Chipping-free dicing of III/V semiconductor materials with the water jet guided laser

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ABSTRACT

For a few years now the semiconductor wafer market has turned a substantial part of its production towards compound materials, faster than the well-known silicon. The mechanical and chemical properties of these III/V semiconductor materials (of which the most used being gallium arsenide, GaAs) require new specialized technologies. In particular, the singulation process is proved to be delicate. Different dicing methods exist, but important differences in results can be observed. The saw creates consequent chipping as well as broken edges. Conventional lasers should be avoided because of important heat damages. The scribe and break method can create cracks that tend to break wafers. The most satisfying results are obtained with the Laser Microjet (LMJ), a revolutionary technology coupling a laser and a water jet. It is faster and cleaner than any other process, and generates an impressive kerf quality. Furthermore, it allows free-shape cutting, which is impossible with blades. At last, the safety question should not be forgotten. In fact, because of the waterjet, no toxic arsenic gas could be detected.

Keywords: Laser cutting, Water jet guided laser, GaAs, Compound semiconductors, Chipping-free

1. INTRODUCTION

Silicon has dominated the semiconductor wafer market for more than three decades. However, the continuing demands for higher speed and increasing miniaturization have driven the wireless and broadband communications industries to use the brittle and difficult-to-handle, but much faster (meaning higher carrier mobility), III/V semiconductor materials, such as gallium arsenide (GaAs) and indium phosphide (InP). Indeed, these materials' electrical properties give them several performance advantages over pure Si, including high frequency operation, improved signal reception, better signal processing in congested frequency bands, and greater power efficiency. According to IC Insights, market research firms based in Scottsdale, Arizona, compound semiconductor ICs are still largely based on GaAs, which accounted for 87% of the market in 2002. Most of the big players in the semiconductor market have turned their production in this direction.

IC Insights expects the compound semiconductor IC market to experience an average annual growth rate of 22% from 2002 through 2007. In comparison, the total IC market will grow at a rate of 10% over the same time period. The compound semiconductor IC market peaked at $2.42 billion in 2000, but fell to $1.69 billion in 2002. IC Insights forecasts strong growth in the following years, with a continual expansion through 2007, when the market will have more than doubled to $4.65 billion. [1].

The GaAs market is no longer considered a niche market. Today, if the most important application remains the wireless communication industry, GaAs is revealing its potential in opto-electronics for applications in the military, the medical and especially the LED lighting domains. Standard production technologies still need to become more adapted to this new high-growth market. Decreasing the chip size below 500µm requires using wafers thinner than 100µm; shrinking the wafers' thickness also have the advantage of lowering its temperature gradient. The use of GaAs wafers,

which might be as thin as 25µm, creates problems when they reach the last level of the production chain – chip singulation. Because GaAs is very brittle and fragile, even improved saw methods using resinoid blades do not provide the desired high cutting speed and yield. Furthermore, considering that dicing is the very last process of wafer manufacturing, which means that the wafer has the highest value at that stage, and the drive toward higher production volumes at lower costs, it is paramount to employ the dicing method that achieves the highest yield. It is also important to consider that although GaAs's price is not as high as it used to be, it is still a costly material.

Another important aspect must not be neglected: manufacturing and processing of compound semiconductors, especially GaAs, reveals serious industrial safety concerns because of the hazardous chemical compounds found in certain processes. Pure compound GaAs contains 51.8%wt arsenic. It is described as toxic by inhalation and a possible human carcinogen. These facts raise a lot of concerns from an environmental, health and safety standpoint.

2. COMPARISON OF THE DIFFERENT DICING METHODS

There are currently three well-known methods to dice GaAs wafers, namely the abrasive saw, scribing and breaking, and laser LMJ dicing processes. Because of GaAs's specific properties, disadvantages of certain methods that are tolerated when dicing Si wafers because it is a rather forgiving material become unacceptable disadvantages when dicing GaAs.

Traditional sawing is the most common dicing technique used in the semiconductor industry in general. Its primary advantage on the Si wafer is the quality of the kerf. But the sawing process induces mechanical constraints that are critical in the case of GaAs. If chipping is acceptable for Si, it is not the case for this brittle compound. Chipping widths of GaAs being larger, the street has to be widened, thereby diminishing the number of chips per wafer. Also, because of the mechanical constraints induced by sawing, chips corners tend to break easily thus rendering the pieces unusable. In general, to achieve an acceptable cutting quality, saw speed has to be reduced to values ranging between 3 and 12mm/s, depending on the wafer's thickness, thereby considerably slowing the whole process. Table 1 shows a comparison of three dicing methods.

