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Simulation design of vibration blade for silicon wafer dicing system

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Abstract

This article presents a recent work regarding the design of an ultrasonic vibration blade for use in ultrasonic wafer dicing applications. The design of the vibration blade comprises the main hub plate, support hub plate, piezo-ring, and diamond blade. Finite element analysis (FEA) was used in the simulation design of the vibration blade to identify the optimal parameters for generating radial vibrations. The analysis revealed that the radial vibration mode can be generated at a frequency of approximately 40 kHz. A thin piezo-ring was selected to induce radial vibrations into the body structure. The main hub was designed with specific slots to facilitate the radial propagation of vibrations. The slot count, slot angles, and pitch angles were adjusted to find the optimal frequency. Additionally, this analysis investigated variables such as inner diameter, outer diameter, and piezo thickness to determine the ideal frequency value. According to the simulations, a slot angle of 20 degrees, a pitch angle of 60 degrees, and six slots provided the best frequency result which is close to 40 kHz. This study conducted experimental impedance frequency tests to validate the simulation's findings. The results demonstrated a close similarity between the experimental frequency and the frequency predicted in the simulation.

Piezo-electric, Simulation, Ultrasonic, Vibration

1. Introduction

The dicing method is a traditional cutting technique used to slice the silicon wafer as the final step in the microchip manufacturing process. In this process, it is crucial to maintain the standard quality of the kerf/groove without any chipping, fractures, or damage. The conventional approach in silicon wafer processing typically involves using grinding grains or abrasive cutters on the tool. However, a significant drawback exists in this conventional method due to the brittle nature of silicon, leading to numerous edge chippings when the abrasive particles impact the workpiece.

There are various dicing methods used to slice silicon wafers besides the conventional approach, including scribing [1], laser dicing [2], plasma dicing [3], ultrasonic dicing [4], and more. Scribing is a straightforward method for cutting silicon material. However, a significant challenge arises when the depth of the cut exceeds the critical depth of brittle-ductile transition, leading to cracks or breakage [1]. Laser dicing shows promise as a future dicing method, despite significant drawbacks such as the thermal effect, formation of a porous layer, and high-stress concentration on the material [5]. Additionally, plasma dicing is considered one of the best candidates; however, its real industrial implementation poses challenges.

One of the methods is ultrasonic dicing [4], which involves imparting simultaneous vibration to the saw blade. Consequently, the abrasive grains can cut a minimal depth of the material. Ultrasonic dicing offers several advantages over other methods, including reduced damage and fracture of the kerf, ease of implementation, lower cost, and comparable processing time to conventional dicing methods. To implement the ultrasonic dicing technique, the design of an ultrasonic vibration dicing blade has been developed.

The primary objective of this brief paper is to introduce the simulation and prediction of vibration amplitude. The slot count, slot angles, and hinge angles were adjusted to determine the optimal desired frequency. Subsequently, the impedance frequency was identified at approximately 40.604 kHz.

2. Design, Simulation and Experimental Setup

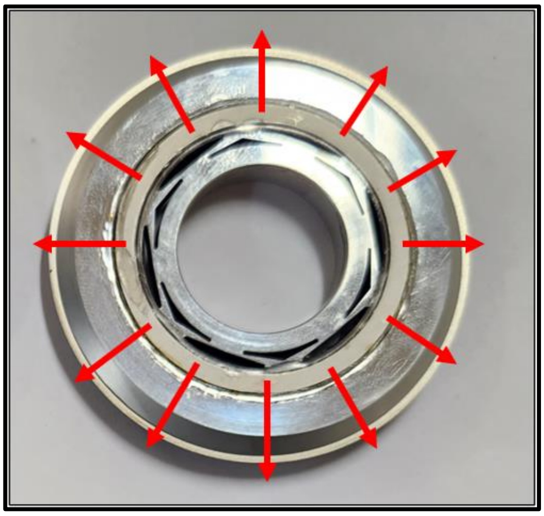
2.1. Design and FE simulation setup

Figure 1(a) illustrates the design of the ultrasonic dicing blade, comprising a piezo, main hub, saw-blade, and support hub. The material composition of each component is depicted in Table 1. The main hub was intricately designed with specific slots to facilitate radial propagation of vibrations, utilizing a triangular double slot configuration. Throughout the design process, adjustments were made to the slot count, slot angles, pitch angles, and the dimensions of the piezo were roughly examined to understand its impact. The piezo vibrates along radial direction. As shown by the red arrow in Figure 1(b).

