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Die separation processes for compound semiconductor devices are typically based on either diamond scribe and break techniques or on ganged sawing of the substrate using water-cooled saws. These mechanically dependent processes can suffer from several limitations, including overall throughput of the process (and throughput scalability as wafer sizes increase), physical damage to the dies incurred during the sawing or scribing operation, and the real estate cost of needing large scribe lines or streets for relatively small devices like LEDs. A plasma etch process has been developed for compound semiconductor device die separation, eliminating the real estate penalty, physical damage caused by mechanical processes, and has no scaling issues associated with larger wafer diameters.. This article will report on the overall benefits of the plasma etch die separation processes, offer some cost of ownership comparisons, and show results from work performed for LED die separation using plasma etch.

Feasibility Analysis for Dry Plasma Scribe Lane Etch for Die Separation in Compound Semiconductors

Introduction

As compound semiconductor device volumes increase and competition in the marketplace drives down chip prices, all opportunities for production cost savings must be considered. Dry plasma processing has played an increasingly important role in many front-end wafer processes and in the back-end process of backside via hole formation. The benefits of dry plasma processing in these applications include improved dimensional control, improved profile control, reduced defect density, increased throughput, and increased yield. In addition to these device level improvements, many advanced automation and material handling features have been introduced to back-end production. This, based on years of development for front-end silicon IC manufacturing1. Back-end production has not yet experienced the same level of technical enhancement as front-end processing. One area of interest for the application of dry plasma processing in back-end processing is the extension of backside through-wafer via hole etching to wafer scale single pass die scribing. Historically, this scribing step prior to breaking and die separation has been accomplished by sawing. More recently, techniques such as automated diamond scribing or pulsed laser scribing have been introduced and used with limited success. As wafer sizes increase, an alternative scaleable die scribe process, such as the promise of plasma etch, must be developed and leveraged to overcome inevitable physical and economic challenges of future-generation compound semiconductor device production.

Analysis

In order to establish the feasibility of dry plasma scribing, two aspects of the process have been investigated. First, the extendibility of via

Method	Wafer Thickness (micrometers)	Depth of Cut (micrometers)	Bottom Radius (micrometers)	Concen. Factor (k)	Bending Stress $(k / (t - d)^2)$
Saw	100	50	12	1.61	0.00064
Saw	200	100	12	2.03	0.00020
Scribe	100	2	0.1	18.75	0.00195
Scribe	200	2	0.1	26.61	0.00068
Plasma Etch	200	60	3.5	3.96	0.00020

Table 1: Theoretical Maximum Bending Stress for Saw, Scribe, and Plasma Etch

hole etching to scribe line trench etching had to be established. Second, cost of ownership calculations were made to measure the potential benefit of the technique to justify the expense of new capital equipment for this process.

Application Development

In the course of etch process development over the last several years, great strides have been made in improving the quality and throughput of backside via hole etching for GaAs and other compound semiconductors. Figure 1 is an example of such a via hole structure. The integration of plasma dry etch for this application involves the use of sapphire carriers to support the GaAs wafer substrate that is mounted device-side-down and mechanically thinned by polishing prior to lithography and etch[2]. In the last two years, GaAs etch rates have been increased from 3 to greater than 8 microns per minute, and as a result significant reductions in per-wafer cost of ownership have been realized. Figure 2 illustrates the reduction in cost as a function of average etch rate. Scribe line trench etching is a natural extension of this production-proven process.

The structure used for process development was based on a LED die structure on a GaAs substrate. In this case, the wafer was etched from a front-side mask that protected the device features leaving only the scribe lane exposed. The goal was to achieve a nominal 60-micrometer depth for a 10-micrometer wide scribe lane. The nominal die size was 225 x 225-micrometers with a wafer thickness of 200-micrometers. The apparatus used for the etch process in this study was a TEGAL 6520 HRe- ™ high-density plasma reactor[3]. Figure 3 is a schematic diagram of the target structure. Figure 4 is a SEM photo of the resulting etched feature. The average etch rate for the scribe trench, including the epitaxial layers, was 6-micrometers-per-minute. Equation 1 represents the theoretical stress concentration for a scribe trench assuming a hyperbolic bottom shape.

Equation 1:

$$k = (0.355(t - d) / r) + 0.85)^{0.5} + 0.08$$

Equation 2:

$$\text{Bending Stress} = k / t^2$$

Where k is the stress concentration factor; t is the wafer thickness; d is the depth of cut; and r is the bottom radius. The maximum bending stress at the surface is then given by Equation 2. The estimated stress given by the plasma etched scribe feature described above is 0.0002. This compares favorably with results for saw and diamond tip scribe techniques[4]. See Table 1.

