Polymer Stencils for Fine Pitch Applications

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ABSTRACT

The experts are unanimous: laser technologies are increasingly gaining in importance for future production processes in the electronic industry. A key role is layed by laser systems in the miniaturisation of electronic components in particular. The putting into practice of innovative concepts or installation and connection technology (packaging) would be either not possible or only incomplete without the application of laser technology. In numerous fields of microelectronics and micro material processing, especially UV-lasers have proved to be useful tools. More and more application fields are opened-up. UV-lasers for via drilling, for laser direct imaging and flex routing are on the cutting edge of technology [1,2,3,4].

State-of-the-art polymer stencils for fine pitch applications are a new application field for the use of UV-lasers. Wafer bump stencils for the Flip Chip on Board (FCOB) assembly are a prime examples of where this new technology can be applied. Following are the advantages of this technology in combination with the use of laser-cut polymer stencils are shown.

INTRODUCTION

2000 was the most successful year ever for the electronic industry. The total volume of the world's largest market exceeded US $ 1,000 billion for the first time [5]. This figure marks the latest milestone in a success story going back more than twenty years. This development is also associated with much stricter production conditions. This involves two trends in particular which have to be tackled by manufacturers and designers: increasing miniaturisation and considerably faster development speeds. Because of the increasing competition, the life cycles of electronic products in recent years have been dramatically shortened. Because more and more functions have to be integrated in smaller and smaller spaces, conventional methods soon reach their limits when it comes to printed circuit board production and packaging. The need to turn to new technologies appears to be unavoidable.

In many electronic devices for communication technology, medical technology or automotive engineering the realization of mobile, high functional systems is only possible by packaging technology providing a very high degree of miniaturization. The use of advanced IC packaging will become mainstream in upcoming PCB assembly technology. Most of these future area-array packages are based on direct contact between the die pads and the PCB. There are slightly divergent forecasts about mid-term packaging development, but nevertheless it is sure that Flip Chip (FC), Flip Chip on Board (FCOB), Ball Grid Array (BGA) and Chip Scale Packaging (CSP) will play a major role in the transition to the next IC package generation. An example: The use of Flip Chip Packages will increase with an annual growth rate between 200% and 400% in the next few years [6].

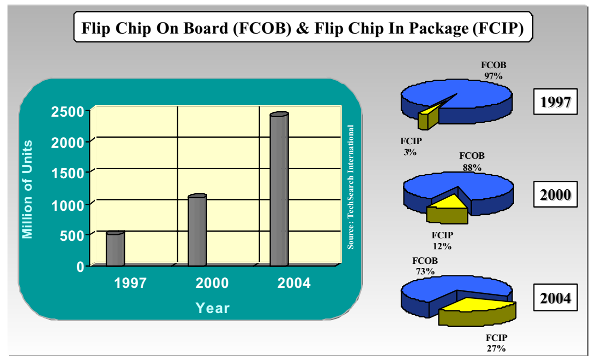


Figure 1. Prospects for the worldwide use of Flip Chip packages (Tech Search International).

Besides a smaller form factor, the main advantages of an advanced package are a greater I/O and functional density with more pads, which leads to a decreasing pin/pad pitch. This trend requires higher efforts from the interconnection technology. The first successfully applied advanced packaging method connects the bond pads of the flipped chip (die) to the substrate by evaporated solder bumps. IBM and Delco used this so-called C4 technology (controlled collapsed chip connect) as a first direct interconnection between IC and substrate [7]. Today most of the flipped chip based packages depend on a bumping technique. Contact from the bond pad to the substrate is realized by a solder sphere – the so-called bump – that compensates the tension due to mechanical and thermal stress.

General requirements for a bumping technology are:

- compatibility to existing wafer technologies
- high yield
- high process stability
- low cost

These goals can be reached for example by an electroless nickel-under-bump metallization (Ni UBM) followed by stencil printed solder application. The principle structure of such a bump is shown in figure 2. A layer of Ni covered by a thin gold (Au) coating is chemically deposited on the aluminum (Al) bond pads. The Ni UBM serves as an adhesion layer and a diffusion barrier between Al and solder. The Au is required to protect Ni from oxidation before the solder application. Solder is applied by stencil printing of paste and subsequent reflow. Then the wafers are cleaned to remove flux residues [8].

