

Fig. 4. “Lines” and “BGA” patterns on PCB after etching process

In Fig. 4 tests of lines and BGA patterns after etching process are presented. It shows, that copper tracks on PCB have smooth edges and endings, which is a critical parameter in high density interconnects technology. It proved, that with LDI technology we can produce patterns with parameters comparable to conventional photolithography technology.

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 obtain good results in imaging of the PCB covered by conventional photoresist which UV-sensitivity was 55 mJ/cm^2. We obtain 50/50 μm tracks and spaces on photoresist layer which is in a low range position of super fine line technology of tracks dimensions criteria on PCB. To check different situations which can be present in a real PCB patterns we have developed a special test patterns: “Lines” and “BGA”. The result of imaging test patterns proved our previous researches of the imaging process.

When portable electronic devices become more compact 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.

Presently, our system for LDI is designed for imaging of the circuitry patterns on PCB covered by photoresist on area 6 x 6 cm, but we are planning 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. Such system can be used for rapid prototyping of small parts important in medicine and other related fields where high precision and complex shape are required.

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