Another potential benefit of the plasma etch technique is the extendibility of single pass processing to "mini batch" runs of multiple wafers mounted to a single larger carrier. For example, four smaller 2-inch wafers can be

Die Size (per side) (um)	Scribe Speed (in/sec)	2" Wafer (4 per carrier)		4" wafer		6" wafer	
		Scribe (wafer/hr)	Plasma (wafer/hr)	Scribe (wafer/hr)	Plasma (wafer/hr)	Scribe (wafer/hr)	Plasma (wafer/hr)
200	3	0.21	8	0.05	2	0.02	2
	9	0.63		0.15		0.06	
500	3	0.52	8	0.12	2	0.05	2
	9	1.55		0.36		0.16	

Table 2: Wafer Throughput Model - Diamond Scribe vs. Plasma

Die Size (per side) (um)	Scribe Speed (in/sec)	2" Wafer (4 per carrier)		4" wafer		6" wafer	
		Scribe (die/hr)	Plasma (die/hr)	Scribe (die/hr)	Plasma (die/hr)	Scribe (die/hr)	Plasma (die/hr)
200	3	8k	286k	8k	163k	8k	763k
	9	23k		24k		25k	
500	3	3k	48k	3k	28k	3k	129k
	9	9k		10k		10k	
Assumptions: 10-micrometer Streets and 3-mm Edge Exclusion in all cases							

Table 3: Die Throughput Model - Diamond Scribe vs. Plasma

	Scribe	Plasma
Original Equipment Cost	$100k	$800k
Depreciation Life	5-year	5-year
Net Availability	80%	80%

Table 4: Equipment Cost and Availability Factors - Diamond Scribe vs. Plasma

mounted to a single 8-inch diameter carrier; this would increase the net throughput four-fold without increasing the footprint of the tool. Also, plasma processing delivers superior repeatability compared to mechanically-based scribe techniques since there are no saw blades to foul or diamond scribe tips to dull. This improves single-pass yields and reduces consumable costs.

Cost of Ownership Modelling

Cost-of-ownership modelling for production capital equipment rests on several major factors and a myriad of minor ones. The major factors are capital depreciation cost, total equipment availability (utilization), and die throughput. Minor factors include consumable cost, clean-room cost (footprint), and labor cost. For the purposes of this study, only the major factors were used in the calculations. The first model developed for the analysis was for tool throughput. Tables 2 and 3 summarize the output of the modeling for diamond scribe and dry plasma etch in terms of wafer and die throughput respectively.

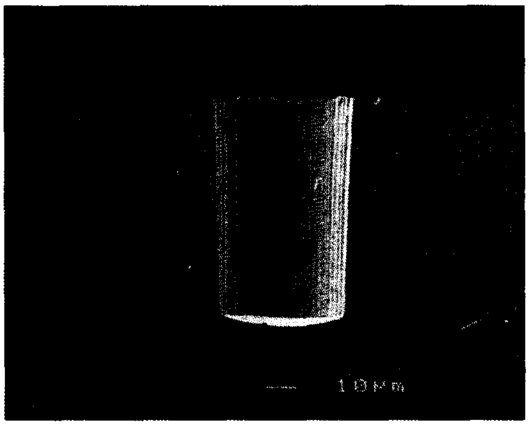

Figure 1: Backside Via Hole Dry Plasma Etch.

Die throughput for the diamond scribe process is strictly limited by the linear speed of the cutting tool. As such, the peak die-per-hour throughput is limited and does not scale with wafer size and drops linearly with increased die size. In stark contrast, the die throughput of dry plasma processing continues to climb linearly with total wafer surface area and the inverse square of the die size. This non-linear behavior plays an important role in the trends for cost of ownership.

The other major factors are capital equipment cost and equipment availability. The assumptions for the purpose of this study are shown in Table 4. Since determining the actual equipment availability factor is meaningless outside of direct fab production experience, an assumption of 80% net availability was used to avoid any subjective influence on the model. This takes into account all time lost to scheduled and un-scheduled downtime and operator unavailability.

The simple calculation for cost of ownership (COO) is stated in Equation 3.

Equation 3:

$$COO = (C / L) / (168 * 52 * A * T)$$

Where C is the original equipment cost; L is the depreciation life; A is the net availability; and T is the equipment throughput. COO can therefore be stated in terms of cost per wafer or cost per die depending on which throughput units are selected. Taking all factors into account, the throughput tables can be re-cast in terms of COO. See Tables 5 and 6.

