Model 850, Model 920
Model 153

Evaluation of the Polishing Quality for Edge Polished Silicon

Applications Laboratory
Report 58

Lapping and
Polishing

1.0: Purpose

Optical crystal preparation is common among many different fields of research and product development. Producing high quality, well-polished edges of silicon, lithium niobate ($LiNbO_2$), and other related materials used in electro-optic devices has become of paramount importance for communications products. Modulators, oscillators, waveplates, compensators, and many other devices depend upon the quality of the edge and the surface polish quality to eliminate signal losses due to scattering effects. This report evaluates the quality of polishing protocols used for preparing edges of Silicon materials, commonly used for a wide range of similar applications.

2.0: Experiments and Procedures

A bulk silicon wafer was cut into several sections of 10mm wide x 15mm long dimensions for polishing experiments. Cutting of the pieces was done using a Model 850 Wire Saw and abrasive slurry. The primary advantage that the Model 850 offers is the minimal edge damage that is created during the cutting process, thus reducing subsequent lapping and polishing steps to minimize processing time.

2.1: Wire Sawing Parameters

Cutting of each part was done using 23 µm boron carbide (B_4C) abrasive slurry with a 0.010" stainless steel wire. Each cut was completed in less than 2 minutes, with a total preparation time of 30 minutes for 20 slices. Cutting of glass slide material for polishing processing was also done using the same methods.

ABRASIVE:	23 µm B_4C abrasive suspension
WIRE:	0.010" stainless steel
LOAD:	100 grams (10 notch)
SPEED:	4 on dial (220 rpm wire speed)
SLURRY PUMP:	5 on dial
CUTTING TIME:	2 minutes / cut

2.2: Wafer Slice Mounting

Following the cutting process, two pieces of Si material were waxed together to form a 'sandwhich' between two glass slides. The glass slide materials act as a buffer between the Si, thus preventing edge rounding effects that are problematic for these types of devices. The entire 'sandwich' was waxed together using MWH 135 mounting wax. This wax melts at 135°C, is acetone and isopropyl alcohol soluble, and provides good adhesion between materials. Once the 'sandwich' of specimens had been created, the stack was then waxed into a special mounting block to allow edge polishing of the materials to take place. The mount is a star shaped, vertical mounting block designed to be easily reversible to prevent extra mounting techniques to be employed. Mounting of the stack was done using a lower temperature wax, MWM070. The MWM 070 melts at 70°C, is soluble in warm water, and provides good adhesion as well. The difference in temperature for mounting was important to prevent the stack of samples from moving during the mounting process to the star shaped mounting block. A schematic illustration of this design is shown in Figure 1. Special precautions to make the samples uniform in height were taken. The mounting block was placed onto a hot plate using a small pedestal to allow for the pieces to mount uniformly onto the mounting block. Small amounts of wax (MWM 070) were applied to the mounting block and the wafer pieces were attached. Figure 1 shows an illustration of the mounting procedure and an image showing the resulting mounted wafer pieces.

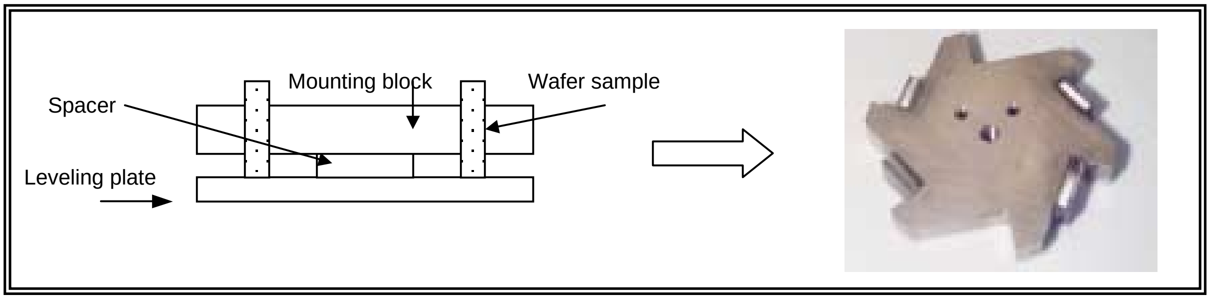

Figure 1: Illustration of the mounting process used for attaching the wafer pieces to the mounting block. The mounting block is placed onto a spacer and leveling plate all on the surface of the hot plate to facilitate even mounting of the wafer pieces. Wax is applied to the mounting block and the assembly is allowed to cool.

