Emerald Insight

Circuit World

Recent progress in direct exposure of interconnects on PCBs

Robert Barbucha Jerzy Mizeraczyk

Article information:

To cite this document:
Robert Barbucha Jerzy Mizeraczyk , (2016),"Recent progress in direct exposure of interconnects on PCBs", Circuit World, Vol. 42 Iss 1 pp. 42 - 47
Permanent link to this document:
http://dx.doi.org/10.1108/CW-10-2015-0050

Downloaded on: 26 January 2016, At: 03:20 (PT)
References: this document contains references to 10 other documents.
To copy this document: permissions@emeraldinsight.com
The fulltext of this document has been downloaded 4 times since 2016*

Users who downloaded this article also downloaded:

Michal Baszynski, Edward Ramotowski, Dariusz Ostaszewski, Tomasz Klej, Mariusz Wojcik, Mikko Kohvakka, Anssi Kamari, (2016),"Evaluation of new technologies and materials for printed circuit boards with improved heat dissipation properties", Circuit World, Vol. 42 Iss 1 pp. 32-36 http://dx.doi.org/10.1108/CW-10-2015-0054

Alena Pietrikova, Peter Lukacs, Dagmar Jakubeczyova, Beata Ballokova, Jerzy Potencki, Grzegorz Tomaszewski, Jan Pekarek, Katerina Prikrylova, Martin Fides, (2016),"Surface analysis of polymeric substrates used for inkjet printing technology", Circuit World, Vol. 42 Iss 1 pp. 9-16 http://dx.doi.org/10.1108/CW-10-2015-0047

Wojciech Grzesiak, Piotr Ma#ków, Tomasz Maj, Beata Synkiewicz, Krzysztof Witek, Ryszard Kisiel, Marcin My#liwiec, Janusz Borecki, Tomasz Serzysko, Marek #upnik, (2016),"Application of direct bonded copper substrates for prototyping of power electronic modules", Circuit World, Vol. 42 Iss 1 pp. 23-31 http://dx.doi.org/10.1108/CW-10-2015-0051

Access to this document was granted through an Emerald subscription provided by
Token:JournalAuthor:AFFA52AD-15DA-4090-BC64-F4F0678EF283:

For Authors

If you would like to write for this, or any other Emerald publication, then please use our Emerald for Authors service information about how to choose which publication to write for and submission guidelines are available for all. Please visit www.emeraldinsight.com/authors for more information.

About Emerald www.emeraldinsight.com

Emerald is a global publisher linking research and practice to the benefit of society. The company manages a portfolio of more than 290 journals and over 2,350 books and book series volumes, as well as providing an extensive range of online products and additional customer resources and services.

Emerald is both COUNTER 4 and TRANSFER compliant. The organization is a partner of the Committee on Publication Ethics (COPE) and also works with Portico and the LOCKSS initiative for digital archive preservation.

*Related content and download information correct at time of download.

Downloaded by Doctor Robert Barbucha At 03:20 26 January 2016 (PT)

Recent progress in direct exposure of interconnects on PCBs

Robert Barbucha
Institute of Fluid Flow Machinery PAS, Gdansk, Poland, and
Jerzy Mizeraczyk
Department of Marine Electronics, Gdynia Maritime University, Gdynia, Poland

Abstract

Purpose – This paper aims to use a survey of techniques to present the patterning of electric circuitry on printed circuit boards (PCBs). Second, a proposal of a new technology for direct exposure of interconnects on PCBs, using a digital micromirror device (DMD) is presented.
Design/methodology/approach – In this proposal, the DMD chip was incorporated into a prototype system for exposure of soldermask pattern for a mass scale production. As a light source, 52 semiconductor UV lasers were combined together to deliver UV powerful beam onto the DMD chip area.
Findings – A laser beam power of around 9 W was achieved from a single exposure head. With five exposure heads installed into a single machine, it is possible to expose 1,400 PCB panels per day. Such a production rate from a single exposure machine satisfies the demands of biggest PCB factories.
Research limitations/implications – The Gaussian energy distribution of the laser beam from the 52-lasers head on the PCB surface was experimentally found. Because the exposure image needs to be highly uniform, this made a problem when the printed circuitry quality is considered. This problem was solved by using a software algorithm.
Practical implications – The use of UV lasers exposure heads brings economical advantages over conventional bulb UV lamps. The power consumption drops down ten times for lasers source.
Social implications – Because the exposure processing can be made with lower electric costs and higher yield, it will make the PCBs cheaper.
Originality/value – At present, the idea of collecting a great number of lasers as a UV source for exposure head is attractive solution.

