New and Innovative die singulation technology for Compound Semiconductors with Zero kerf loss and completely no damage on the side wall

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ABSTRACT

In semiconductor die fabrication, the die singulation process is the last step. The singulation process determines the number of dies obtained from a wafer, which directly affects the cost of the die. Singulation also strongly affects the quality of the die due to damage and chipping.

INTRODUCTION

Compound semiconductor devices have high cost per unit area, and they are easily damaged, so improvement of the singulation process is very desirable. This paper describes a new low-cost high quality singulation technology called the Scribe and Break (SnB) method. We focus our discussion on singulation of SiC wafers, which are the most difficult compound semiconductor for die singulation. We will also discuss the singulation of GaN and GaAs wafers.

SnB METHOD

The SnB method (see Fig. 1) was originally developed as a cutting technology for brittle materials (mainly glass), and it is now widely used. SnB essentially eliminates kerf loss, which provides a big cost savings. SnB is also environmentally friendly because it eliminates the water waste stream present in saw singulation. The chip periphery is not heated in SnB singulation, which avoids damage to chips that is present in other singulation methods.

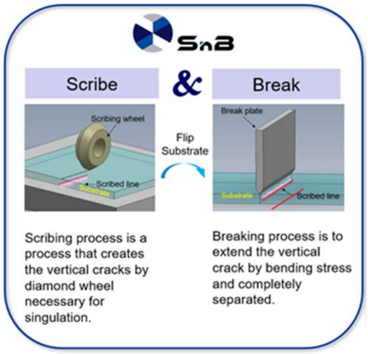


Fig. 1 Schematic overview of SnB process.

The details of the scribing process are important for SnB. The scribing process is divided into two steps. In the first step, initial cracks are formed by utilizing the strain in the compressive stress region generated by the pressurization just below the wafer (see Fig. 2). These cracks form when the scribing wheel is rolled across the wafer surface layer. In the second step, (see Fig. 3), a deeper ~20um vertical crack forms, and propagates downward from the initial small crack. Vertical crack propagation is driven by the force of the returning compressive stress, after the scribe wheel has passed by, and after the scribe wheel load has been removed.

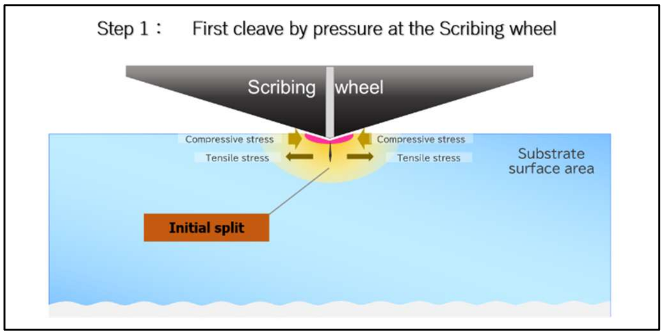


Fig. 2: Process of generating initial cracks inside the wafer with a rotating scribing wheel.

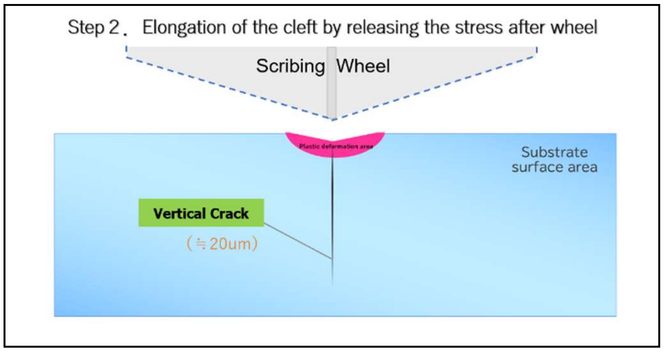


Fig. 3: Process of propagate initial cracks and forming vertical cracks as the scribing wheel passes through and unloads.

