Slotting of inkjet printer chips using the water jet-guided laser technology

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Abstract

Inkjet printers use a series of nozzles to eject drops of ink directly onto the paper. The head of the inkjet-printer contains a silicon chip, which acts among others also as a barrier between the orifice plate with hundreds of nozzles and the ink reservoir. A rectangular slot needs to be created on the silicon chip. The conventional sandblasting manufacturing technique does not anymore provide satisfactory results for the new generation of printers. Synova's Laser MicroJet®, a hybrid technology, which uses a water jet to guide a laser beam down to the workpiece, has recently been adapted to this application, demonstrating very promising results allowing both high processing speed and quality.

Keywords: inkjet printer heads, laser, water jet guided laser, silicon, slotting

1 Introduction

Inkjet printer heads are being considered as one of the largest market shares of the MEMS market. Printer manufacturers mainly use two inkjet technologies. In the Thermal "Bubble" Jet Technology, resistors create heat and vaporize ink to create a bubble. As the bubble expands, a very small quantity of the ink is pushed out of a nozzle onto the paper. When the bubble collapses, a vacuum is created, pulling more ink into the print head from the cartridge. The Piezoelectric Jet Technology employs piezo crystals, which are located at the back of the ink reservoir of each nozzle. When a piezo crystal receives a tiny electric charge it will vibrate. The inward vibration forces a minute amount of ink out of the nozzle, while the outward vibration pulls some more ink into the reservoir to replace the dispersed ink.

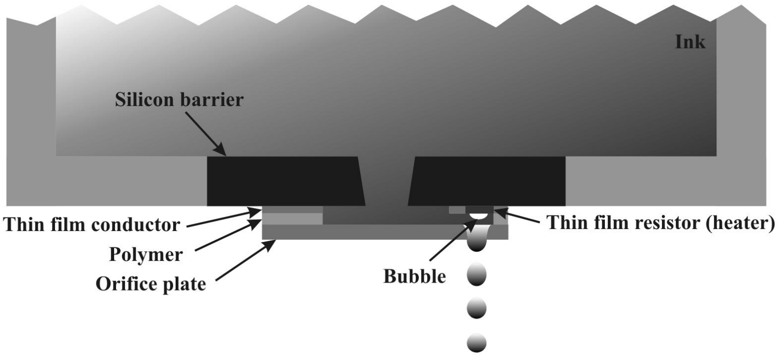

Fig. 1: Basic principle of a inkjet-printer head

A silicon chip is used as a barrier between the orifice plate, which contains hundreds of nozzles, and the ink reservoir (see Figure 1). To let the ink pass through, slots are created directly in the 8” silicon wafer – prior to dicing into chips. The wafer thickness usually varies between 600 and 700 microns. The size and the geometrical shape of the slots will vary depending on the technology used for the procedure (thermal or piezoelectric jet), as well as the size of the cartridge and the number of nozzles (dpi-resolution). The main targets of inkjet printer head manufacturers are low fabrication costs while improving production yield and product performance. Different technologies are being used for the manufacture of slots on patterned silicon wafers.

2 Conventional manufacturing processes

Silicon wafer slots with widths larger than 150 microns can be created by conventional sandblasting method. So far, these methods have not provided satisfactory results for narrow slots below 150 microns. Sandblasting limits the diameter of holes and their density, as the edges tend to be conical. Additionally, this process is incompatible with clean room conditions. Etching processes are slow, expensive and require masks. Dry laser slotting creates heat affected zones, slag and micro cracks. Further drawbacks such as low throughput, additional processes and compromises have to be taken into account if conventional lasers are applied.

An alternative technology able to combine high quality and high speed is therefore desirable for this particular application. The water jet-guided laser technology has been recently applied for this application. Results of silicon slotting for inkjet-printer heads using the water jet-guided laser are very convincing.

3 Water jet-guided laser

Initially, the water jet-guided laser (also called Laser MicroJet$^{®}$) was developed for medical applications. Today it is used for precision micro-machining in a wide range of industrial fields, such as semiconductors and electronics. The basic principle of this technology is to use an ultra-thin, low-pressure water jet to guide a laser beam to the workpiece. To achieve this, the laser beam is focused through a transparent window into a nozzle placed at the bottom of a water-filled chamber. The cylindrical hair-thin water jet generated below the nozzle guides the laser beam by means of total internal reflection at the water/air interface, similarly to conventional flexible glass fibers (see Figure 2). The water jet is thus able to guide the light through the kerf down to the bottom of the cut – a very valuable property. The only losses are caused by the absorption in the liquid, depending on the applied wavelength, and Raman-scattering at high peak powers.