Analysis of the simplified COO model indicates some trends. First, in terms of cost per wafer, the COO of diamond scribe equipment rises dramatically as wafer size increases (10x) and

Die Size (per side) (um)	Scribe Speed (in/sec)	2" Wafer (4 per carrier) Scribe ($/wafer)	Plasma ($/wafer)	4" wafer Scribe ($/wafer)	Plasma ($/wafer)	6" wafer Scribe ($/wafer)	Plasma ($/wafer)
200	3	13.55	2.86	57.87	11.45	132.97	11.45
	9	4.52		19.29		44.32	
500	3	5.53	2.86	23.78	11.45	54.75	11.45
	9	1.84		7.93		18.25	

Table 5: COO Model ($/wafer) - Diamond Scribe vs. Plasma

Die Size (per side) (um)	Scribe Speed (in/sec)	2" Wafer (4 per carrier) Scribe ($/die)	Plasma ($/die)	4" wafer Scribe ($/die)	Plasma ($/die)	6" wafer Scribe ($/die)	Plasma ($/die)
200	3	0.00038	0.00008	0.00036	0.00007	0.00035	0.00003
	9	0.00013		0.00012		0.00012	
500	3	0.00091	0.00047	0.00086	0.00041	0.00085	0.00018
	9	0.00030		0.00029		0.00028	
Assumptions: 10-micrometer Streets and 3-mm Edge Exclusion in all cases							

Table 6: COO Model ($/die) - Diamond Scribe vs. Plasma

die size decreases (2x). This runs counter to industry trends toward larger wafers and smaller die size. Second, in terms of cost per die, the non-linear gain in die throughput for plasma etch overcomes the substantial difference in initial equipment cost for larger wafer sizes and smaller die.

Conclusion

Larger wafer diameters and smaller die sizes are placing increasing pressures on mechanical scribe techniques for die separation for compound semiconductors. Dry plasma etch processing offers a promising scaleable alternative in terms of scribe quality and repeatability, process extendibility, and production cost of ownership. Feasibility has been established for GaAs scribe lane etching, though full integration of this technique and its long-term advantages requires further study.

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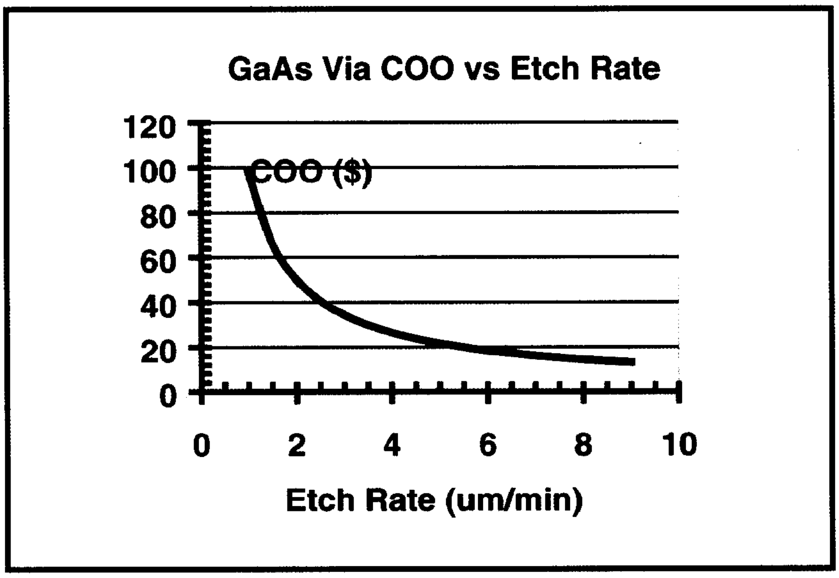

Figure 2: Cost of Ownership Reduction for Backside Via Hole Etch.

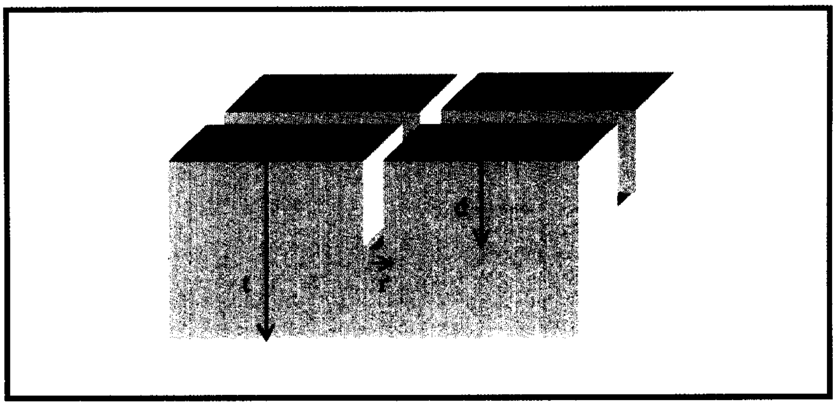

Figure 3: Schematic Diagram of Plasma Etch Scribe Lane.