No chipping was observed around the scribe lines. All cracks formed by scribing were vertical cracks (normal to the surface). No horizontal cracks were observed along the scribe line. From these results, it can be predicted that a chip-free cut surface can be obtained during the break process. (Fig. 4)

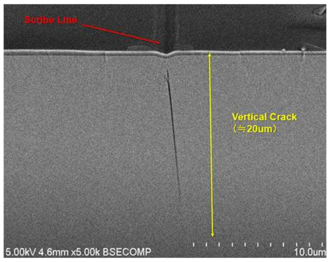
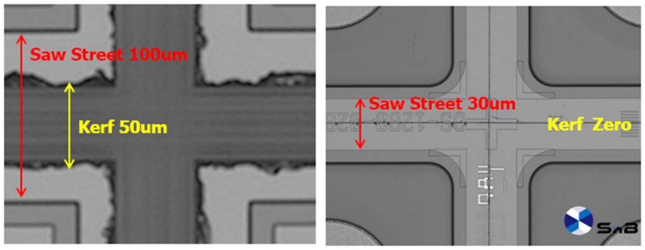


Fig. 4: SEM observation of SiC wafer scribe lines and vertical cracks.

ZERO KERF LOSS

In the scribing process, the rotating scribe wheel does not remove any material. It just generates a slight plastic deformation on the wafer surface. This means the SnB singulation process essentially eliminates kerf loss, so it provides a significant increase in the number of dies per wafer compared with saw separation. Fig. 5 and Fig. 6 shows a comparison of the two methods.



Blade dicing SnB

Fig. 5: Comparison of the Saw Street and Kerf width of SiC singulation method.

Following number of die obtained from 6 inch SiC wafer

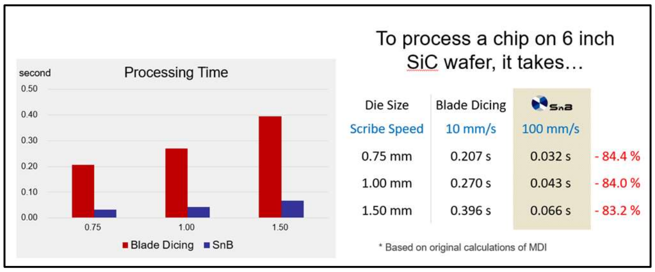
Die Size	Blade Dicing	SnB	
Saw Street Width	80 µm	30 µm	
0.75 mm	23,936 pcs	27,144 pcs	+ 13.4%
1.00 mm	14,076 pcs	15,504 pcs	+ 10.1%
1.50 mm	6,536 pcs	6,964 pcs	+ 6.5%

* Based on original calculations of MDI

Fig. 6: Comparison of the number of SiC die gained by Saw Street reduction.

HIGH-SPEED PROCESSING

Conventional methods have many problems; for example, SiC is very hard, so saw speeds are necessarily very slow (10mm/sec or less). Also, GaAs and GaN are very brittle and prone to chipping when sawed at high speed. In contrast, the SnB process singulation process can be fast due to its hardness-independent die singulation method for these materials and supports die singulation speeds of (100-300 mm/sec) which are 10X to 30X faster than conventional blade dicing, and without chipping or other damage (see Fig. 7).



To process a chip on 6 inch SiC wafer, it takes…

Die Size	Blade Dicing	SnB	
Scribe Speed	10 mm/s	100 mm/s	
0.75 mm	0.207 s	0.032 s	- 84.4 %
1.00 mm	0.270 s	0.043 s	- 84.0 %
1.50 mm	0.396 s	0.066 s	- 83.2 %

* Based on original calculations of MDI

Fig. 7: Comparison of SiC singulation processing speed between conventional blade dicing and SnB methods.

HIGH QUALITY AND HIGH RELIABILITY

Since the SnB process is a cleavage-based cutting method, it is possible to separate pieces while maintaining the cut surface crystal. This can be confirmed by the EBSD observation shown in Fig. 8.