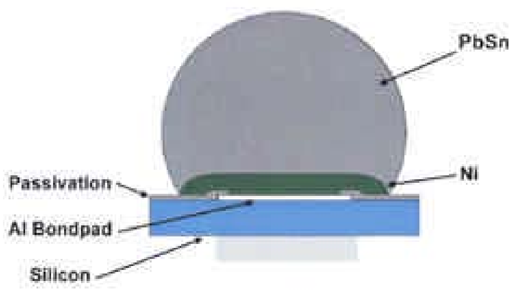


Figure 2. Scheme of a solder bump with Ni UBM (IZM Berlin).

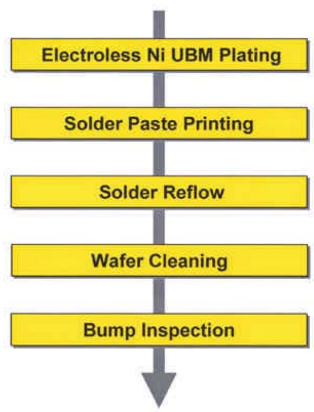


Figure 3. Bumping Process Steps (EKRA GmbH).

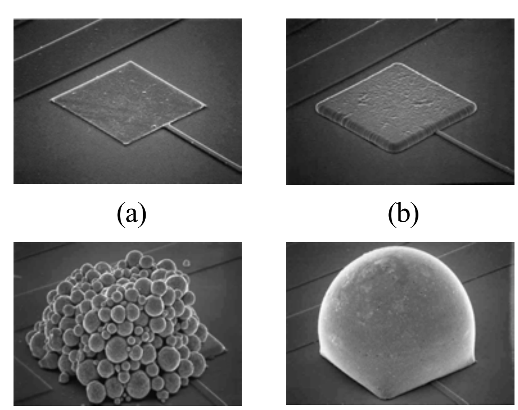
The bumping, especially the application of bumps on a semiconductor wafer holds a key position regarding the successful and economical use of Flip Chip technology. Especially the wafer bumping by solder paste printing provides a very high compatibility with existing PCB technologies, together with remarkably low costs and an already profound understanding of the process basics. The challenge is to develop this technique for the mass production for Flip Chips with a suitable pitch of 250 µm and below.

The conventional printing methods and materials are not suitable for applications with ultra fine pitch structures. To achieve reproducible and homogeneous solder deposits, the process techniques for fine pitch printing require an improvement of the physical properties of solder paste, of the stencil materials and the stencil processing technologies as well as of the printing equipment. Using solder printing for ultra fine pitch applications, solder pastes with very small particle sizes require a nitrogen atmosphere and a well-controlled temperature profile of the reflow furnace [8].

The stencil printing process has many variables. The following factors have to be taken into account to achieve high quality and reproducible precision of ultra fine pitch printing:

- Printing equipment: printer, wafer holder
- Stencil: aperture quality, wall smoothness, thickness, size, geometry
- Machine setup: print speed, pressure, snap-off, separation speed, alignment
- Squeegee: material, hardness, angle
- Solder paste: particle size, distribution, viscosity, thixotropy, slump characteristics, metal content
- Environment: temperature, humidity, dust
- Operators: training, awareness

In the past few years, tools and processes for fine pitch printing have been improved. Efforts have been focused on the development of soldering materials, in particular of solder pastes. For flip chip applications, the particle size of the solder paste is an important factor. Therefore some suppliers developed pastes with homogenous distributions of particles and sizes smaller than 25µm. Volume and height of the deposited solder depends on the thickness and the aperture size of the applied stencil and on the squeegee material. After printing, the bumps are reflowed in a convection oven under nitrogen atmosphere. The height and the diameter of the reflowed solder sphere is determined by the printed solder paste volume. SEM pictures of a pad after the different process steps are shown in figure 4. The stability of the paste volume for every single bump – which influenced the yield mainly – is chiefly dependent on the quality of the stencil. This is similar to the solder paste printing process at PCB manufacturing where nearly 64% of the reject rate is related to printing defects [9].



