Comparison of CO_2 Emissions among Dicing Processes

Engineering R&D Division, T-Pro

Abstract

Semiconductor manufacturing processes consume large amounts of utilities such as electricity, DI water, and process gases, making the reduction of their environmental impact increasingly important. This paper compares the life-cycle CO_2 emissions of major wafer dicing processes on a per-wafer basis. In addition, the effects of DI water recycling and die size on CO_2 emissions are evaluated.

1. Introduction

In recent years, reducing CO_2 emissions from corporate activities has become a major global challenge. With the growing adoption of AI and the expansion of data centers, increasing attention is also being directed toward the environmental impact of semiconductor manufacturing processes. Semiconductor manufacturing consumes large amounts of electricity, deionized water (DI water), process gases, and other utilities. Consequently, semiconductor equipment manufacturers are expected to quantitatively assess the environmental impact of their products. This paper focuses on equipment used in semiconductor die dicing processes and compares their CO_2 emissions per silicon wafer.

2. Scope and Calculation Methodology

ISO 14067 [1] specifies principles and requirements for quantifying the carbon footprint of products by converting greenhouse gas (GHG) emissions at each life-cycle stage into CO_2 equivalents. Referring to this standard, the equipment life cycle was divided into five stages: Raw Materials, Manufacturing, Transportation, Use, and Disposal. CO_2 emissions were calculated for each stage. To account for differences in throughput among dicing processes, CO_2 emissions at each stage were converted into emissions per wafer and used as the basis for comparison.

2-1. Dicing Processes Evaluated

CO_2 emissions were calculated for four major silicon wafer dicing processes (Fig. 1). Blade Dicing was evaluated assuming the use of a water temperature control unit (DTU). Stealth Dicing™ was evaluated using a combination of a laser saw to form the modified layer and a die separator to separate the wafer along this layer [2]. Plasma Dicing was evaluated using a combination of a laser saw for mask patterning and a conventional plasma etching system [3].

No.	Process	Configuration
①	Blade Dicing (DTU)	DFD6363+DTU1550
②	Stealth Dicing™	DFL7362+DDS2300
③	Laser Full Cut	DFL7262
④	Plasma Dicing	DFL7262+Conventional plasma etching system

Fig. 1 Major dicing processes and their equipment configurations

2-2. Die Conditions

In order to compare the dicing processes under equivalent conditions, the die size and wafer thickness were specified, and the processing conditions for the Use stage were determined (Fig. 2).

Material	Silicon
Wafer diameter	⌀300 mm
Thickness	20 μm
Size	10 mm×10 mm
Street width	50 μm

Fig. 2 Die conditions

2-3. Calculation Methodology

For the Raw Materials stage, CO_2 emissions were calculated by selecting appropriate emission factors based on the materials and weights of the components used in each piece of equipment. For the Manufacturing stage, CO_2 emissions were calculated based on the CO_2 emissions data of the manufacturing factory. However, some emission sources were excluded for certain equipment, including accessory units and equipment manufactured by other companies as detailed data on raw materials and manufacturing processes were unavailable. Therefore, CO_2 emissions from processes involving such equipment may have been underestimated. For the Transportation stage, CO_2 emissions were calculated based on equipment weight, average transportation distance, and transportation method. For the Use stage, CO_2 emissions were calculated based on the consumption of utilities (Electricity / City water / DI water / Compressed Air / Exhaust) under standard operating conditions. In addition, CO_2 emissions from major consumables required for continuous equipment operation, such as dicing blades, laser heads, and wafer protective films, were calculated for all stages from Raw Materials to Disposal using the same methodology as that applied to the equipment. When process gases were used as consumables, CO_2 emissions were calculated based on gas flow rates, gas densities, global warming potentials, and typical byproduct formation and decomposition rates. From the perspective of the equipment life cycle, all CO_2 emissions associated with these consumables were included in the equipment's Use stage. For the Disposal stage, CO_2 emissions were calculated by multiplying the weight of each piece of equipment by an appropriate emission factor. CO_2 emissions at each stage were divided by the total number of wafers processed over a 15-year operating period to obtain emissions per wafer. The emission factors used in these calculations were obtained from data provided by AIST-IDEA [4], Tokyo Electric Power Company Group, Tokyo Metropolitan Waterworks Bureau, or SEMI.

