New process for stencil cutting: water jet guided laser

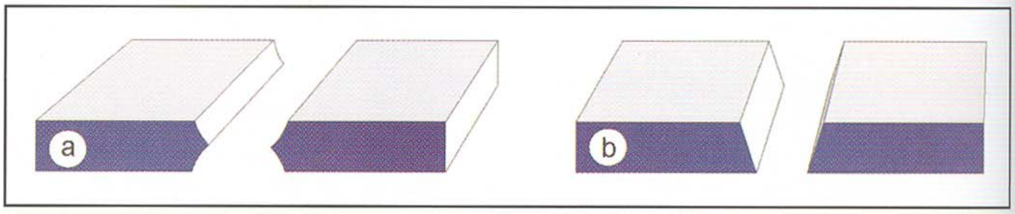

Figure 1. Aperture section: chemical etching (a), laser (b).

Stencil manufacturing requires precision, quality and speed. Today, several different technologies are available. Chemical etching produces low-quality apertures and electroforming is a costly solution. Conventional 'dry' lasers generate heat damages and depositions. The water jet guided laser technology, which uses a water jet to guide a laser beam by total internal reflection, is an ideal process for stencil cutting. The molten material is efficiently removed, mechanical constraints and heat damage are negligible - and high speeds can be achieved. Wafer bump stencils for BGA and screens for OLED displays can also be produced using this technology.

Delphine Perrottet, Christophe Boillat, Simone Amorosi and Bernold Richerzhagen, Synova SA

Keywords:
Guided laser, water jet, stencil cutting, precision processing.

Stencils for SMT

Stencil cutting imposes rigorous requirements: precision, quality and speed are paramount. When the number of apertures increases, achieving high speed is very important. The tapered angle of the apertures must be controlled, since it is necessary to ensure that the solder paste detaches easily from the stencil. It is also essential to avoid burrs and particle deposition and ensure high cutting precision so that the volume of solder paste in each solder bump is precise and consistent. Last, applied forces and heat affected zone (HAZ) should be reduced to the extent possible when cutting thin metal foils. Stainless steel expands by 16 to 18 um per meter length per °C as the material is heated. Consequently, stencils measuring 500x500 mm must be cut with an average temperature as stable as ±0.6 °C to achieve a ±5 um tolerance.

Different manufacturing techniques

A variety of technologies are used in stencil manufacturing, including chemical etching, electroforming and lasers.

Chemical etching

Etching is a productive method because it is parallel, especially when the number of apertures is extremely high. However, the quality of the apertures is low. This is due to the two-step ablation method. Each aperture is achieved starting from both sides, one after the other. This creates an internal bulge at the point of junction (*see Figure 1*), which is problematic when applying the solder paste through the stencil.

Electroforming

Electroforming is a parallel method that guarantees high precision in small dimensions. Its drawbacks are high cost and low yield.

Conventional laser

Laser cutting is an attractive method combining high quality, flexibility in forming aperture shapes, and relatively low running cost compared to the previous methods. High precision helps to eliminate bridging and improves both paste release and consistency across the stencil. Heat effects constitute the laser's primary limitation. The laser creates a heat-affected zone, which makes its use difficult for fine-pitch structures.

In addition, small particles and burrs remain. Time-consuming post-processing steps, such as mechanical brushing, are required. The large assist gas jet usually used (typically 0.5 to 1 mm in diameter, pressure ranging from 6 to 15 bars) does not adequately remove the molten material as apertures are left partially filled with slag and dross formations. Moreover, insufficient melt removal facilitates residual heat transfer from slag to the work piece. Heat load generates heat-affected zones and oxide layers on the walls and increases positioning errors due to expanding stencil. The gas applies a considerable mechanical force on the work piece (ranging typically from 1 to 5 N) that can be problematic with fine structures. The cutting speed is too low for stencils with 100,000 holes and more.

Water jet guided laser

The water jet guided laser (Laser-Microjet) is an innovative hybrid method combining a laser beam with a low-pressure water jet that provides highest quality in a single step process at low cost and high production rates. It possesses all the advantages of the laser without its drawbacks.

The laser-microjet

The basic principle of the Laser-Microjet is to focus a laser beam into a nozzle while passing through a pressurized water chamber. The water jet emitted from the nozzle guides the laser beam by means of total internal reflection at the water-air interface, similar to conventional glass fibres. The water jet can thus be described as a fluid optical wave-guide of variable length (*see Figure 2*) that delivers the laser power directly onto and through the work-piece with negligible losses.

Only the laser beam is used for material ablation. Its intensity is constant along the cylindrical water jet, as the beam fills up its guide homogeneously. Very thin jets can be obtained, as the nozzle diameter can be set between 75 and 25 um. The water jet pressure usually ranges from 100 to 500 bar, depending on the nozzle diameter. For example, when using a water jet measuring 28 um in diameter and 400-bar water pressure, the flow rate is only 0.5 liters per hour. The maintenance cost of the whole system is low, with low water consumption and use of maintenance-free fiber lasers (applicable for thin stencils).