(a) (b) (c) (d)

Figure 4. SEM pictures of solder bumping steps (IZM Berlin): (a) bond pad in initial state (b) with Ni/Au UBM, (c) with printed solder paste, (d) after solder reflow.

At present, there are common SMT laser-cut stainless steel stencils in use. For this kind of fine pitch application, etched stencils are no longer suitable. But even with a laser-cut stainless steel stencil the printing reliability is not sufficient. Improvements and adjustments to this very special wafer bumping technology are necessary.
In the following, a new technology is introduced which describes the production of a laser-cut polymer stencil suitable for solder paste printing for fine pitch applications.

EXPERIMENTALS

The experimentals are concentrating on the major factors of the solder paste printing process. Major factors include the material the stencil is made of, the laser equipment to cut the stencil, the printing equipment, and of course the solder paste itself.

Substrate

The substrate material has to meet the following criteria in order to fulfill the requirements of the complete process.

- material has to be qualified for industry
- material thickness has to be very constant
- material has to have very good electrical, thermal and mechanical parameters
- material has to be suitable for metallization
- material has to be suitable for laser structuring but should not suffer damages from ablation

A special polyimide film from the company, DuPont (Kapton®) has turned out to be a suitable material for these applications. The high performance film offers superior dimensional stability and improved adhesion with most adhesion systems.

Physical Properties	
Ultimate Tensile Strength	231 MPa (23°C)
Tensile Module	2.5 GPa (23°C)
Stress to prod. 5% Elongation	90 Mpa (23°C)
Thermal Properties	
Linear Expansion	20 ppm/°C
Shrinkage	0.17% (30 min. at 150°C)

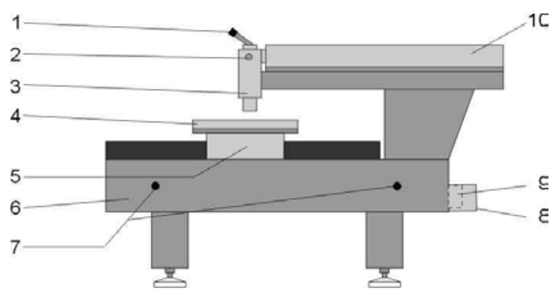
Table 1. Physical and thermal properties of Kapton® Type 100 HN Film, 25 µm (1 mil).

The mechanical parameters of the Kapton® are important with respect to the stencil preparation process. The foil is spread onto a metal frame with a specific tension which is important for the printing process. The good physical and thermal properties of the Polyimide guarantee a stencil layout without deviation from the original even under production conditions.

The metallization suitability is another important criteria. After a drying process (75 µm thickness required 270°F, 8 h) the film is provided with a very thin Cr-layer of 20 nm. This pretreatment is necessary to prevent the foil from static charging during the printing process. Sputtering as well as vapor deposition technology are able to use. The peel strength has been measured after electroplating with Cu to 35 µm (1.4 mil) with a result of >15 N/cm.
Especially the peel strength of the compound has been tested in climate and life cycle tests. Reliability tests (1,000 h) at a temperature of 270°F showed a decline of the peel strength of approx. 25% after 100 hours which then stays constant. The same can be noticed during the 85°C / 85% RH test.

Laser Equipment for Producing Stencils

The laser system comprises a laser source and a positioning unit. The laser source generates highly focused light. This beam is suitable for cutting polymer foils. The foil to be cut is moved under the focused laser beam with the positioning unit to make cutouts. The principle of the laser system is shown in figure 5.



1 – observation optics	6 – granite base
2 – interlock switch	7 – transport eyes
3 – laser cutting head	8 – pneumatic box
4 – clamping frame	9 – compressed air
5 – xy-positioning unit	10 – laser source

Figure 5. Principle of the Laser System.

Laser Source

The laser source is a solid state UV-laser developed by LPKF Laser & Electronics AG. Based on a Q-switched Nd-YAG laser in combination with an optical module, the frequency of the laser is tripled. Therefore the wavelength is changed from the IR (1064 nm) to the ultraviolet. The laser works at 355 nm with a maximum power of 2.5 W at 20 kHz. The pulse repetition rate is available ranging from of 10 kHz up to 50 kHz. UV-laser light proved to be very useful for the processing of polymers.

