Wafer Slicing and Wire Saw Manufacturing Technology

I. Kao (PI)
and V. Prasad, J. Li, M. Bhagavat
Department of Mechanical Engineering, SUNY Stony Brook, NY 11794-2300

Abstract: Wire saw, with its ability to cut very thin wafers from large diameter crystalline ingots of semiconductor materials, has emerged as a leading technology for wafer production in semiconductor and photovoltaic industry. Nevertheless, the wire saw cutting process remains lacking a theoretical methodology and is not properly understood. The modern times compulsion of more accurate and efficient manufacturing has made it imperative to understand this abrasive slurry cutting process and to optimize it. As a sequel to this understanding, control tools can be developed to monitor the optimum process. In this paper, comparison are made between the wire saw and the inner diameter (ID) saw which has been used to cut semiconductor wafers. This comparison brings out superiority of wire saw over ID saw in most respects.

Introduction: Wire saw, operating on the Free Abrasive Machining (FAM) technique, is an emerging technology for large diameter thin crystal wafer production in semiconductor and photovoltaic (PV) industry. Its advantages span from producing very thin wafers with small kerf loss to high yield and productivity. Since medieval times wire saws have been known to be used in cutting hard materials like granite slabs and other variety of stones. However, requirements on wire saw cutting in terms of wafer thickness and quality are very different in electronics and photovoltaic applications than the traditional use of the process.

An evaluation of wire saw cutting process has shown that it is a poorly understood phenomenon and no model exists for simulation design and control. Even so, in crystal cutting applications, it has shown potential to produce better surface finish and thinner wafers with much higher yield than ID saws. This, coupled with total absence of any commercial US technology in this field makes this process worthy of detailed study.

The primary objective of this initial study of the long-term research project is to evaluate the current wire saw slicing technology and to compare it with the ID saw technology most commonly used for wafer slicing. Such a comparison is expected to shed light on the superiority of wire saw over other conventional crystal sawing methods, thus in turn bringing out the importance of concentrating efforts on the wire saw.

Wire saw manufacturing processes: Figure 1 shows the schematic of a wire saw. In the wire saw, a single strand of thin wire (175 μm in diameter) moves from a feed reel to a take-up reel. In between, the wire goes through the entrance side of storage system called the "carriage" and into the rectangular arrangement of fixed shafts with replaceable wire guides. The wire wraps around the wire guides which have hundreds of grooves. This creates a multiple net of parallel wires known as *web* through which the ingot crystal is fed together with abrasive slurry to produce a cut.

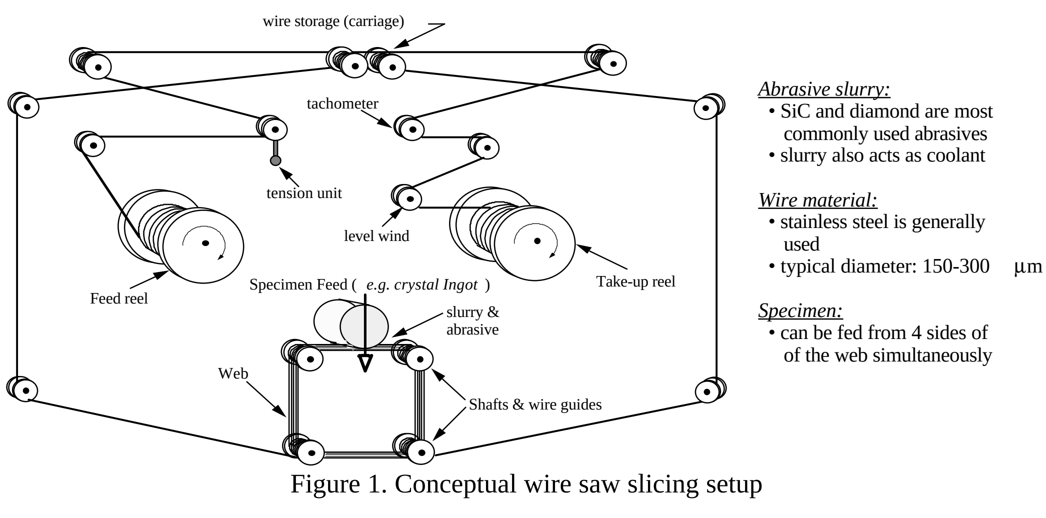

Figure 1. Conceptual wire saw slicing setup

The current wire saw can cut up to four ingots simultaneously from four sides of the web, thus showing a vast improvement in productivity over the ID saw. On account of the thin wire, the kerf loss in wire saw cutting process is minimized. Additionally, the future use of large diameter crystals favors wire sawing because ingot diameter capacity of wire saw is limited by only shaft spacing of wire guides of the web and the travel.