In addition to the long working distance, the water jet guided laser offers several other advantages over conventional lasers. First, the water jet prevents heat propagation outside the immediate cutting area by efficiently cooling the kerf between the laser pulses. Thus, heat effect is negligible and no oxidation is visible. Second, the water jet efficiently removes the molten material generated by laser ablation, keeping cuts clean. In addition, a water film on the material surface prevents particle contamination. The mechanical force applied by the Microjet is low enough to leave the material unscathed (less than 0.1 N, 10 times lower than the one applied by the assist gas jet used in conventional laser cutting).

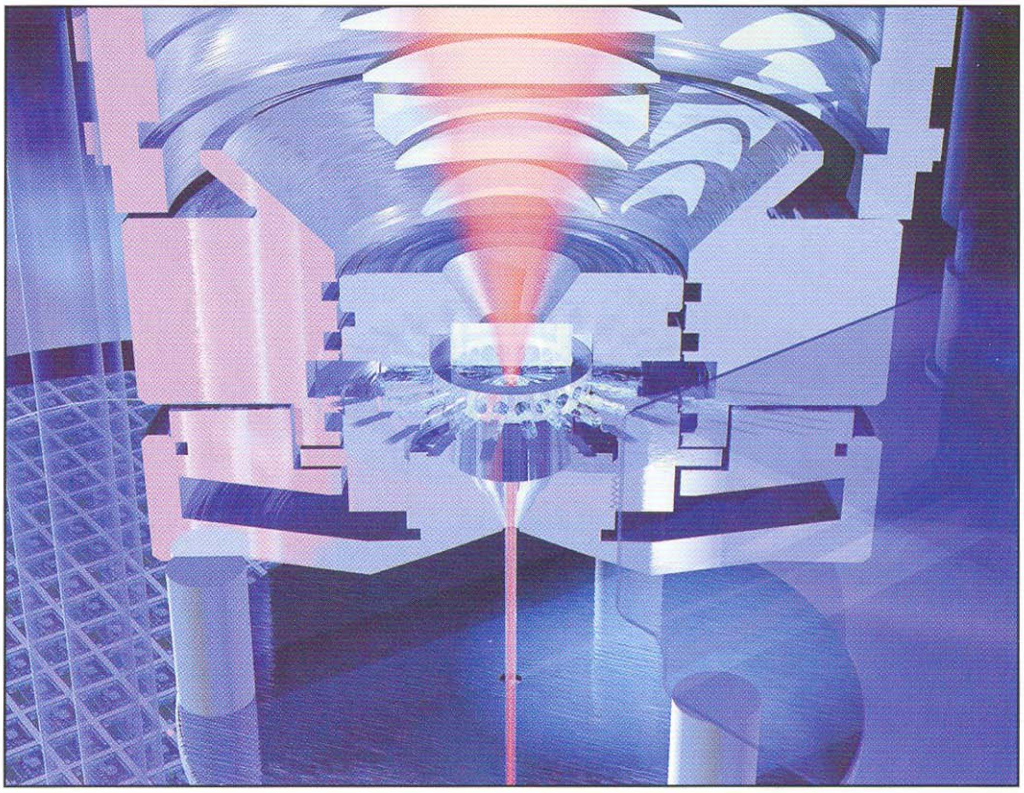

Figure 2. The Laser-Microjet principle.

A new way to cut stencils

The water jet guided laser is well suited for stencil cutting as the process is fast, accurate and clean. A high cut quality can be achieved using an infrared pulsed laser (*see Figure 3*), manufactured by Trumpf. This laser's many advantages - high beam quality, reliability and sturdiness - prove useful when coupled in water, especially when processing stencils between 100 and 200 µm thick.

In percussion drilling, it can make very small round holes at high speed - up to 50'000 apertures per hour in 50-µm thick steel. However, as the roundness is not perfect in percussion drilling, the water jet guided laser is usually used in trepanation drilling (e.g. the axes are moved in a circular motion), which produces high quality apertures.

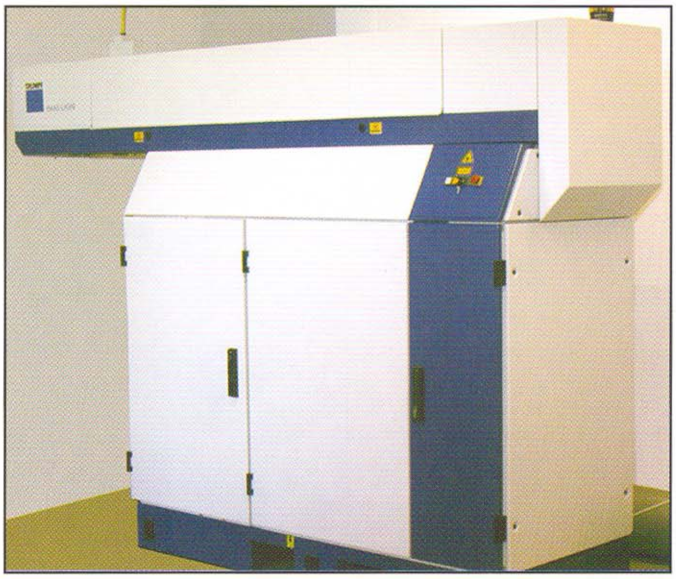

Figure 3. Infrared Trumpf laser coupled in water for stencil cutting.