Positioning System

The positioning system of the laser system is an air-bearing precision xy-table on a massive granite stand. Both axis are guided with air bearings along high precision granite paths and glide on highly polished granite surface. With this construction, both – high precision of the axis of movement and precision of the z-guidance control are guaranteed. Onto this table the substrate is fastened by means of a clamping frame. The servomotor driven xy-positioning unit moves the foil into the focus point of the laser. The respective positioning coordinates are sent from a PC to a control system. This system controls the cross table as well as the laser.

The following parameters can be achieved with this system (table 2).

Laser System Parameters	
Total processing range	600 mm x 600 mm
Max. frame size	820 mm x 800 mm
Max. speed	150 mm / sec.
Axial precision	+/- 4 µm on full working area
Right-angle precision	less than 2 angular seconds
Repeatability	+/- 1 µm

Table 2. Laser system parameters.

Inspection Equipment

Especially when printing on wafer level, the dimensional accuracy of the stencil plays a key role for the production process. Both, the form deviation and the positional accuracy of each single hole has to be checked.

The inspection system's most important part is the camera modul, a solid block of aluminium with four precisely aligned line CCD sensors, each equipped with a high resolution lens with a focal length of 180 mm. There are approx. 7900 active pixels on every CCD sensor. The typical line of view for one camera is 125 mm, so the optical resolution of the system is over 1500 dpi. For each camera it is possible to set gain and offset (dark level) of the video signal as on pixel level.

The stencil is inspected using back-light illumination.

During the inspection the substrate is moved along an linear encoder axis rectangular to the camera line. The camera controller sends illumination data of each pixel to a PCI line grabber, capable to grab four cameras at the same time.

Approx. 360 scan lines along with the position information from the linear encoder are send to the PCI grabber each second. This is close to 12 million bytes/s of data flow. The PCI line grabber operates in Bus Master mode, filling the PC memory with scan lines without intervention of the processor. While scanning the scan lines are processed (binarized) in order to reduce the amount of information.

Sub pixel interpolation techniqes are used to increase the resolution up to 12000 dpi.

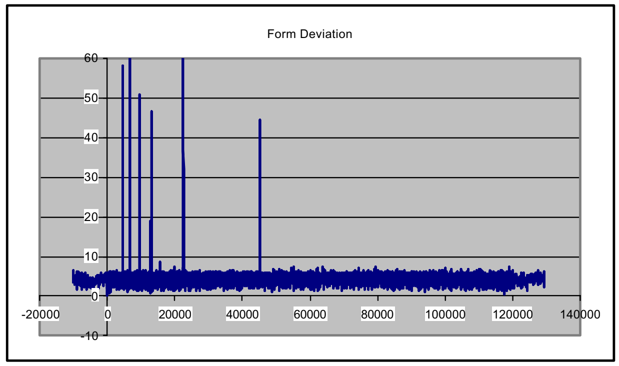


Figure 6. Form deviation of the apertures (8 inch wafer, C118-layout).

Figure 6 shows that the form deviation is within a range of + 1 µm up to + 7 µm. The fact that the deviation is exclusively in the positive sector has been found out to be related to the thermal expansion of the substrate material. In ongoing tests a linear expansion factor has been taken into consideration for the cutting data preparation. The Further examinations manifest the form deviation in a range of +/- 3 micron, which reflects the axial precision of the positioning system (Table 2).

Inspection System Parameters	
Scan area	660 mm x 470 mm
Max. frame size	820 mm x 1000 mm
Max. frame height	40 mm
Resolution	< 3 µm

Table 3. Inspection System parameters.

Printing Equipment

EKRA GmbH has developed a turnkey wafer bumping line to meet the high requirements. This process is absolutely necessary for the automatic handling of the wafer from the cassette into the printer and after printing into a cassette or onto the conveyor of the oven. To guarantee this sophisticated print process, automatic stencil cleaner, 2 1/2 D-Inspection and an EVA™ Vision System are used.

