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Reverse Engineering of Commercial Ultrasonic Saw Blade Cutter for Cutting Semiconductor Material

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ABSTRACT

This paperpresents preliminary results for reverse engineering the vibrational characteristics of a commercial ultrasonic saw blade cutter for cutting semiconductor material, in particular silicon wafers. It is widely acknowledged that the saw cutting method is typically employed to slice the silicon wafer, which is the final product in the microchip manufacturing process. The addition of an ultrasonic-assisted method is anticipated to enhance the quality of the kerf groove, reducing the occurrence of chipping or damage. Consequently, an ultrasonic saw blade cutter design has been developed, drawing inspiration from a commercial ultrasonic saw blade. In order to gain insight into the device's underlying principles and functionality, a reverse engineering process was employed. Reverse engineering is a technique employed in engineering whereby an object is dismantled in order to gain insight into its operational principles. The objective is to enhance its functionality and to identify the optimal designparameters. A reverse engineering process was under taken on a commercial ultrasonic saw blade, comprising an experimental benchmarking exercise, which included impedance testing, an impulse hammer test and a vibrational amplitude measurement. The results of the vibrational analysis indicated that the resonance frequency and the vibrational amplitude are approximately 41 kHz and 0.8 µm, respectively, when a voltage of 120 Hz is applied.

Keywords: Reverse engineering; Simulation; Ultrasonic; Vibration; Saw Cutting
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INTRODUCTION

Reverse engineering is engineering method to copy and replicate of the mechanical object in the purpose of improvement and redesigning to know the scientific knowledge behind designing (Kumar et al., 2013). Reverse engineering plays a crucial role in driving technological advancements and fostering creativity in product development (Bertoni, 2019). In this research, the reverse engineering is used to replicate and re-design a product to improve its performance and to fully understand the working principle of the product. In the field of engineering, the process of reverse engineering typically commences with the measurement of the object's geometry, which is wanted to be replicated. This is essential to ascertain the object's surface or solid model, which can then be explored in Computer Aided Design (CAD) or even Computer Aided Manufacturing (CAM) (Várady et al., 1997). Therefore, to fully understand to know the concept design of an object or product, the researcher needs an understanding of the functionality of the original the object during replicating process. Reverse engineering is utilized to re-produce either a high-value commercial parts for industrial profits or historical parts with high value. The reverse engineering of a product consists of some processes for example "predict", "observed"," disassembled"," analysed", and" tested" (Otto et al., 1996).

Reverse engineering application refers to the practice of analysing and understanding the design, structure, and functionality of a product or system through the process of reverse engineering. This method involves disassembling the product, studying its components, and reconstructing or redesigning it based on the acquired knowledge (Maier et al., 2009).

Reverse engineering applications are widely used in various industries, including software development, manufacturing, aerospace, and medical (Zhang, 2003) to improve product performance, enhance compatibility, or create innovative solutions. Researchers can uncover valuable insights by reverse engineering a product or system, to identify weakness or inefficiency, and develop strategies for optimization (Youssef et al., 2008) and innovation (Rozesara et al., 2023). Reverse engineering is employed for innovation and development purposes in the enhancement of the ultrasonic dicing saw blade within the dicing saw process.

The dicing saw process is a crucial step in the production of microchips, where a silicon wafer is sliced into its final form (Pei et al., 2008). To achieve high-quality results, it is essential to maintain a consistent kerf or groove without any defects, such as chipping or fracture (Luo et al., 2008). Traditionally, grinding grains or abrasive cutters have been used in silicon wafer processing. However, this method has a significant drawback due to the brittle nature of silicon (Arif et al., 2012), which can lead to edge chipping when the abrasive particles collide with the workpiece. Beyond the grinding traditional method, there are several alternative dicing saw process that can be used to slice silicon wafers, including scribing (Oliver et al., 2008), laser dicing (Marks et al., 2021), water jet-guided laser (Dushkina et al., 2003), plasma dicing (Matsubara et al., 2012), and ultrasonic dicing saw process (Shen et al., 2019), among others. Scribing (Oliver et al., 2008) is a relatively straightforward process for cutting silicon material. Nevertheless, despite its simplicity, scribing can still be prone to issues such as cracking or breakage if the depth of cut exceeds the critical threshold for brittle-ductile transition.

Laser dicing (Wang et al., 2022) represents a cutting-edge technique employed in the semiconductor industry for the precise and efficient dicing of wafers. The process involves the utilization of a femtosecond laser beam for selective ablation (Marks et al., 2021) or cutting of semiconductor materials, such as silicon, with the objective of separating individual chips or components on a wafer. Laser dicing offers a few advantages over traditional mechanical dicing methods, including higher precision, reduced material waste, and precise cutting resolutions. Laser dicing (Marks et al., 2021) has emerged as a promising alternative for wafer dicing, despite the presence of a number of significant challenges. One of the principal disadvantages is the possibility of thermal damage, in addition to the formation of a porous layer and high-thermal stress concentrations on the surface.