Table 1. Cutting rates of the Laser-Microjet.

Type of aperture	Aperture size	Number of apertures per hour (rate)
Stencil thickness: 50 µm		
Round	ϕ 80 µm	~ 30'000 / hour
Square	90 µm x 90 µm	25'000 / hour
Stencil thickness: 100 µm		
Round	ϕ 150 µm	8'000 / hour
Square	150 µm x 150 µm	5'000 / hour

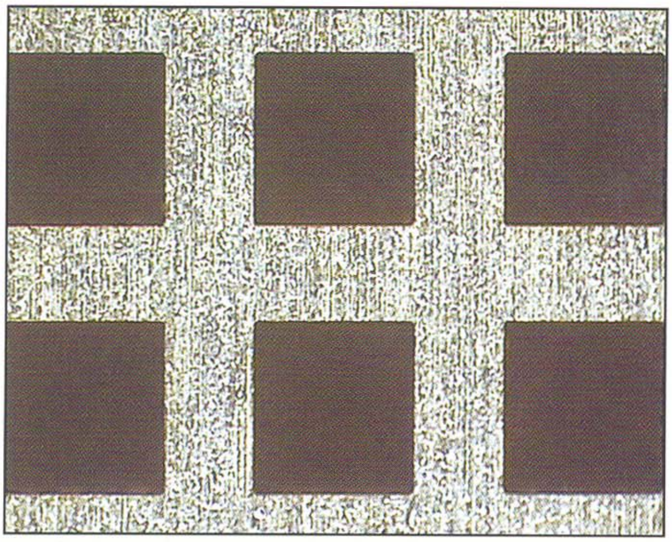

Figure 4. Square apertures, 600 µm x 600 µm, in 50-µm thick stainless steel; rate: 5'000/hour.

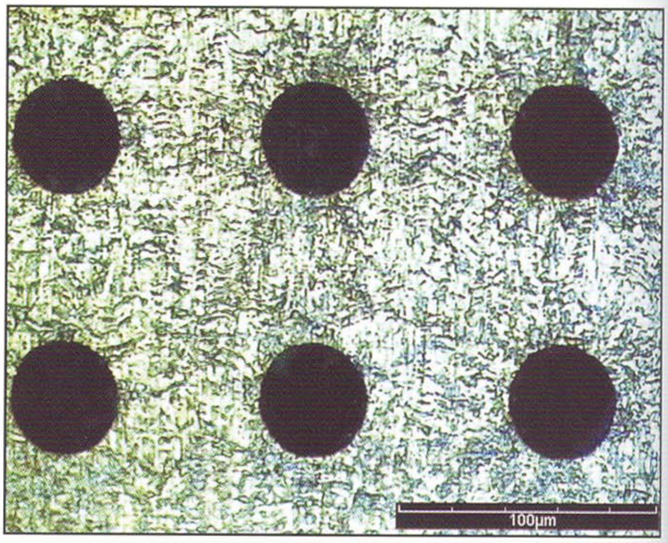

Figure 5. Round apertures, diameter 40 µm, in 40-µm thick stainless steel; rate: 40'000/hour.

Table 1 shows the drilling rates, according to the thickness of the stencil, for the two common shapes of apertures - rounds and squares.

Figure 4 shows square apertures (600 µm x 600 µm) made in a 50-µm thick stainless steel sheet. The resulting speed was 5,000 holes per hour. The edge is clean and the material has no visible heat effect.

Figure 5 shows a round aperture (diameter 40 µm) made in a 40-µm thick stainless steel sheet. The resulting speed was 40,000 holes per hour. The infrared fiber laser was used with this stencil (average power 30 W), coupled with a thin water jet (diameter 23 µm).

Summary

In combination with the water jet guided technology, the laser now takes a leap forward in performance. It provides high flexibility, high speed and the ability to cut small apertures with clean edges. It avoids dross and slag and the material is free from mechanical and thermal stress induced by inadequate fixation and work piece vibrations and from heat damage. This new method for cutting stencils is fast, clean, and cost efficient.

The key goal for the future is to decrease the diameter of the water jet (currently 25 µm) to below 20 µm.

Delphine Perrottet received her M.Sc. in micro-engineering from the Swiss Federal Institute of Technology Lausanne (EPFL). She then worked one year in the literary trade as a publisher. In 2004, she joined Synova SA as their press contact.