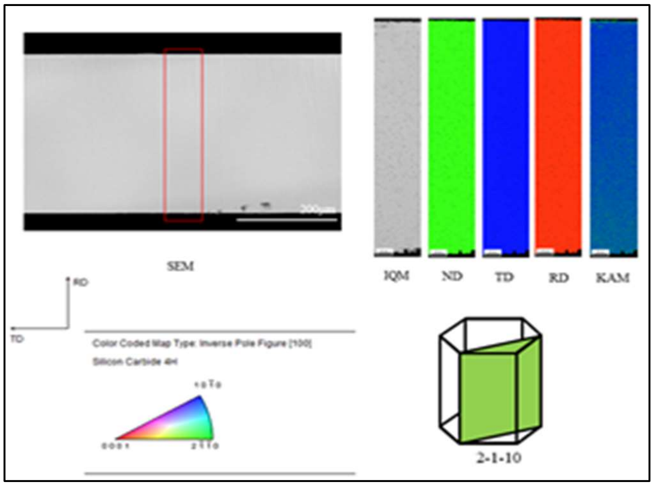


Fig. 8: EBSD analysis results of SiC singulation surface.

As a result of the remaining crystalline surface, microcracks on the cut surface are virtually non-existent, enabling damage-free singulation (Fig. 9).

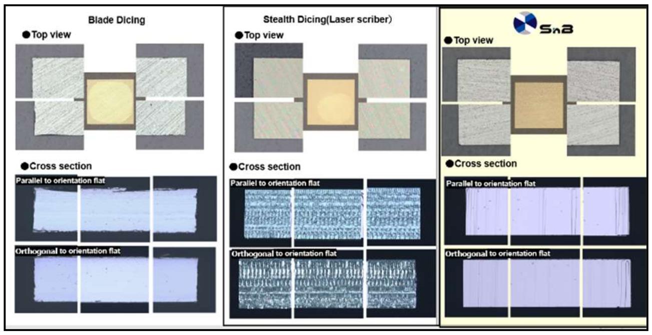


Fig. 9: Comparison of SiC die surfaces quality by different singulation methods.

The three-point bending strength measurement has also shown that the resistance strength is higher than that of the conventional method (Fig. 10).

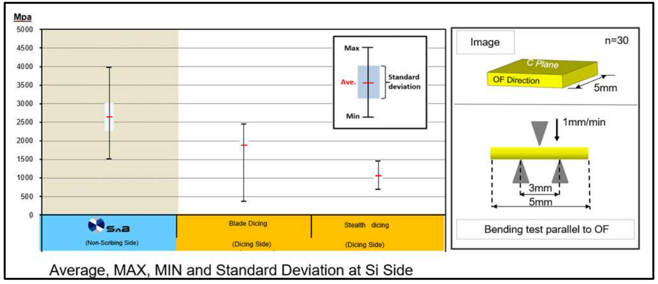
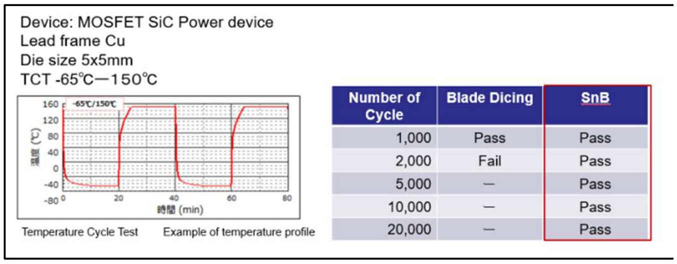


Fig. 10: Comparison of die bending strength tests for SiC by the three-point bending method.

As a result, the reliability evaluation results such as Thermal Cycle Test (TCT) of the final device also show that the possibility of microcrack propagation on the cut surface due to numerous stresses in the post process is extremely (Fig. 11)



Device: MOSFET SiC Power device
Lead frame Cu
Die size 5x5mm
TCT -65℃—150℃

Number of Cycle	Blade Dicing	SnB
1,000	Pass	Pass
2,000	Fail	Pass
5,000	—	Pass
10,000	—	Pass
20,000	—	Pass

Fig 11: Performance evaluation (TCT) results for SiC Packaged devices.