The jet length that can be used for the light guiding is roughly 1000 times the nozzle diameter. Accordingly a 50 micron jet can guide the laser beam for 50 mm. The water jet diameter is approx. 83% of the nozzle diameter because of the usage of sharp edged nozzles and the consequential jet retraction effect (vena contracta). The laser source is typically a pulsed all solid state laser at the fundamental wavelength of 1064nm, or a frequency doubled (532nm) or tripled (355nm) laser. It is possible to use conventional lamp pumped or diode pumped lasers, or fiber lasers. A pressure intensifier pump delivers a constant water flow with pressures ranging from 2 to 50 MPa. Flow rates are typically only 5 to 75 ml/min so recycling is not necessary. Today's optimized water jet nozzles with diameters of 30 to 150 micron are made out of diamond or sapphire.

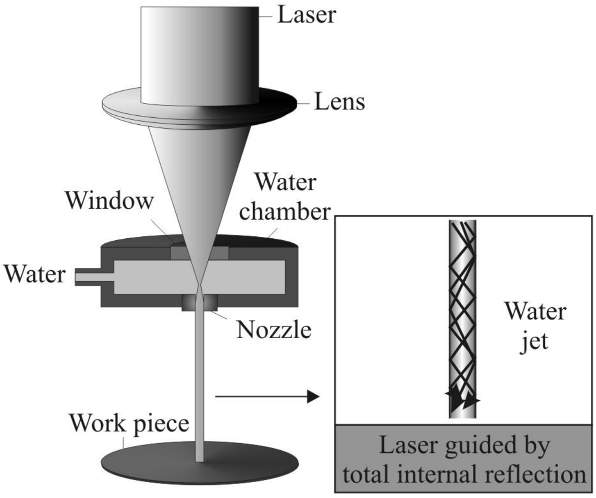

Fig. 2: Basic principle of the water-jet-guided laser technology

The capabilities and performances of this process are different from those of conventional dry lasers [1]. First, because the water jet is cylindrical and the laser beam parallel, kerf walls are parallel. The working distance – corresponding to the stable length of the jet – can be several centimeters long, depending on the jet diameter. Therefore, there is no need of focus control.

Second, heat damage is nonexistent, since the water jet cools the edges between the laser pulses. The temperature of the cut edge rapidly decreases to the water temperature and heat generated by the laser is not conducted further into the material. The negative effects of heating, such as micro cracks, oxidation, structural changes or low fracture strength, do not appear.

Contamination is greatly reduced, as the water jet, whose pressure ranges from 50 to 500 bars, develops a high kinetic energy fully dedicated to the removal of the molten material. Additionally, a thin water film is generated on the wafer surface during the process, preventing particle deposition. Since the water jet is very thin (diameter ranging from 20 to 100 microns), the mechanical force applied on the wafer is negligible (less than 0.1 N). As a result, the process does not generate chipping or micro-cracks.

For several years, the water jet-guided laser technology has been successfully used for semiconductor micro machining (dicing and grooving). The process is especially efficient on thin wafers and on brittle materials (such as GaAs) since it is a damage-free tool [2]. High process rates are reached. Virtually there is no chipping on the wafer front and back side. The heat damage to the material is negligible and surface contamination can be avoided. The technology has therefore an important potential for silicon slotting of inkjet-printer heads. For this specific application, additional advantages include straight slot walls, no transition region (vertical slot ends) and the possibility to program the slot width – as it does not depend on the nozzle diameter.

4 Damage-free laser slotting

The first tests of the water jet-guided laser for silicon-barrier slotting showed very promising results. Slots in 675-µm thick patterned silicon wafers were achieved in 10 seconds per slot (overall cutting speed: 1.2 mm/s). To protect the fragile structure on the wafer front side, the slotting was executed from the backside and the process that was applied for the slotting ensures that the slot ends are always very steep (see Figure 3). For this sample, a green Nd:YAG laser (wavelength 532 nm) was coupled with a 100-µm water jet nozzle.

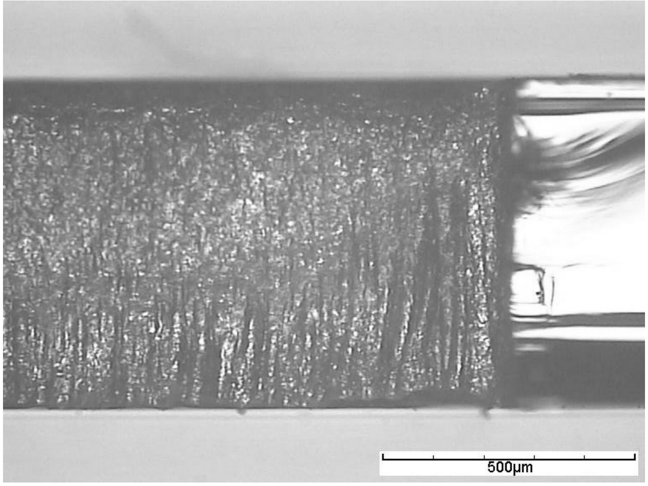

Fig. 3: Parallel slotting wall and vertical slot end (broken after slotting)

However, some issues remained after these preliminary tests. It was observed that the exit edge was a bit chipped at different locations. The speed also needs to be improved. To reduce irregularity, a smaller nozzle (30 µm) was used to execute a “race-track” contour with removal of the inner part (see Figure 4). The same green laser was applied for this test.