Keywords PCB, UV laser, Exposure, Digital micromirror device, Laser direct imaging, Soldermask

Paper type General review

1. Introduction

The printed circuit board (PCB) industry has been a global business for a long time. PCBs can be found in the majority of electronic devices, which have become smaller, lighter and more efficient. The complexity of the electrical interconnections of PCBs is still growing and calls for either 25/25 μm or 15/15 μm (line/space) technology are more and more frequent. Thus, new sophisticated interconnect exposure machines need to be developed to meet these demands. One of the most important processes in PCB manufacturing is the exposure of the circuitry pattern on the photoresist layer deposited on the PCB surface. For many years, a conventional photolithography process utilizing special masks (phototools) for transferring the circuitry pattern onto a photoresist-covered PCB has been used (Bruning, 1997). However, as the circuitry complexity and miniaturization of copper tracks has increased, photolithography has become insufficient to meet the industry requirements. To meet these requirements, new technologies and exposure machines have been developed. Since 2004, laser direct imaging (LDI) technology has become the dominant method for manufacturing high-density interconnect (HDI) PCBs. It has been introduced by Orbotech with its Paragon machines. Inside these machines, large scan optics (LSO) and high-power UV laser systems are used to scan raster-style circuit data onto full-scale photoresist-covered PCBs with very high productivity rates (Barclay and Morrell, 2001). Also, several small-scale versions of LDI devices have been introduced to the market (Barbucha *et al.*, 2008), e.g. the Limata UV-P 300 machine (www.limata.de/en/). However, their productivities are lower than for the mass-scale Paragon machine.

Recently, spatial light modulator (SLM) devices for Micro-electro-mechanical-system-based (MEMS-based) digital light processing have brought innovation to the micro display technology. One of the most popular SLM devices is a digital micromirror device (DMD) introduced by Texas Instruments Inc (Dudley *et al.*, 2003). Being an MEMS chip, DMD found application as a light micro-modulator for projected images in a new kind of exposure machine. An exposure machine using such a micro-modulator for the direct exposure of interconnects on PCBs is capable of becoming

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/0305-6120.htm**

Circuit World
42/1 (2016) 42–47

[ISSN 0305-6120]
[DOI 10.1108/CW-10-2015-0050]

Received 20 October 2015
Revised 20 October 2015
Accepted 27 October 2015

highly productive, and, as such, it can become a competitor to the mass-scale machines offered by the Orbotech company. The main part of such machines with a DMD is an exposure head with a UV light source to generate a given pattern on the substrate. To be highly productive, the exposure head has to employ a high-power UV source.

The most important parameter in PCB manufacturing for mass-scale applications is productivity. It is described by the number of panels that one machine can expose in 24 hours. To increase the productivity, every part of the exposure machine must by pushed to the limits of current technology. As mentioned, one of the most essential parts of the exposure machine, in terms of productivity, is the UV light source (a high-power UV source is needed). At present, the only high-power UV sources available on the market are mercury–halogen lamps. A system with a 1 kW UV light source (a matrix of UV lamps coupled with fibers) is capable of exposing 300 double-sided solder masked PCB panels per day, e.g. the Mercurex system from Dainippon Screen (http://focus.ti.com/pdfs/dlpdmd/Mercurex.pdf). Unfortunately, this is too slow and does not meet with the market needs, where the exposure of 1,500 double-sided panels per day is required. This implies that new, more efficient UV light sources are needed. One proposal is using an array of UV diode lasers to form a high-power UV source (e.g. the technology of soldermask exposure requires a UV energy density of over 200 mJ/cm^2).