Following the mounting of the wafer pieces the assembly (wafer pieces mounted to the star shaped mounting block) was placed into the Model 153 Edge Polishing Lapping and Polishing Fixture. The Model 153 is unique in that it allows for virtually any length of specimen to be mounted into the fixture while controlling the thickness that is removed from the specimen. A schematic illustration of the fixture is shown in Figure 2.

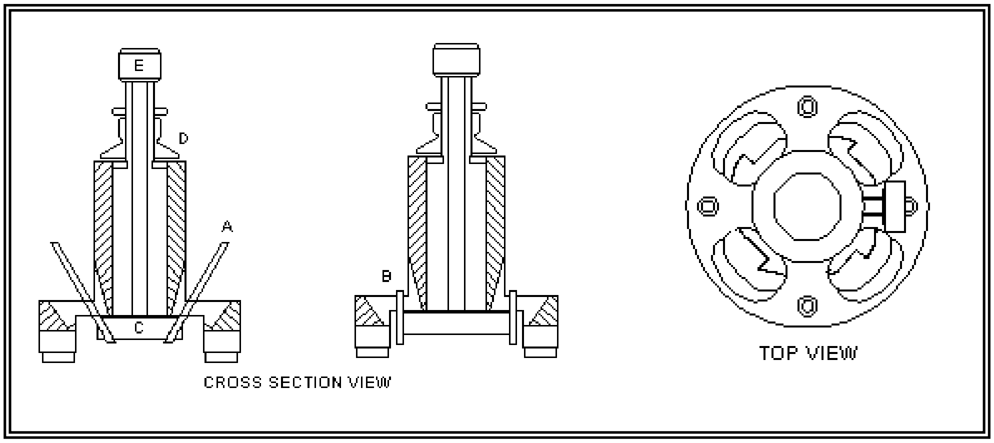

Figure 2: Schematic illustration of the Model 153 Laser Rod Polishing Fixture. The illustration on the left shows the original design for lapping and polishing laser rod crystals. The illustration at right shows a modified mounting block designed to accommodate square wafer pieces as prepared in this report.
A- Laser rod; B- Wafer piece; C- Mounting plate; D- Micrometer dial; E- Draw rod

2.3: Lapping

Lapping and polishing the end faces of the Si wafer pieces is needed to remove mechanical damage from the sawing process and to produce the smooth, high quality polish necessary for most optical materials. Lapping the specimen to produce a flat, uniform surface is required for making the edges perpendicular to the surface of the wafer piece and to eliminate any uneven edges that may have been produced in the wire sawing operation.

Initial lapping was completed using a flat, cast iron lapping plate with boron carbide (B_4C) abrasive suspension. The plate is first conditioned to remove any surface irregularities present on the lapping plate and to charge the plate with the desired abrasive particle size. Conditioning is carried out for about 30 minutes using a 14 μm B_4C abrasive suspension with a conditioning ring and Model 92002 Workstation. After plate conditioning is completed, the Model 153 is set up to remove 500 microns and the fixture is lapped for 20 minutes.

2.4: Polishing

Polishing is needed for removing the mechanical damage from lapping and to produce the optical quality polish required for device production.

2.4.1: Modified Diamond Film Polishing Procedure

Samples were produced using a modified procedure where abrasive suspension was used in conjunction with the diamond lapping films. Final polishing using an embedded lapping film with colloidal silica particles was used to produce the final surface finish. The procedure is described below.