Comparison between wire saw and ID saw: Table 1 summarizes the principal differences between the wire saw and the ID saw.

PROPERTY	WIRE SAW	ID SAW
Method of cutting	Lapping	Grinding
Typical cut surface features	Wire marks	Chipping and fracture
Depth of damage	Uniform 10 to 15μm	Variable 20 to 30μm
Productivity	300 to 2000 sq.in./hr	200 to 400 sq.in/hr
Number of wafers cut per run	As high as 3200 wafers	A single wafer per cut
Kerf loss per cut	Typically 200 to 300μm	From 300 to 500μm
Minimum thickness of cut wafer	As low as 200μm	300 μm
Yield of 0.025 inch thick wafers	31 wafers per inch	27 wafers per inch
Maximum diameter of cut crystal	300mm-diameter crystals	Up to 200mm-diameter

Table 1. Comparison between wire saw and ID saw

The FAM process of the wire saw produces considerably less depth of damage and more uniform surfaces than that in the grinding process of the ID saw. This results in low residual stresses in wire saw cut crystal wafers and makes the wire saw more amenable to cutting of very thin wafers because the constructive interference of stress fields, when two cuts are made very close to each other, becomes less significant. Higher residual stresses are not desirable since they lead to breakage of thin wafers in both the cutting process and post-process handling.

In the PV applications where the post processing is not required, it is of cardinal importance to have least damaged wafer surfaces. The lesser surface damage, however, may not be as important to semiconductor industry where the sliced substrate is lapped, edged and polished well beyond the damage region. Nevertheless, smaller residual stress in the substrate will make it easier to handle the cut wafers without breaking and to produce more homogeneous wafers for the fabrication processes. The other field where a low damage on the cut surface is of importance is in slicing of optical material (e.g., $KTaO_3$) crystals. Here residual damage to the material adjacent to the cut produces objectionable levels of birefringence in materials with high strain-optic coefficients.

Also the well-known fact of getting a smooth surface by burnishing, wherein the working forces are much less than in polishing, makes wire saw more capable of giving good surface finish than the ID saw. The control of wire saw in terms of wire stiffness and vibration and slurry concentration management can be facilitated by properly modeling the manufacturing processes. Comparing to grinding and other cutting processes, the wire saw has much less brute force during the cutting process and thus has a potential of more energetically efficient cutting. This also can be advantageous in the processes wherein the temperature rise of the crystal at the local contact areas is not permissible from the metallurgical point of view due to possible change in its microstructure.

Currently, the cost of consumables (abrasives and slurry base) for the wire saw operation is still higher than that of the ID saw. The cost and ease of process control of the ID saw gives it a slight edge over the current wire saw. But this can mostly be attributed to total lack of methodical approach in research of wire saw manufacturing processes. Development of systematic modeling and control strategies can improve the wire saw manufacturing process and make it more cost-effective.

Conclusion: The objectives of the ongoing research in the modeling and control of wire saw are to provide systematic methodology to analyze and improve the wire saw manufacturing processes and to make it more cost-effective. Optical measurement techniques will also be introduced for in-situ and post-process measurements. Moreover, a US-based technology in wire saw manufacturing process and equipment technology will be developed.

Acknowledgment: The project has been supported by the NSF Grant DMI-9634889 (1996--1999). We also like to thank the GT Equipment Technology, Inc., our industrial partner, for their supports in this project.

References:

[1] R. K. Sahoo, V. Prasad, I. Kao, " An Integrated Approach for Analysis and Design of Wafer Slicing by a Wire Saw." To appear in ASME Transactions, Jl of Electronic Packaging.

[2] Ray Wells, "Wire Saw Slicing of large Diameter Crystals" Solid State Technology. September 1987. pp63-65

[3] M. C. Huffstutler et al, "Wire Saw Cutting Technique for Optical Crystals" Ceramics Bulletin 1966. Pp1098