This paper, apart from outlining the progress in exposure equipment for PCBs, is focused on a new design of exposure head for LDI machines with a DMD, in which the UV light comes from an array of numerous UV (Blue-Ray) 405 nm lasers. Due to their present commonness throughout the world, the price of UV 405 nm lasers has become lower compared to LED and mercury lamp sources, which makes UV 405 nm lasers attractive for implementing in UV exposure machines. In this paper, also, on the basis of the presented new exposure head, the possibilities for the improvement of the direct exposure of interconnects on PCBs are discussed.

2. Progress in the exposure equipment for PCBs

Actually, the PCB was invented by an Austrian engineer, Paul Eisler, as a part of radio set while he was working in England around 1936 [7]. However, the first attempts to form integrated electric circuits were made before this by Thomas Edison (a chemical method of plating conductors onto a linen paper in 1904) and German inventor Albert Hanson (flat foil conductors laminated to an insulating board as multiple layers in 1903) (Harper, 2003). Since then, PCB technology has moved a long way to evolve into its present form (multi-layers, through-hole connections, HDI etc). Since the 1980s, surface-mounted devices (SMDs) have been increasingly used in electronic devices, instead of the earlier through-hole leaded components. This has led to smaller boards for a given functionality and lower production costs. As SMD components have become smaller, the PCB interconnects have needed to follow this progress in miniaturization. Thus, new development methods had to be implemented, in particular, new production machines with improved resolution had to be introduced to satisfy modern PCB requirements. In the next three sub-sections conventional and novel PCB manufacturing methods (LDI and DMD technologies) are presented.

2.1 Conventional photolithography method for PCB manufacturing

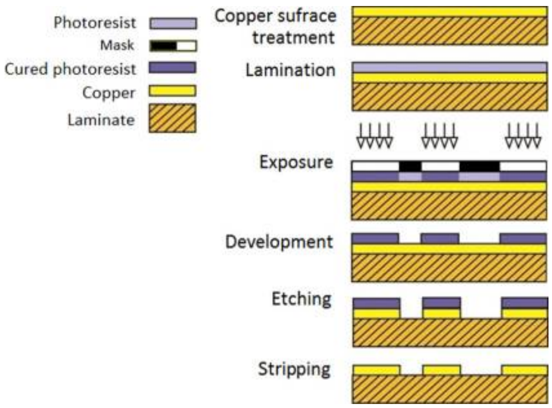
For many years the vast majority of PCB manufacturers have been producing circuit boards using masks to create circuit patterns in a photoresist (Figure 1). This technology utilized transparent masks with a circuitry pattern on them. The exposure process was carried out inside UV exposure machines, which utilized high-power halogen-mercury lamps as the source of UV light. This technology is called photolithography. Figure 1 shows six operations in the conventional photolithography process. The process starts with surface preparation of the copper layer (brushing, pumice and lamination). Then follow circuit pattern exposure, development, micro-etching and stripping (removing the photoresist layer). The circuit pattern exposure method utilizes masks which must be fabricated before performing the PCB exposure. The masks are made with digital printers. An advantage of using these masks is that they can be used many times for mass production. However, their poor durability is a disadvantage (the masks are vulnerable to contamination and dimensional changes caused by temperature and humidity variations). Also, the alignment of the masks on PCBs causes problems. At present, photolithography technology has reached its limit in terms of creating high density interconnects on PCBs. It is normally not possible to create finer tracks on PCBs below 150 μm (lines/spaces) (Barbucha *et al.*, 2006). Further progress in PCB manufacturing has been made via a new LDI technology utilizing UV lasers.