The water jet-guided laser method (Tabie et al., 2019) represents a novel approach to semiconductor processing, whereby the precision of laser technology is combined with the efficiency of water jet cutting. This method allows for the precise cutting and shaping of semiconductor materials in terms of cutting quality, material removal rates, and process control in semiconductor cutting. The disadvantages of this method include the complexity of the process, which requires sophisticated equipment and is costly to operate and maintain. Additionally, there are limitations in terms of material compatibility, particularly regarding thickness, and the method presents environmental challenges due to waste generation. In addition, while plasma dicing (Matsubara et al., 2012) demonstrates considerable potential for semiconductor processing, the absence of chipping and slow rate of etching time present significant challenges to real implementation.

Ultrasonic dicing saw process (Shen et al., 2019) is a promising technique that involves using ultrasonic motion along the radial axis of the cutter wheel to aid in the cutting process. This technique simultaneously vibrates the saw blade, allowing the abrasive grains to cut a small the depth of material. The advantages of ultrasonic dicing method include reduced damage to the kerf, ease of implementation, lower cost, and similar processing time compared to conventional dicing methods. In this study, reversed engineering was utilized to redesign the commercial ultrasonic dicing saw blade. The primary goal of this proceeding paper is to present the measurement and experimental benchmark of the commercial ultrasonic dicing saw blade. The experimental benchmarks comprise impedance testing, an impulse hammer test and a vibrational amplitude measurement which are the subject of this paper.

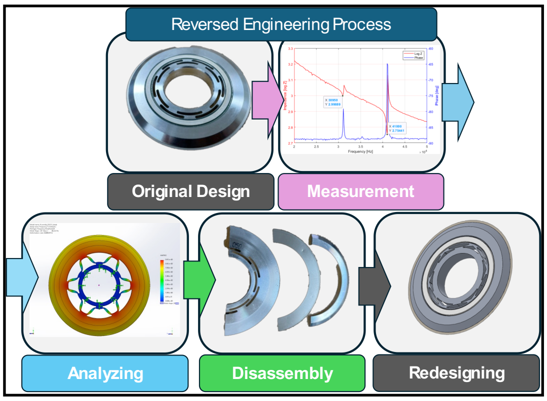


Figure 1. Reversed Engineering Process

METHODS

This paper presents a benchmarking study of a commercial dicing saw blade, employing impedance testing, an impulse hammer test, and a vibrational amplitude measurement. Figure 1 illustrates the process of reverse engineering, which comprises the following stages: the original design, measurement benchmarking, analysis, disassembly, and redesign. The initial design is based on the commercial product manufactured by the DISCO company. Subsequently, In the measurement process, the impedance test employs an impedance analyser (type PV520A), the impulse hammer test utilises a dynamic analyser (HP 35665A), and the vibrational amplitude measurement employs a data-acquisition (DAQ) USB-6363. In the case of the impulse hammer testes, the experimental setup is shown in Figure 2. Subsequently, the object was analysed using modal and harmonic analysis to validate the measurement results and confirm the accuracy of the measured data. Then, the object was disassembled in order to obtain engineering values, including dimensions, geometry/shape, and tolerance. In final stage of the reversed engineering process, the ultrasonic dicing saw blade was redesigned with the objective of improving its vibrational characteristics. However, the redesign of the object is not subject of this paper. The present paper is solely concerned with the measurement results of the commercial ultrasonic dicing saw blade. The complete results will be presented in the full version of the paper, which will be published in the future.

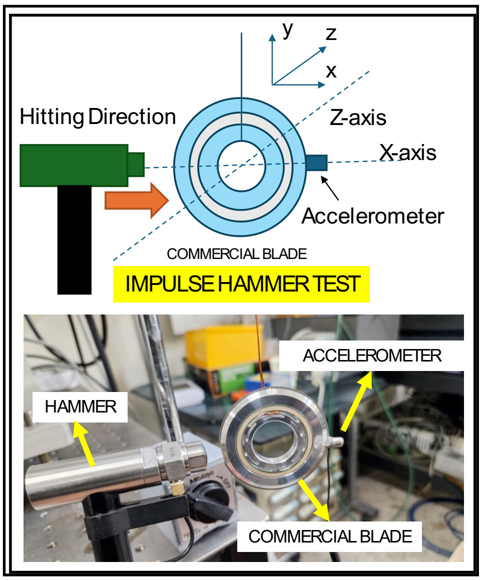
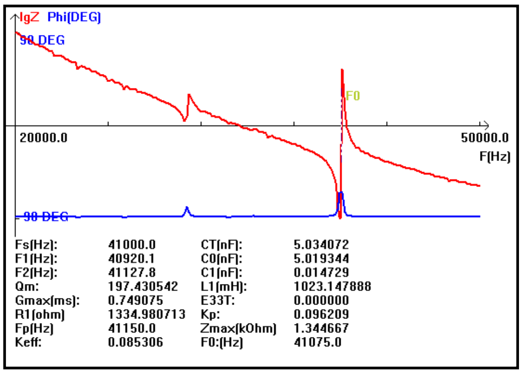