Print Parameter	
Print speed	5 -199 mm/s
Print pressure	0 - 240 N / +-0.04 bar
Snap-off speed	0.1 -10 mm/s
Snap-off	-2 up to +6 mm

Table 4. Printing parameters.

Solder Paste

The solder paste DSC 09-419 from Heraeus was developed for printing ultra fine pitches. The paste contains an extremely fine powder ($Sn_{63}Pb_{37}$, type 6). Typical values are 10% below 7 µm, 50% below 11 µm and 90% below 16 µm. The values were determined by laser granulometry.

RESULTS AND DISCUSSION

The tests have been performed on 8 inch wafers with benchmark layouts. The final application is an 8 inch wafer with more than 20,000 I/Os. There are two different types of ICs on the wafer. One layout with a 250 µm pitch which requires a bump height of 125 µm and one layout with a 200 µm pitch which requires a bump height of 100 µm. The thickness of the stencil is 75 µm. The apertures in the stencil are 250 µm x 170 µm and 180 µm x 130 µm.

The laser ablation of the polymer material has been optically evaluated during the tests. It showed that extensive tests for the determination of an optimum choice of power, frequency and cutting speed are necessary. All three parameters have an influence on the energy density on the substrate. If the power density is too low, the ablation will not be sufficient to cut through the complete material. Too high power densities (>500 mJ/cm²) result in a damage of the substrate material. An optimum combination of parameters to cut a polyimide film of 75 µm thickness is given in table 5.

Laser power	2 W – 3 W
Laser frequency	20 kHz – 30 kHz
Cutting speed	15 mm/s – 25 mm/s

Table 5. Optimum laser cutting parameters, 75 µm polyimide film.

Figure 7 and 8 shows a comparison between a metal stencil and a polymer stencil which has been cut with the above mentioned optimum parameters. It is evident that there are no melting traces in the polymer material. This demonstrates the so-called "cold ablation" of the UV-laser in plastics. The ablation created by the high photon energy of UV-laser light is a kind of photochemical process. The long carbon chains of the polyimide are cracked and leave a sharp non-melted edge.

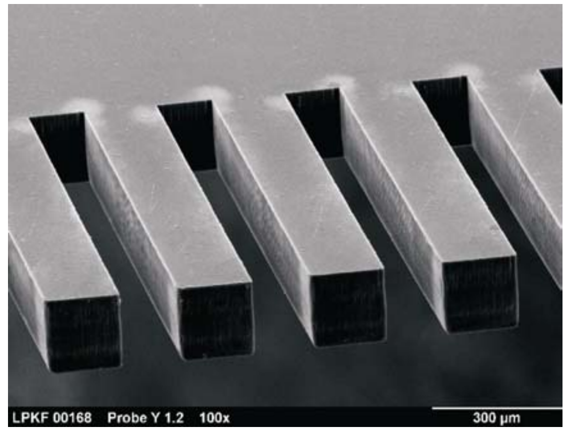


Figure 7. SEM-pictures of a laser-cut polymer film.

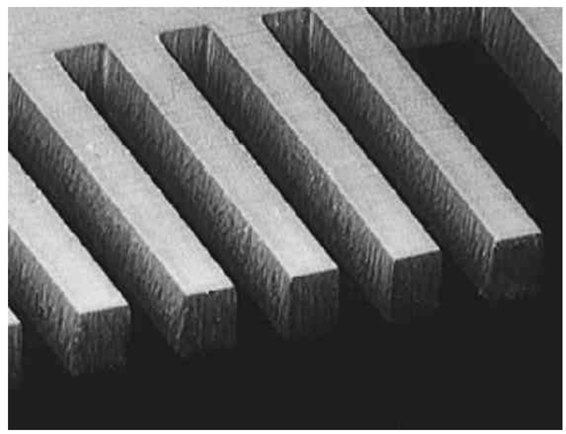


Figure 8. SEM-pictures of a laser-cut stainless steel foil

Measurements of the inner wall roughness of apertures show a significant decrease of approximately 50 %. Another positive result is that there is no phase at the backside of the substrate (laser leaving) which is a typical appearance when cutting holes in metal sheets. Both characteristics have a major influence on the paste release. The lower roughness leads to a faster and thorough release of the paste out of each aperture. The sharp edges of each hole (without an angle at the laser leaving) result in a sharp contour of the paste volume. An increase of the printing speed up to > 70 mm/s (5 times higher than with a conventional stencil) are possible with a still constant bump geometry.