2.2 Laser direct imaging technology

Since 2004, LDI has become the most comprehensive imaging solution for HDI boards. It was introduced to the market by the Orbotech company with their Paragon 9,000 machine (www.orbotech.com/solutions/Eng/569/). LDI uses a focused laser beam to directly expose a PCB panel coated with photoresist. Thus, it eliminates the use of masks, whereby inherent problems such as:

- repeat defects from phototool handling and off-contact exposure;

Figure 1 Conventional photolithography steps utilizing masks to transfer electric pattern onto PCB



- poor dimensional stability of the phototools (changes of size with temperature and humidity); and
- material changes of each panel and between panels of the same batch, are avoided.

LDI is carried out using a laser beam that is scanned across the photoresist surface and switched on and off by means of a computer control system according to the specific circuit pattern required (Figure 2). Recently, LDI systems have been introduced that can expose fine lines and spaces on photoresist with a resolution below 10 μm (Dlugan *et al.*, 2000). It is used with the most challenging designs for ball grid array (BGA) and chip scale package (CSP) applications.

The Orbotech Paragon 9,000 machine is intended for use in the mass production of PCBs. The manufacturer claims that it can scan 160 PCB panels per hour. The internal optical design (LSO) is similar to that of a desktop laser printer. The machine uses a high-power UV laser (15 Watt, λ = 355 nm). Due to a telecentric optical design, the laser beam can be focused to a very small spot (diameter of around 5 μm). This allows the production of circuit patterns with a density as small as 8/8 μm (lines/spaces), which is suitable for most advanced PCB designs. The major advantage of LDI technology lies in the reduced number of manufacturing steps needed to fabricate patterns on PCBs. Table I shows the differences in number of steps between conventional photolithography and LDI technology. Apart from the reduced number of manufacturing steps, LDI technology enables the mass production of HDI boards, which was not possible using conventional photolithography.

2.3 DMD in a PCB manufacturing process

Recently, spatial light modulator (SLM) devices called DMDs have been introduced to micro-display technology. DMDs, invented by Texas Instruments in 1987, have become the core of the DLP (digital light processing) technology used for video projection, which is widely used in multimedia projectors (Dudley *et al.*, 2003). Because this technology offered improved image projection performance over the existing LCD display technology, it was just a matter of time before it was used in other industrial applications. There are many applications of DMD. For example, it can be used for the following (Favalora, 2003; Nesbitt *et al.*, 1999):

- switching light in a fiber optic networks;
- multi-media projectors;
- volumetric displays;
- back light modulator in large TV sets;
- patterning in biomedical applications (e.g. vascular imaging);
- 3D cameras (to project a mesh onto 3D objects);
- holography and data storage;
- microscopy, endoscopy and spectroscopy.

Figure 2 Raytracing simulation for exposure head

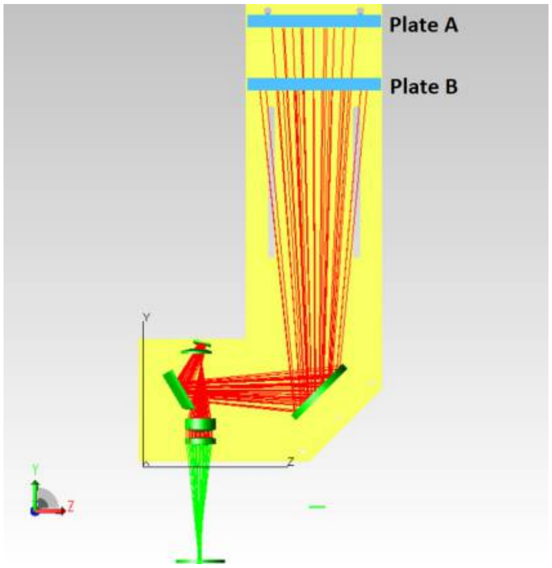


Table I Steps in the conventional and LDI methods of manufacturing the electric circuit patterns on PCBs

Conventional method	LDI method
Preparing computer data for imaging masks	Preparing computer data for laser imaging
Imaging Masks	Preparing copper surface of PCB
Development of masks	Lamination of photoresist
Conditioning of masks	Direct exposure
Preparing copper surface of PCB	
Lamination of photoresist	
Fitting masks on PCB and creating vacuum	
UV imaging in UV curing machine	