Table 1 Material composition of each component

No	Component	Material
1	Piezo	Ceramic
2	Main-Hub	Aluminum
3	Saw-Blade	Diamond
4	Support-Hub	Aluminum

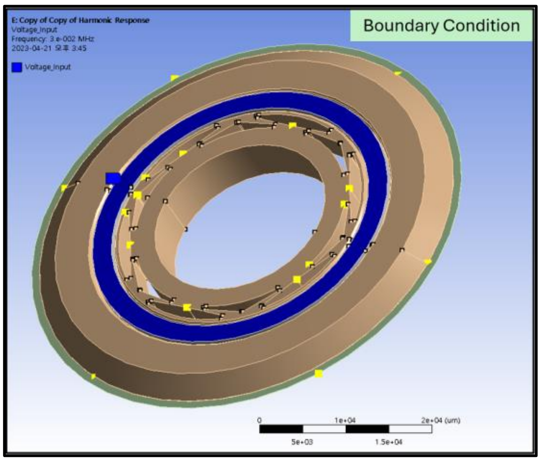
(a)



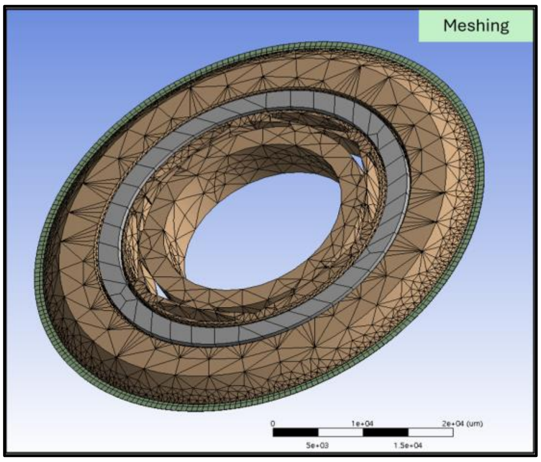
(b)

Figure 1. Ultrasonic dicing blade design

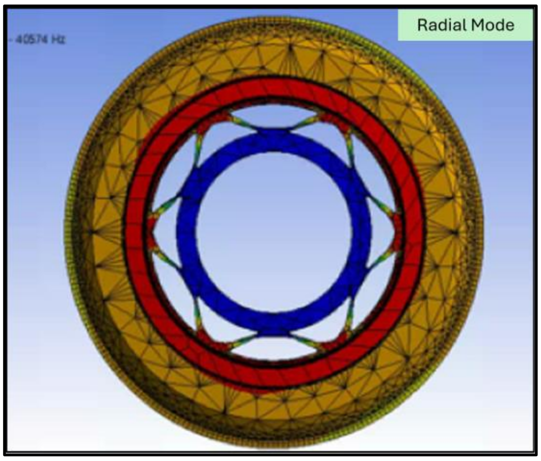
Finite Element (FE) simulation was conducted using ANSYS v19.2, with modal analysis performed to assess the radial vibration mode. Figure 2 depicts the setup for the FE simulation in ANSYS v19.2, showcasing the boundary conditions, meshing, and frequency results.



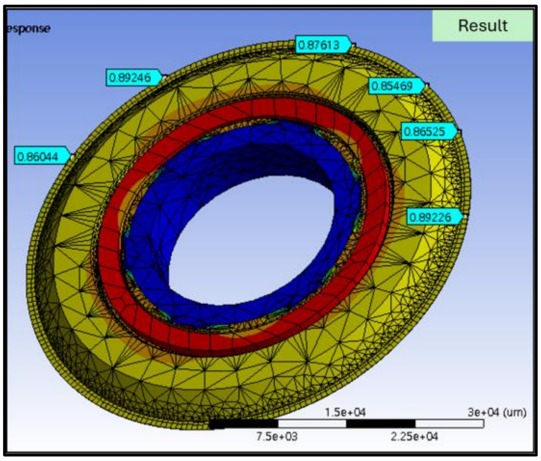
(a)



(b)



(c)

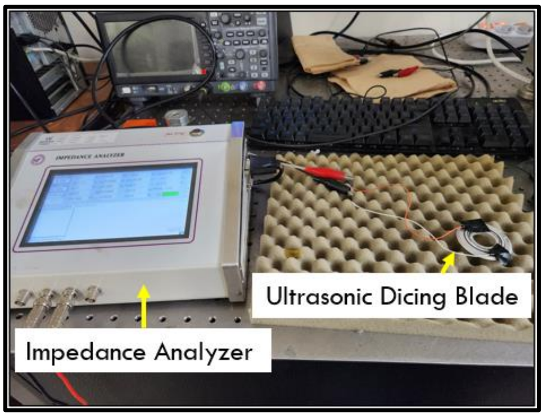


(d)

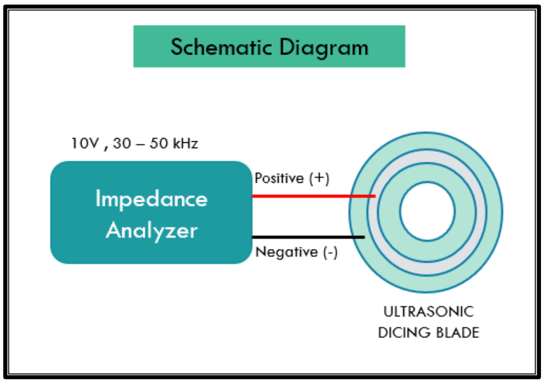
Figure 2. FE simulation setup in the ANSYS software

2.2. Experimental setup

Figure 3 illustrates the experimental setup for impedance frequency testing. In Figure 3(a), the impedance analyzer was employed to validate the ultimate design of the ultrasonic dicing blade. The blade was connected with the impedance analyzer by cable, the positive electrode is connected to the piezo and the negative electrode is connected to the body. A frequency range of 30 to 50 kHz was chosen with an input voltage of approximately 10 V. Figure 3(b) shows schematic diagram of the measurement. The displacement optical sensor was used to obtain the amplitude of the blade.