3 μm Diamond Film with 1 μm Al_2O_3 Suspension

LAP SPEED:	2 (110 RPM)	LOAD:	100 GRAMS
ARM SPEED:	10 (40 RPM)	ABRASIVE:	1 μm Al_2O_3 suspension
TIME:	15 minutes		
SLURRY DRIP RATE:	None		

1 μm Diamond Film with 0.5 μm Al_2O_3 Suspension

LAP SPEED:	2 (110 RPM)	LOAD:	100 GRAMS
ARM SPEED:	10 (40 RPM)	ABRASIVE:	0.5 μm Al_2O_3 suspension
TIME:	15 minutes		
SLURRY DRIP RATE:	None		

0.08 μm Colloidal Silica Film with 0.08 μm SuperSil Suspension

LAP SPEED:	2 (110 RPM)	LOAD:	100 GRAMS
ARM SPEED:	10 (40 RPM)	ABRASIVE:	0.08 μm SuperSil Suspension
TIME:	15 minutes		
SLURRY DRIP RATE:	None		

4.0: Results

Following the preparation of the edges, each of the specimens were removed from the mounting block and cleaned. All of the edges were cleaned using optical grade wipes with acetone and isopropyl alcohol. Removal of any contamination from the surface without scratching the edge is critical both to device quality and to the measurement techniques applied. After the specimens were cleaned the surface quality of the specimens was evaluated using an inverted light microscope equipped with a Kodak MDS 120 Digital Camera. The microscope was fitted with a C-mount adapter to allow for digital images to be captured with the Unitron Inverted Microscope. A series of pictures were taken and are displayed below to illustrate the surface quality obtained from the process.

4.1: Modified Diamond Film Result

The image below is a montage of several images taken of the Silicon surface following polishing with the protocol described in Section 2.4.3. Two pieces of Si are waxed together and the surface quality shown is improved over the diamond film process. Surface damage and scratches have all been removed (with a few minor exceptions), illustrating the proper quality of polish desired for these applications.

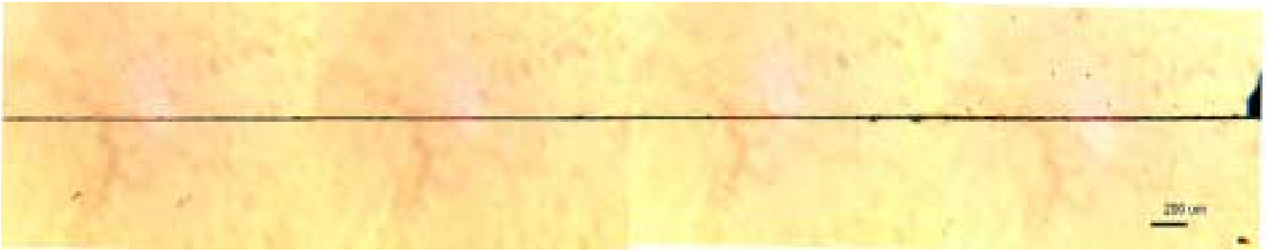

Figure 3: OLM image montage of the silicon surface after edge polishing. The combined abrasive suspension / diamond film process exhibits a superior surface finish than those previously obtained in this report.

5.0: Surface Roughness Measurements

Quantifying the surface roughness after polishing is a critical step in determining the performance of the polishing protocol. After the specimens were polished, a laser confocal measurement tool was used to evaluate the surface roughness in local areas of the edge polished wafers. Several measurements were taken at various points on the edge-polished surface, and the average of these measurements were then taken and plotted into the surface scans shown below. Each scan was run perpendicular to the interface between the two Silicon wafer pieces.

Using the laser confocal measurement tool manufactured by Keyence Corporation, the average surface roughness of the edge polished Silicon was obtained. The confocal tool uses a principle known as the 'active confocal principle', where a focused laser is placed on the surface to profile and the specimen is scanned below the laser. A tuning fork located in the optics oscillates and records the position of the reflected beam at any given point, thus translating the signal into a measurement of the surface roughness. A simple diagram of the system is shown below.