A DMD is an MEMS chip, based on microscopically small mirrors (10.8 × 10.8 μm each), which are arranged in a matrix (1920 × 1,080) and having two states: "on" and "off" state. In the "on" state, the light from the projector bulb is reflected by the DMD towards the lens, making the pixel appear bright on the projector screen. In the "off" state, the light is directed elsewhere (usually onto a heatsink), making the pixel appear dark. Very soon after the invention of DMD, it was demonstrated that a DMD chip could be used as a light modulator to pattern PCB track images on UV-sensitive resist during the PCB imaging process (Meisburger, 2007). Due to the small dimensions of each micromirror in the DMD, it is possible to project features as small as 10 μm on to the PCB resist. Alongside LDI, DMD is one of the most promising current technologies for the mass production of HDI.

3. UV laser source for DMD exposure system

The future of DMD technology for the mass production of PCB boards depends on developing a high power UV light source for fast exposure of PCB panels. A new UV source is presented in this paper that has a power of 9.2 W, and composed of dozens of UV diode lasers. The proposed multi-diode laser UV source unit uses a special mechanical construction, in which 52 UV blue-ray (405 nm) lasers are arranged in circular arrays on two Plates A and B (Figure 2). When designing the UV laser source, a computer-aided design (CAD) model of the source was simulated using the Trace Pro program. This simulation allowed the design of the optical paths of the laser beams, which are to be collected together in one point. The results of both CAD design and real examples are shown in Figure 3. The cone angles of the laser beams were set to fit into the DMD micro-mirror cone angles (±10 degrees). Every UV diode laser had a special housing, the central part of which was a movable ball-shaped metal element for precise setting of the direction of the laser beam. The brass housing also worked as a radiator for the heat dissipation from the laser diode. The upper plate of the laser array collected 17 UV lasers, while the lower plate consisted of 35 UV lasers (every single UV laser power was set to 200 mW). The lower plate had through-holes to pass the laser beams from the upper plate. Every UV laser unit was set up separately to obtain the required beam spot size at a proper distance from the DMD chip. It was also required to separately set precisely, a distance between every diode laser and focusing lens in every laser unit. The size of the collected UV light beam was set to slightly overlap the DMD chip area. The Gaussian UV light distributions of all overlapped laser spots resulted in a non-uniform UV distribution over the DMD chip. According to the digital data grabbed from a beam profiler, a map of intensity was prepared (Figure 4). The data were normalized to 100 per cent of maximum UV light intensity. As can be seen in Figure 4, the intensity of the UV light on the DMD chip surface was non-uniform. It dropped down to 30 per cent of the maximum intensity level on the bottom-left corner and along the bottom edge. The maximum intensity was in the centre, with a little shift into the upper right quarter. To make this distribution uniform, a special software algorithm was developed. This algorithm controlled the timing of every pixel – "weak" pixels became longer in the "on" state than "strong" pixels. To make this possible, it was necessary to obtain a cross-section of the intensity characteristics from a centre section of the DMD chip. Data of 1,024 normalized intensity values from a center part of the exposure area in a horizontal direction is presented in Figure 5. A black curve represents a polynomial approximation, which was used in the software to make an intensity compensation during a gray-scale imaging process. The result of the intensity correction is shown in Figure 6. It indicates that a corner of a square photoresist field was underexposed and looked irregular after the development, while the same corner of the square after the correction was applied was correct. Examples