Dicing method	Minimal street width	Time to process a wafer	Dice shape limitation	Mechanical problems
Abrasive Saw	80µm	50 minutes	Linear No size limit	Chipping Broken corners
Scribe and Break	15µm	30 minutes	Linear At least 1x1mm	Broken wafers
Laser Microjet	40µm	15 minutes	Free-shape At least 0.5x0.5mm	No chipping No broken corners

Table 1: Comparison of the three dicing methods for a typical GaAs wafer - 400 cuts, 8 inches, 200µm thick

With the scribe and break method, street width can be reduced drastically, increasing the number of dies per wafer. This is a real advantage when processing an expensive compound material. However, automation is too low to ensure an acceptable yield. For example, wafers do not always break along the scribed line. This often results into total wafer breakage and loss. This means as well that the processing speed is slow, and a large amount of scrap wafers are required for qualifications.

Use of the Laser Microjet, not to be confused with a standard laser, appreciably increases the speed and kerf quality of GaAs wafer dicing. Moreover, it allows free-shape cutting, including multi-project wafers, which is not possible with conventional sawing techniques.

3. WATER-JET GUIDED LASER PROCESSING

The Laser Microjet (LMJ) uses a thin water jet as a light-guide to guide the laser onto the work piece (see Fig.1). Apart from guiding the laser, the water jet cools the piece exactly at the place where it is being cut and heated, also removing the molten material. In fact, LMJ is a low-temperature laser dicing system since the measured temperature during any working conditions does not exceed 160°C [2].

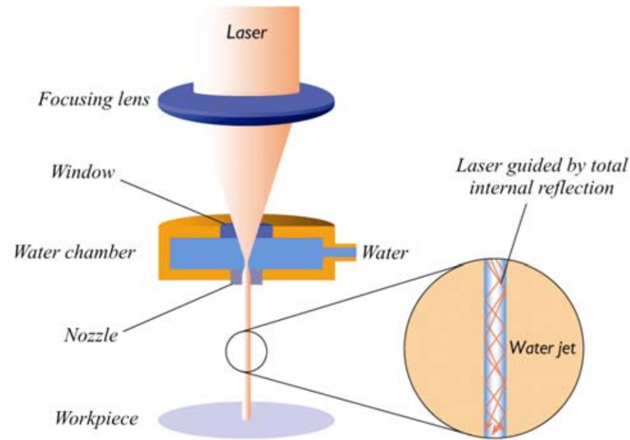

Fig.1. Principle of the Laser Microjet dicing technique

The low-pressure jet also insures that no mechanical and no thermal damages are incurred by the wafer during dicing (see Fig.2). The LMJ is therefore particularly efficient on brittle and difficult to machine materials such as GaAs, even for thickness as small as 25µm. Furthermore, the high laminarity of the water jet provides a constant kerf width equal to the diameter of the jet (25 to 75µm according to the nozzle diameter). Another interesting advantage of the LMJ for this specific application is that its speed increases when samples become thinner, while in the case of sawing, it is just the opposite. For thin GaAs wafers, achievable LMJ cutting speeds are very high.

Since GaAs is expensive and that it enters in the fabrication of applications that require the more compactness, i.e. thin chips, achievable cutting speeds are very high. Compared to the saw, speeds up to 8 times faster can be achieved for thin wafers (100µm and under), and up to 5 times faster for thicker wafers (thickness between 100 and 300µm). As for running costs, they are very small compared to the saw and scribe break method. Indeed, once the nozzle is aligned it can last for hundreds of hours without requiring replacement.

Thin GaAs wafers are usually completely diced by the LMJ. Fig.2 shows results for a Q-switched YAG laser, wavelength 1064nm, average power 50W, and pulse repetition rate 35kHz. The water jet diameter was of 25µm, and the water pressure 400Bar. The resulting cutting speed was 60mm/s.