3. Calculation Results

3-1. Comparison of CO_2 Emissions among Dicing Processes

The calculated life-cycle CO_2 emissions showed that the combined contribution of the Manufacturing, Transportation, and Disposal stages was less than 1% for all processes. The Use stage, which includes CO_2 emissions associated with consumables, accounted for the majority of total emissions (Fig. 3). CO_2 emissions during the Use stage depend on the consumption of utilities and consumables during equipment operation. These results indicate that utility and consumable consumption significantly influences total life-cycle CO_2 emissions. Comparing the relative CO_2 emissions among the different dicing processes, Stealth Dicing™ and Laser Full Cut generated less CO_2 than Blade Dicing, with emissions

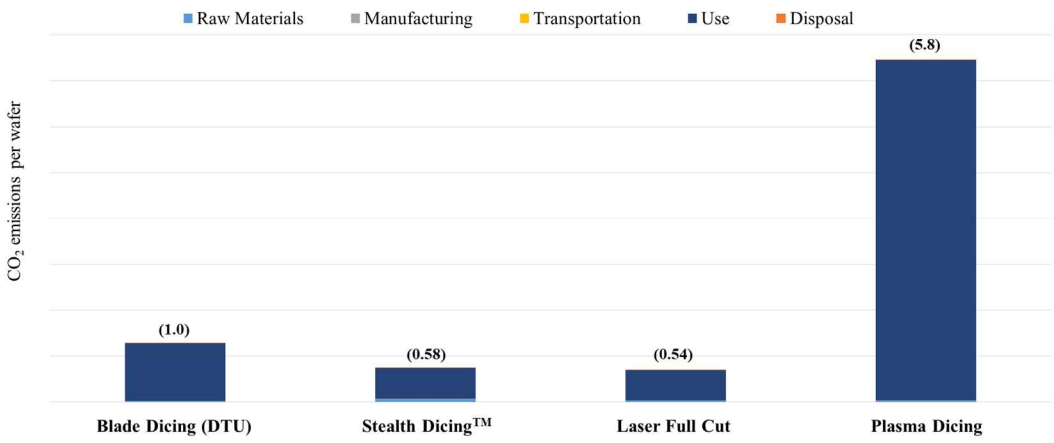


Fig. 3 Comparison of CO_2 emissions among dicing processes

(Values in parentheses indicate relative CO_2 emissions normalized to Blade Dicing (DTU) = 1.0.)

approximately 0.58 and 0.54 times those of Blade Dicing, respectively. This difference is attributed to the fact that Blade Dicing consumes a large amount of DI water during processing, whereas Stealth Dicing™ and Laser Full Cut are dry processes that do not require DI water for processing. In contrast, CO_2 emissions from Plasma Dicing were approximately 5.8 times as high as those from Blade Dicing. This was primarily attributed to the high electricity consumption of the plasma etching system and the use of process gases. These results indicate that, under the conditions evaluated in this study, Stealth Dicing™ and Laser Full Cut, which do not require DI water for processing, generated the lowest CO_2 emissions per wafer, while Plasma Dicing generated the highest emissions.

3-2. CO_2 Reduction Effect of DI Water Recycling

To evaluate the CO_2 reduction effect of DI water recycling in Blade Dicing, CO_2 emissions were compared between a blade dicer connected to a DTU and one connected to a Deionized Water Recycling Unit (DWR) (Fig. 4).

The results confirmed that connecting a DWR to a blade dicer reduced CO_2 emissions per wafer by approximately 60%. The resulting emissions were also lower than those of the two laser-based processes shown in Fig. 1. The substantial reduction in CO_2 emissions during the Use stage can be attributed to two factors. First, the DWR recycles cutting water at a high recycling rate of 99.5% [5]. Second, the temperature variation of the cutting water circulating between the blade dicer and the DWR is small, allowing temperature control with less electricity than a DTU. Furthermore, a DWR can be operated more efficiently when connected to multiple blade dicers. Therefore, CO_2 emissions in actual production environments are expected to be even lower than those calculated in this study.