Figure 3 CAD design of laser UV source and two real examples

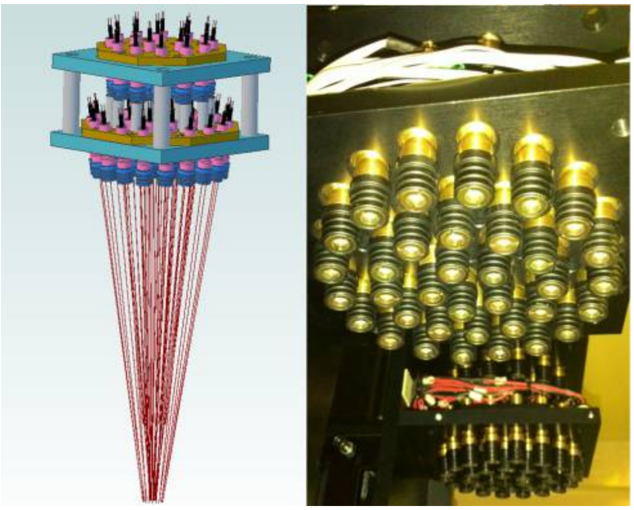


Figure 4 Normalized UV light intensity distribution grabbed at working area

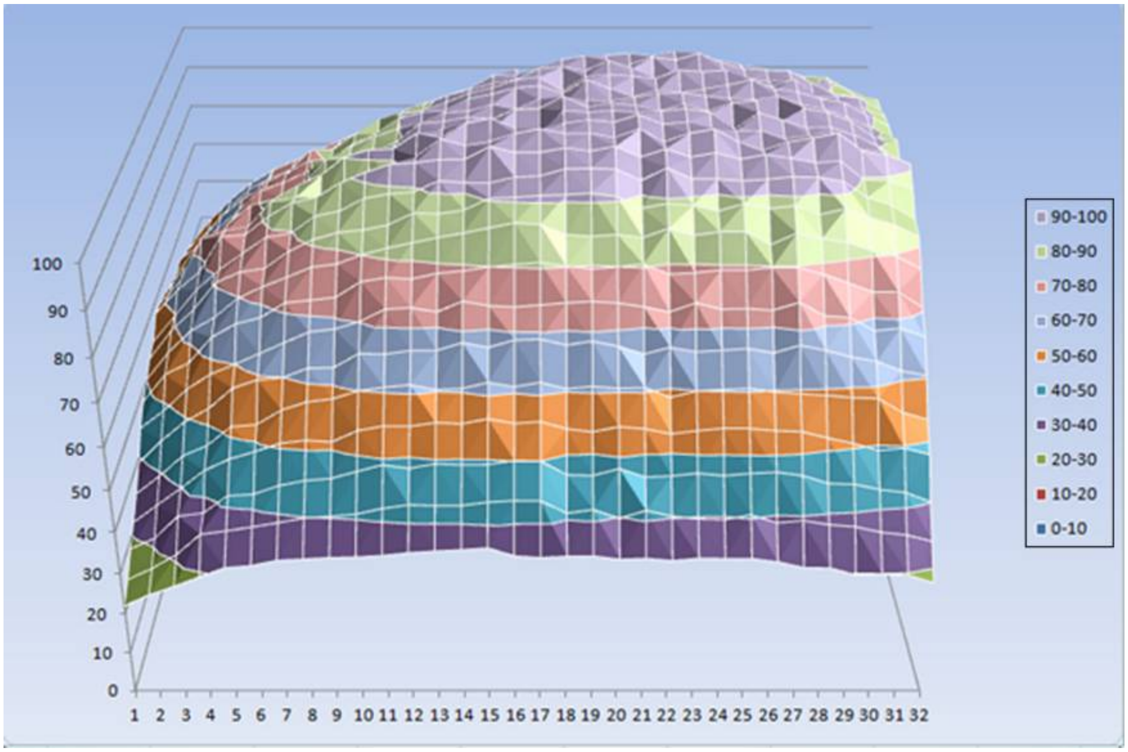


Figure 5 Polynominal approximation of intensity distribution in the center part of exposure area