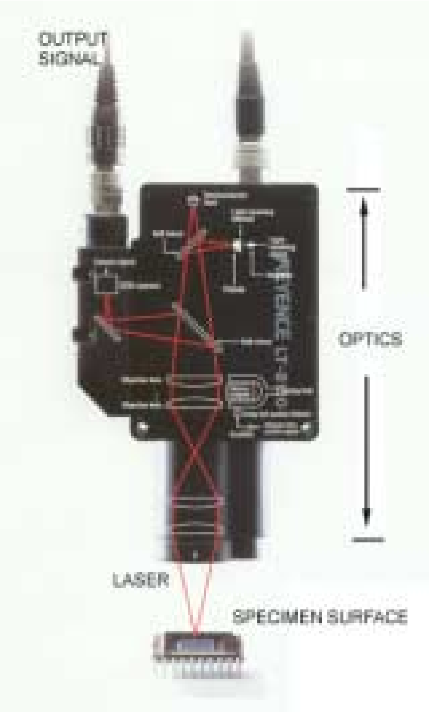

Figure 4: Schematic illustration of the laser confocal measurement tool. A focused laser is directed onto the surface of the specimen by a set of optics inside the confocal measuring tool. A tuning fork oscillates the laser to focus on the surface, and the reflected signal is focused into a light collecting signal. The exact position of the tuning fork is translated into a vertical measurement and the signal is sent to a computer.

5.1: Surface Profile of Modified Diamond Film Polished Samples

The surface profile of the samples polished with the modified diamond film protocol is shown below. These samples exhibit the best quality of finish and highest degree of flatness. The total deviation shows a variation of less than 1 micron.

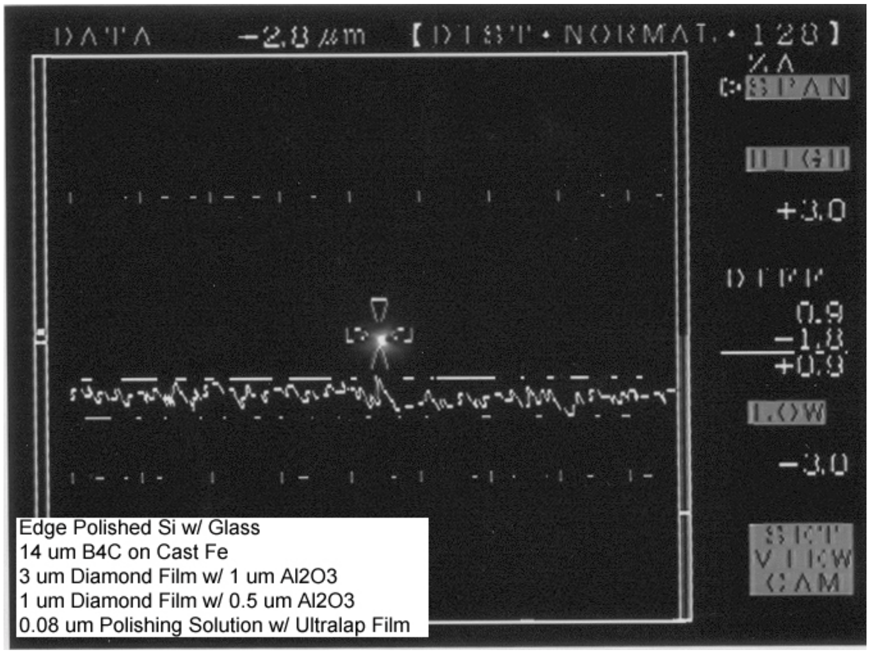

Figure 10: Surface profile of modified diamond film polishing protocol. The surface roughness and flatness shows a deviation of less than 1 micron.

6.0: Conclusions

This report has demonstrated that the surface quality (flatness, roughness, polishing quality) is superior when polishing with a diamond film process following rough lapping. The removal of subsurface damage after rough lapping is critical in the final polsih quality of the edge polished wafers. A tool for edge polishing small wafers has been developed and can be a critical tool in the preparation of these types of optical quality devices.