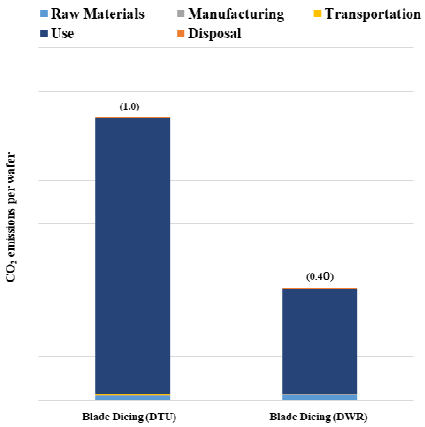


Fig. 4 CO_2 emissions from Blade Dicing with a DTU versus a DWR

3-3. Effect of Die Size

In general, when the wafer thickness is constant, the throughput (wafers/h) of a blade dicer decreases as the die size decreases. In contrast, plasma etching processes the entire wafer surface simultaneously. Therefore, die size has very little influence on its throughput. To investigate the effect of die size on CO_2 emissions, the throughput of the plasma etching system was assumed to remain constant regardless of die size. The die size was then changed from the conditions shown in Fig. 2 to 3 mm × 3 mm, while all other conditions were left unchanged. CO_2 emissions were calculated for Blade Dicing and Plasma Dicing. For 10 mm × 10 mm die, CO_2 emissions from Plasma Dicing were approximately 5.8 times those from Blade Dicing. However, for 3 mm × 3 mm die, this ratio decreased to approximately 1.8 times, indicating a substantial reduction in the difference between the two processes. Even under the 3 mm × 3 mm condition, CO_2 emissions from Plasma Dicing remained higher than those from Blade Dicing. Compared with Blade Dicing connected to a DWR, Plasma Dicing generated approximately 5.5 times more CO_2 emissions. Although plasma etching itself is a full-wafer process that is largely unaffected by die size, the preceding protective-film patterning process using a laser saw requires longer processing time as the number of dicing streets increases with decreasing die size. In addition, CO_2 emissions associated with process gases are considered to remain a significant contributor.

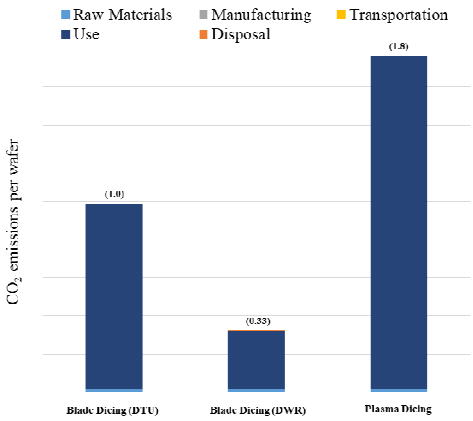


Fig.5 CO_2 emissions from Blade Dicing and Plasma Dicing for 3 mm × 3 mm die

4. Conclusion

In this study, life-cycle CO_2 emissions were calculated for different dicing processes and compared on a per-wafer basis. Under the conditions evaluated, CO_2 emissions from Blade Dicing connected to a DTU were higher than those from Stealth Dicing™ and Laser Full Cut, but lower than those from Plasma Dicing. The results also showed that the consumption of utilities and consumables during equipment operation is a major factor influencing total life-cycle CO_2 emissions. Furthermore, connecting a DWR to

Blade Dicing reduced CO_2 emissions per wafer by approximately 60%. When die size was reduced to 3 mm × 3 mm, the ratio of CO_2 emissions from Plasma Dicing to those from Blade Dicing connected to a DTU decreased from approximately 5.8 to 1.8. This indicates that die size-dependent variations in process throughput affect the relative CO_2 emissions of different dicing processes.

References

[1] ISO 14067:2018.
[2] DISCO CORPORATION, “Stealth Dicing™.”
[3] DISCO CORPORATION, “Plasma Dicing.”
[4] AIST Solutions, “AIST-IDEA.”
[5] DISCO Technical Review, “Usefulness of the ultra-compact deionized water recycling unit for dicing saws.”