(a)



(b)

Figure 3. Impedance frequency experimental setup

3. Simulation Result

Table 2 presents the results of FE simulation for modal analysis. The radial mode is approximately 41.334 kHz for a slot angle of 20°, pitch angle of 60°, and slot count of 6. The radial frequency experiences a slight increase with a slot count of 8. However, the radial mode is nonexistent with a slot count of 12. The torsional frequency values range between 13 and 18 kHz, making them potentially beneficial for vibration-assisted cutting applications requiring low frequencies (< 20 kHz). A frequency of 41.334 kHz is considered sufficient for vibration-assisted applications.

Table 2 Frequency and slot dimension

Slot Angle /°	Pitch angle /°	Slot count	Torsional /kHz	Radial /kHz
10	30	12	18.992	NA
15	45	8	16.181	42.638
20	60	6	13.539	41.334

Table 3 Frequency and piezo thickness variation

Inner DIA /mm	Outer DIA /mm	Thickness /mm	Torsional /kHz	Radial /kHz
32.3	37	0.5	13.539	41.334
32.3	37	1	13.253	40.201
32.3	37	1.5	12.943	39.056
32.3	37	2	12.591	37.792
32.3	37	2.5	12.183	36.078
32.3	37	3	11.684	32.448

Table 4 Frequency and piezo outer diameter variation

Inner DIA /mm	Outer DIA /mm	Thickness /mm	Torsional /kHz	Radial /kHz
32.3	37	0.5	13.539	41.334
32.3	38.5	0.5	13.461	40.999
32.3	40	0.5	13.366	40.674
32.3	41.5	0.5	13.253	40.357
32.3	43	0.5	13.139	40.054

Table 5 Frequency and piezo inner diameter variation

Inner DIA /mm	Outer DIA /mm	Thickness /mm	Torsional /kHz	Radial /kHz
32.3	43	0.5	13.139	40.054
33.5	43	0.5	13.207	40.304
35	43	0.5	13.284	40.623
36.5	43	0.5	13.367	40.951
38	43	0.5	13.454	41.293

Tables 3, 4, and 5 display the frequency results with variations in the piezo dimensions, including inner diameter, outer diameter, and thickness, respectively. The frequency decreases as the thickness increases, because in piezo, the thickness determines the resonance mode. Thinner piezo exhibits higher resonance frequencies because they support higher-order resonance modes, where the waves travel shorter distances, and there is a slight decrease in frequency when the outer diameter increases. This indicates that the piezo thickness has a significant impact on the frequency. In the case of inner diameter variation, the frequency does not exceed 41.334 kHz.

4. Impedance Frequency Result

The ultrasonic dicing blade has been manufactured with the final dimensions set at a slot angle of 20, pitch angle of 60, and slot count of 6. In Figure 4, the impedance frequency of the ultrasonic dicing blade is depicted with a piezo thickness of 0.5 mm. The resonance frequency (f_s) is measured at approximately 40.604 kHz, and the anti-resonance (f_p) frequency is measured at about 40.790 kHz. The mechanical quality factor (Q_m) is approximately 275.32. The resonance frequency prediction closely aligns with the experimental value, with an error of approximately 1.79%.

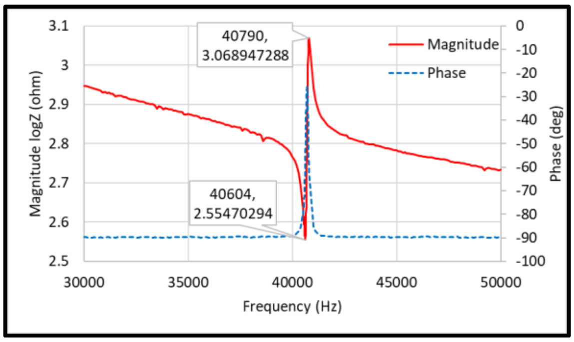


Figure 4. Impedance frequency of ultrasonic dicing blade

5. Conclusion

According to the FE simulation results, the frequency closely aligns with 40 kHz when the design incorporates a slot angle of 20, a pitch angle of 60, and a slot count of 6. The piezo dimension, particularly the thickness, has a significant impact on the frequency. Additionally, the resonance frequency prediction is nearly identical to the experimental value, with an error of approximately 1.79%. The established resonance frequency of the ultrasonic dicing blade is approximately 40.604 kHz.

Acknowledgment

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