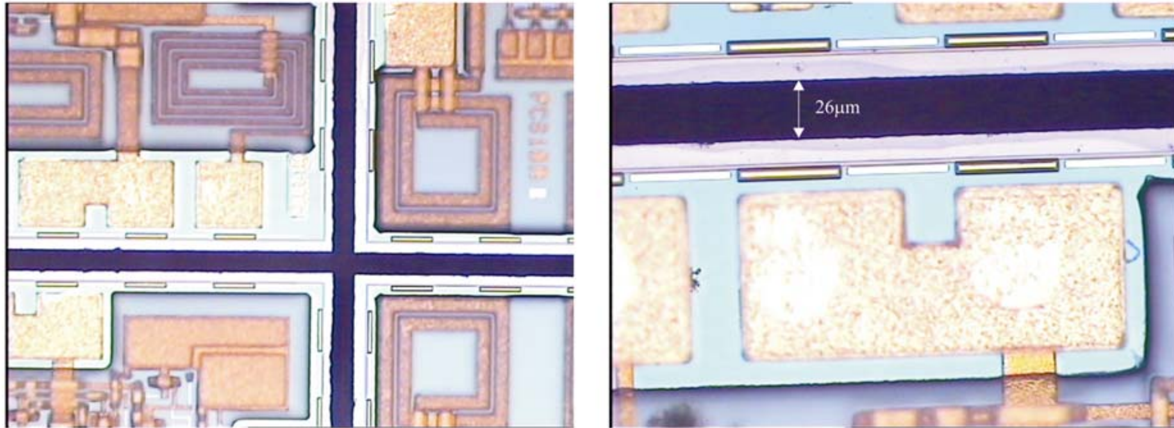

Fig.2. GaAs wafer dicing (100µm thick)

Conventional laser ablation of GaAs creates a lot of debris, hard to remove, that can even damage nearby active components. With the Laser Microjet (LMJ) technology, this problem has been overcome. Using a special thin water film, a new technology specific to Synova SA and to the LMJ, keeps the wafer clean and free of particles. The resulting level of chip contamination is equivalent to conventional saw, but the cut is much faster.

Free-shape cutting, also known as free-form or arbitrary cutting, of thin wafers has become increasingly important for various applications in microelectronics and medicine, in which chips with arbitrary shape are used. Conventional techniques cannot provide the required flexibility and two-dimensional freedom. Fig.3 presents omni-directional cutting with the LMJ. The GaAs wafer (on the left) was 178µm thick, and for a kerf witdh of 75µm, achieved speed was 15mm/s (the dots on the surface are not residues from the cutting process). The InP wafer (on the right) was 250µm thick, and resulting speed was 2mm/s, single pass. Employing frequency doubled Nd:YAG lasers, the cutting speed could soon be improved.

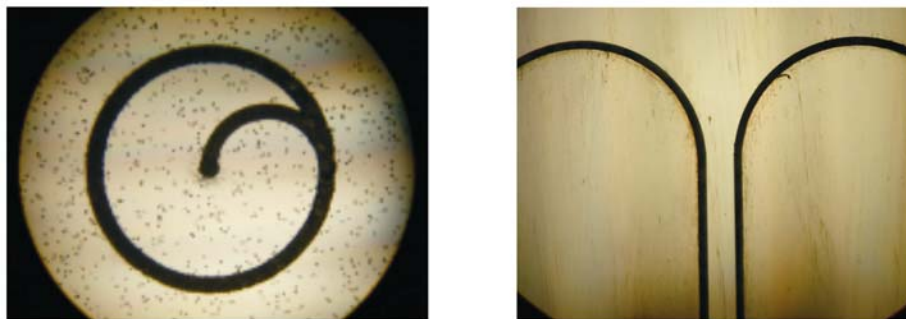

Fig.3. Omni-directional cutting, kerf width 75µm - Left: GaAs (the dots on the surface are not residues from the cutting process) - Right: InP

4. SAFETY

Regarding safety issues, several tests have been performed with the LMJ. The most important result was that no arsine gas is detected in the air while cutting GaAs wafers [3]., an important difference to classical laser cutting (see Table 2).

	PEL	Detected during the test	Recommandations
Arsine gas [ppm]	TLV=0.05	Not detected	
Air concentration of As [μg/m³]	10 (OSHA cancer hazard)	130 (in cutting chamber 4 (outside cutting chamber)	Exhaust system with a particulate filter
Water concentration of As [μg/L]	<20	62700	Closed recycling, Arsenic filter
Arsenic in the human body [μg/L]	BEI=35 50 (EPA)	5.2 (before) 9.4 (after)	Gloves and a HEPA filter
Wipe sample results [μg/cm²]	1	30 (in cutting chamber) 0.062 (next to machine)	Post-cleaning

Table 2: Results from the GaAs safety tests

This is not surprising since the laser beam is coupled in a water jet and laser pulses are very short (around 450ns). The time for interaction of the laser light with the material is therefore very short and immediately followed by the cooling effect of the water. Though, the concentration of Arsenic in the wastewater is high. Therefore, the wastewater should to be appropriately filtered or recycled. In brief, compared to sawing, GaAs dicing with the Laser Microjet does not require any additional security systems.

5. CONCLUSION

To conclude, the Laser Microjet shows indisputable advantages over the more traditional scribe and break and abrasive saw technologies for the dicing of GaAs wafers. 100μm thick wafers can be cut at 60mm/s and outstanding quality is reached. Even although improvements have been done to the traditional methods over the years, they will soon be replaced as wafers become thinner and employ more costly and critical materials. Furthermore, GaAs is not the only material on which the LMJ has already showed industry-leading results.

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