A comparison of typical printing results with wafer bump stencils are given in figure 9 and 10.

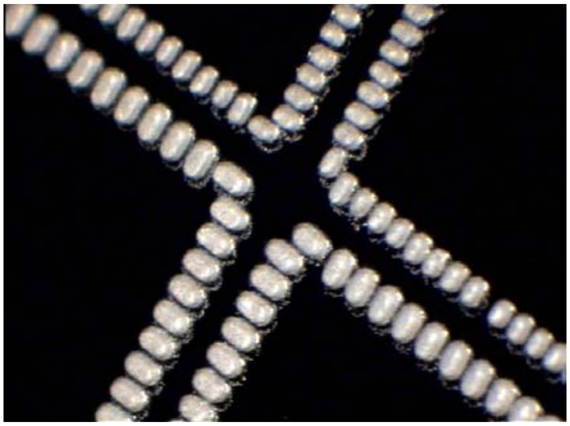


Figure 9. Printing results with a polymer stencil (200 µm and 250 µm pitch).

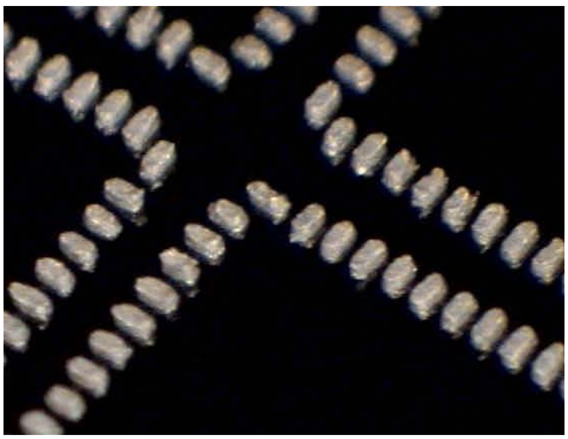


Figure 10. Printing results with a stainless steel stencil (200 µm pitch).

A minimum diameter of 50 µm and an aspect ratio of 1:1.6 represent the actual limits of the solder paste printing process with polymer stencils. The limit criteria are not the feasibility, but an average printing defect rate of more than 50 pps which makes this technology uneconomic for the wafer bumping.

Ongoing tests show a significant influence on the printing process by the solder paste. The flux especially shows a reaction with the polymer substrate – even if the polyimide has an excellent chemical resistance. Solder pastes with water-soluble flux indicate a detectable effect on the polyimide (proven by FT-IR spectrum analysis). The combination of water-soluble flux and ultra fine solder granulation deteriorates the paste release. To cover these results, further investigations are in progress.

SUMMARY AND CONCLUSION

It is proved that thin polymer foils can be cut very precisely and accurately with a UV-laser. Hole diameters down to 50 µm with exact roundness can be realized. This precise technology combined with the advantages of the polymer substrate (e.g. reduced inner wall roughness) make the polymer stencil the perfect tool for fine pitch applications like wafer bumping.

Though it has to be done in a very precise way, the wafer bumping by stencil-based solder paste printing on electroless Ni / Au under bump metallzations is a familiar technique to the widely accepted paste printing on PCBs. The advantages of the cost-effective stencil printing process, combined with the advantages of the polymer stencil make this the right technology for a low cost wafer bumping process with high yield.

Owing to the continuous miniaturization trend toward finer lines, higher number of I/Os, etc. there will be a wide field of applications laid open for the use of advanced stencil. Especially stencils for high density PCBs, which do not require an anti-static coating, are another prime example, where this technology can easily be applied. Similar to the above one can expect similar good printing results.

ACKNOWLEDGEMENT

The author gratefully acknowledges the German Federal Ministry of Education and Research (BMBF) to enable the research project "Ökobump" which is dealing mainly with the above described technology. In this context the author likes to thank all other project partners, especially EKRA GmbH Bönnigheim, Heraeus GmbH Ha nau, IZM Berlin and OKM Messtechnik GmbH Jena.

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