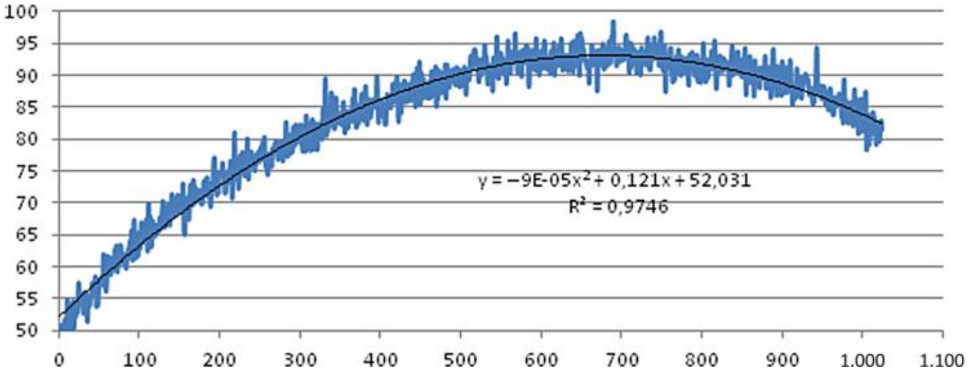
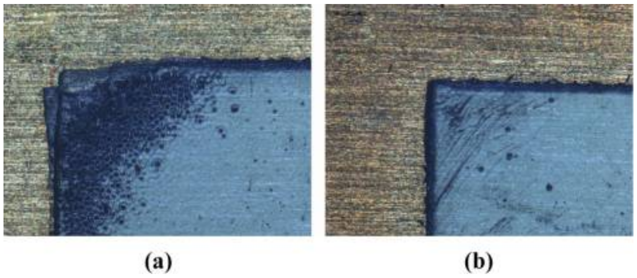


Figure 6 Intensity correction result on photoresist – a) before, b) after vertical/horizontal intensity correction

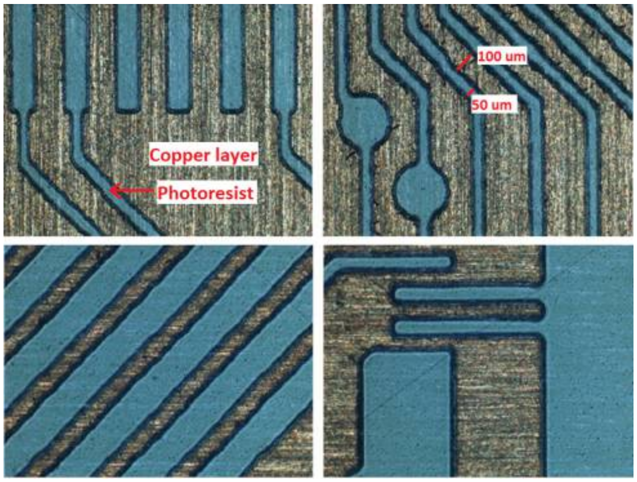


of the photoresist circuit patterns on PCBs are shown in Figure 7. As can be seen, it was possible to fabricate 50 μm /100 μm tracks (track width/space between tracks) using a 0.7'' DMD chip and 1:1 exposure optics. A conventional photoresist with a resolution of around 50 μm and a sensitivity of around 50 mJ/cm^2 was used to obtain these results.

4. Discussion and summary

In this paper, a short survey of circuit manufacturing techniques on PCBs has been presented. From the beginning of the last century, PCBs have become one of the most important parts of electronic devices. Now, when the miniaturization is mostly limited by imagination, PCB manufacturing needs to continue to be up to date with new miniaturization requirements. Thus, new fabrication tools are still invented, such as LDI and the newest DMD technology. These two technologies are used for mass-scale PCB production, e.g. for smartphones and tablets, where most challenging micro-connection designs are used. To improve the productivity of PCB manufacturing lines, new and efficient UV light sources must be developed and implemented in exposure machines.