Figure 2. Impulse Hammer Testing

EXPERIMENT RESULTS

1. *Impedance testing*

Impedance testing is a technique employed for the purpose of measuring the electrical impedance of a given device or system. Impedance is defined as a measure of the opposition that a circuit presents to the flow of alternating current (AC) at a given frequency. Figure 3 illustrates the impedance trend of the commercially available ultrasonic dicing saw blade. In general, the impedance reaches a minimum at the resonance frequency and a maximum at the anti-resonance frequency. The red line represents the impedance value, while the blue line indicates the phase difference. Figure 3 illustrates that the resonance frequency is represented by $\mathbf{F_S}$, approximately 41 kHz, and the anti-resonance frequency is represented by $\mathbf{F_P}$, approximately 41.15 kHz. $\mathbf{F_0}$ represents the midpoint between the resonance and anti-resonance frequencies, occurring at a frequency that is half of the distance between the two. The value of $\mathbf{F_0}$ is approximately 41.075 kHz. The half-power frequency, $\mathbf{F_1}$, and the second half-power frequency, $\mathbf{F_2}$, are indicated as 0.707 times the amplitude peak of the resonance frequency. The quality factor, $\mathbf{Q_m}$, of the original design is indicated as approximately 197.43.



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Fs(Hz):       41000.0       CT(nF):        5.034072
F1(Hz):       40920.1       C0(nF):        5.019344
F2(Hz):       41127.8       C1(nF):        0.014729
Qm:           197.430542    L1(mH):        1023.147888
Gmax(ms):     0.749075      E33T:          0.000000
R1(ohm)       1334.980713   Kp:            0.096209
Fp(Hz)        41150.0       Zmax(kOhm)     1.344667
Keff:         0.085306      F0:(Hz)        41075.0
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Figure 3. Impedance graph of commercial ultrasonic dicing saw blade

2. *Impulse hammer testing*

Tabel 1. Impulse hammer testing results

No.	Mode Shape	Frequency
1	Mode 1	5,888 Hz
2	Mode 2	12,032 Hz
3	Mode 3	21,568 Hz
4	Mode 4	35,264 Hz
5	Mode 5	41,216 Hz

Impulse hammer testing is a method employed in the field of structural dynamics and vibration analysis. It is used to ascertain the dynamic characteristic response of a structure body when an impulse force is applied. In this testing method, an impulse hammer is employed to deliver a rapid and transient force to the body structure, resulting in a measurable response that can be analysed to ascertain the structural characteristics, including natural frequencies, damping ratios, and mode shapes. Table 1 illustrates the results of the impulse hammer testing for the difference vibrational modes. The results of the impulse hammer testing are indicated in the form of a graph and have been extracted to a value based on the maximum peak of the graph. Radial vibrations occur in a few modes; however, uniform radial vibrations occur in vibrational mode 5, with a frequency of approximately 41.216 kHz.

3. *Vibrational Amplitude Measurement*

The vibrational amplitude was measured using three different voltages, namely 30, 70, and 120 volts. The ultrasonic frequency was set to an exact value of 41 kHz, which is precisely the resonance frequency. The vibrational amplitude was quantified through the utilization of an optical fibre displacement output. Figure 4 illustrates the vibrational amplitude when the given voltage was 120 V. The amplitude trend exhibited stability and consistency in the resonance characteristic. The commercial ultrasonic dicing saw blade produces an amplitude peak-to-peak of 0.8 µm. Table 2 presents a summary of the amplitude with the corresponding variation in input voltage. This data can be used as a basis for redesigning the device to obtain a higher amplitude. It is well-established that the amplitude is influenced by the input voltage. When the input voltage is low, the amplitude is low, and when the input voltage is high, the amplitude is high.

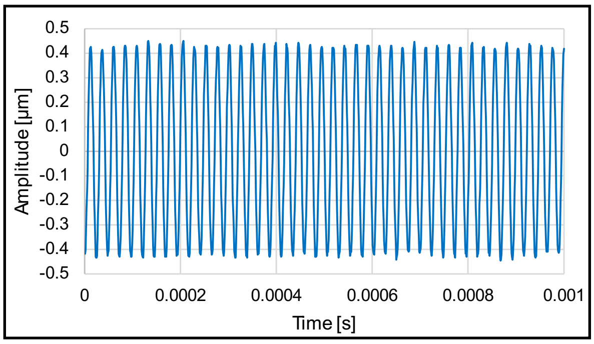

Figure 4. Amplitude graph at given voltage of 120 volts

Tabel 2. Vibrational amplitude

No.	Input Voltage	Amplitude peak-to-peak
1	30 V	0.207 µm
2	70 V	0.545 µm
3	120 V	0.814 µm

CONCLUSION

In conclusion, the commercial ultrasonic dicing blade has been subjected to a vibrational benchmarking analysis. Considering the results, two key points can be briefly summarized as follows:

1. The commercial ultrasonic dicing blade has been found to have a resonance frequency of approximately 41 kHz when tested using impedance and impulse hammer techniques. This result provides a foundation for future improvements to the design.
2. The commercial ultrasonic dicing blade was observed to produce a vibrational amplitude peak-to-peak of approximately 0.8 µm when an the input voltage of 120 volts was applied. This result also serves as a basis for the vibrational amplitude, which will be improved upon in future work.

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