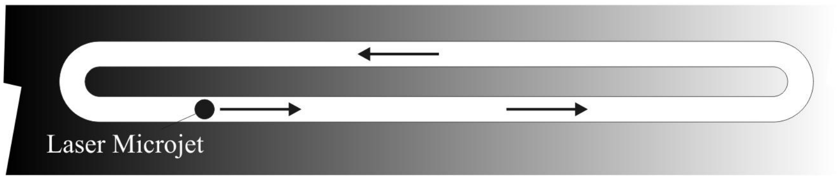

Fig. 4: Race track

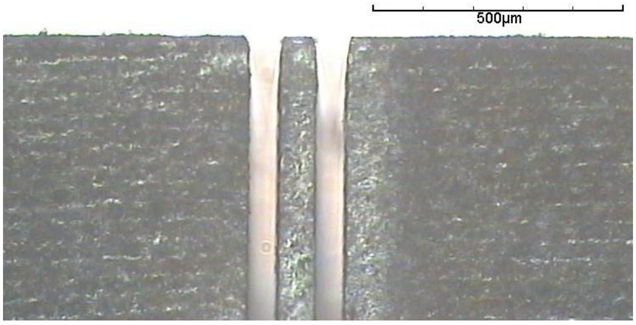

Fig. 5: Cross-section of a “race track” contour slotting

The long working distance of the water jet enables the manufacture of parallel walls on this thick silicon wafer (see Figure 5). With this slotting strategy, the chipping on the laser exit side (the wafer front side) could be reduced to zero and the straightness of the slots could be improved further. The force of the water jet removed the remaining inner part automatically in all cases and no parts remained within the slot. The edge is free of recast and burrs. Taking into account that no protection coating has been used, the cleanliness is outstanding (see Figure 6).

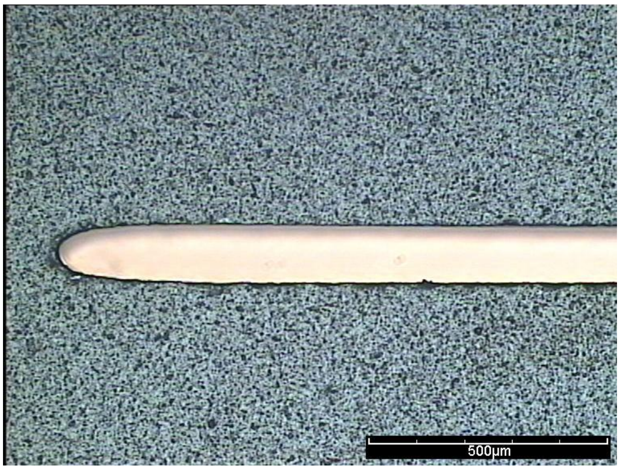

Fig. 6: Beam entrance side (backside of the silicon chip)

Further steps aim at improving speed by the increase of the axis acceleration. With the same laser and nozzle, an overall speed of 5 mm/s was achieved, reducing the cutting time by a factor of 2, e.g. only 5 seconds per slot. Even at this speed, the cut quality is maintained (see Figure 7).

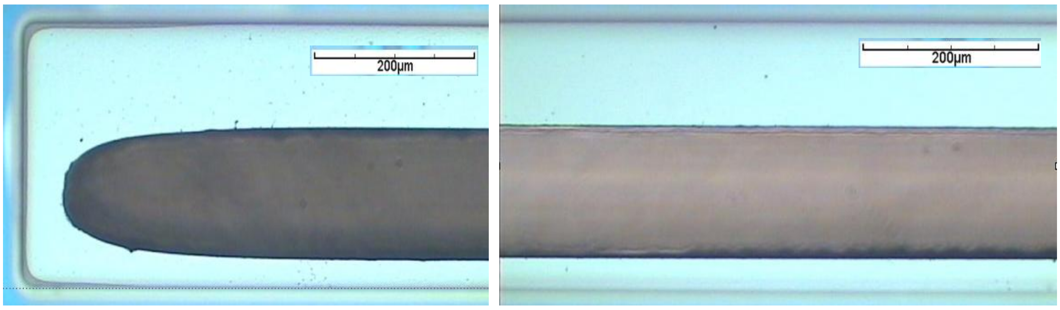

Figure 6: Slot exit side (wafer front side)

Using a 35-µm nozzle, speed could be even increased: 9 mm/s, again reducing the cutting time by a factor of 2 – only 2.6 seconds per slot. However, the edge is slightly rougher.

5 CONCLUSION

The water jet-guided laser technology has proved its capabilities of matching the requirements of silicon slotting for inkjet-printer heads. After a short phase of parameter optimization, the required quality and speed were not only reached but also surpassed. Additionally to produce through-slots, the process can also be used to create blind slots with very accurate control of the depth – variations at the bottom of the slots can be kept to a minimum. The produced slots are free of any length or depth limitations and the quality remains constant over time. The processing speed is high due to a very efficient material removal and the use of a high laser power of up to 100 Watts.

REFERENCES

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