Figure 7 Examples of photoresist circuitry patterns on PCB



In this paper, a multi-diode UV laser source, comprising 52 diodes (405 μm), has been proposed that can generate around 9.2 W of optical power at 405 nm. This UV source was used in combination with a DMD chip and exposure optics to test it in a real application for the exposure of circuit patterns on a PCB. However, a straightforward combination of 52 laser beams collected into one spot formed a Gaussian UV light distribution over the DMD area and this caused irregular photoresist exposure. A software algorithm was developed to overcome this problem and generate a regular (flat) UV light distribution over the DMD area, resulting in uniform photoresist exposure and, eventually, in better PCB quality after the development process. The proposed UV source was intended mainly for soldermasks exposure. Soldermasks are thicker than inner layer resists and require more UV energy to expose them. But, in contrast to HDI patterns, soldermask resolution requirements are not so tough. The smallest features required with soldermask technology allow a 50-μm resolution. This can easily be obtained using a DMD chip as a light modulator. A UV source like that proposed herein can be installed in a single exposure machine to meet industry needs for throughput. This can be inferred from Table II, which shows the basic parameters of a commercial exposure machine for HDI and soldermask manufacturing with a 4W UV head (www.visitech.no). It is seen from Table II that, by applying four units of the proposed UV source at a reduced UV output power of 4 W in a single exposure machine, only 31 seconds is needed for exposure of one panel side of the soldermask (200 mJ/cm^{-2}). This, theoretically, gives a productivity rate of 1,400 panels per day, which is very close to the present market needs. As a conclusion, the new UV source can be attractive for commercial application.

Table II Basic parameters of a commercial exposure machine for HDI and soldermask manufacturing with a 4W UV head

Parameters	High-density interconnects	Soldermasks
Resolution [μm]	15 μm/30 μm (line/space)	60 μm/60 μm (line/space)
Throughput for 24″ × 18″ panel	8 s/side at 15 mJ/cm^2, 6 units	8 s/side at 50 mJ/cm^2, 4 units
Throughput for 24″ × 18″ panel	14 s/side at 40 mJ/cm^2, 6 units	16 s/side at 100 mJ/cm^2, 4 units
Throughput for 24″ × 18″ panel	16 s/side at 50 mJ/cm^2, 6 units	31 s/side at 200 mJ/cm^2, 4 units

References

Barbucha, R., Kocik, M. and Mizeraczyk, J. (2008), "Laser direct imaging system for high density interconnects on PCB", *Electrical Review*, Vol. 84 No. 3, pp. 54-56.

Barbucha, R., Kocik, M., Mizeraczyk, J., Kozioł, G. and Borecki, J. (2006), "Laser direct imaging of tracks on PCB covered with laser photoresist", *Bulletin of the Polish Academy of Sciences, Technical Sciences*, Vol. 56 No. 1, pp. 17-20.

Barclay, B., Morrell, M. (2001), "Laser direct imaging – a user perspective", *Leiterplatten Magazine*, Vols 7/8, pp. 1-11.

Bruning, J. (1997), "Optical lithography – thirty years and three orders of magnitude", *SPIE Proceeding*, Vol. 3051, pp. 14-27.

Dlugan, A., MacAulay, C.E. and Lane, P.M. (2000), "Improvements to quantitative microscopy through the use of digital micromirror devices", *SPIE Proceedings*, Vol. 3221, pp. 6-11.

Dudley, D., Duncan, W. and Slaughter, J. (2003), "Emerging digital micromirror device (DMD) applications", *SPIEE Proceeding*, Vol. 4985, p. 14-29.

Favalora, G. (2003), "Today, most medical imaging systems acquire 3-D data that needs to be compressed to be viewed in standard displays terminals", *Perspecta Product from Actuality Systems Presentation on HIMSS 2003 Conference*, February, San Diego CA, pp. 9-13.

Harper, C. (2003), *Electronic Materials and Processes Handbook*, McGraw-Hill, p. 7.

Meisburger, W. (2007), Maskless Lithography, Inc., US Patents 7167296, 7295362, 7508570, 7639416.

Nesbitt, R., Smith, S., Molnar, R. and Benton, S. (1999), "Holographic recording using a digital micromirror device", *SPIE Proceeding*, Vol. 3637. doi:10.1117/12.343767.

Web sites

http://focus.ti.com/pdfs/dlpdmd/Mercurex.pdf
www.orbotech.com/solutions/Eng/569/
www.visitech.no

Corresponding author

Robert Barbucha can be contacted at: brobert@imp.gda.pl