COMPLETELY DRY PROCESS

Unlike saw singulation where process water is required for sawing and cleaning, the SnB process requires no process water. Air and electricity consumption can also be drastically reduced, contributing to SDGs No7 and No.9 (Fig. 12)
Eliminating the need for process water and wastewater treatment also reduces the fab footprint and allows for easy relocation within the clean room.

Major Utility	Blade Dicing	SnB	Reduction	Remarks
Air(L/min.)	450	50	▲90%	
Vacuum(L/min.)	0	0	—	When equipped vacuum pump on SnB tool
Water(L/min.)	7	0	▲100%	
Power(kW/Wafer)	2.2	0.85	▲63%	Average Power

Preconditions
- Substrate size: 6 inch Die size:1mmX1mm、**WHP**: Blade Dicing 0.8WHP SnB 3.3WHP

Fig. 12: Comparison of UTILITY consumption with conventional method.

DEVELOPMENT OF SPECIAL SCRIBING WHEEL

SiC has strong covalent bonding and a Vickers hardness of around 2,500 HV, which makes it impossible to machine even a single substrate with conventional wheel made by PCD due to their durability. Therefore, a high-precision diamond wheel was developed as a special scribing wheel that is thought to be able to singulation of SiC.

The durability of the special scribing wheel achieved a run of 1,000 m on a SiC wafer, and further extension of the wheel's life can be expected. (Fig.13) This is more than 100 times more durable than the conventional wheel made by PCD. It is assumed that this is due to the selection of the best materials that is harder than PCD and suitable for SiC.

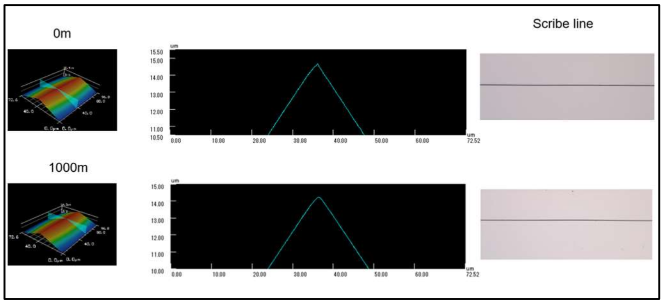


Fig. 13 Comparison of tool tip shape profiles before and after durability tests showing (a) 3D shape and (b) Tip shape profile.

SYSTEM DEVELOPMENT

We have developed and released a fully automated ALL-IN ONE singulation system that upgrades general cutting

equipment for brittle materials (mainly glass) to semiconductor specifications and is already in operation at a mass-production Fab. In addition to Scribe and break functions, inspection functions that lead to preliminary maintenance are provided at each step.
This system achieves high utilization rate and low yield. The equipment received the Good Design Award in 2021[1], see (Fig. 14).

Fig. 14: Fully automated compound semiconductor singulation system (DIALOGIC).

SUMMARY

If this innovative compound semiconductor die singulation method is put to practical use in the future, it is expected to significantly reduce the cost of compound semiconductor ICs. And this is one of the technologies that will ultimately contribute to society.

REFERENCES

[1] M. Kitaichi, Y.ASA,T. Fukunishi "*Novel cutting method of compound semiconductor (SiC) and development of specialized tool*" Abrasive Grain Processing Society Technology Award Introductory article, 2021

ACRONYMS

SnB: Scribe and Break
HAZ: Heat Affected Zone
Cu: Copper
Si: Silicon
SiC: Silicon Carbide
GaAs: Gallium Arsenide
GaN: Gallium Nitride
EBSD: Electron Back Scatter Diffraction Pattern
TCT: Thermal Cycle Test
SDGs: Sustainable Development Goals
PCD: Poly-crystalline Diamond