



1.0: Purpose

The primary aim of this report is to describe and compare various lapping and polishing techniques available for preparing smooth, highly polished surfaces of small Si wafers and die. Lapping and polishing techniques using the Model 920 Lapping and Polishing Machine and the Model 155 Lapping and Polishing Fixture will be investigated to determine the best method for preparing these types of materials. Comparison of free abrasive lapping techniques, cloth polishing techniques, and paper techniques will be done based on preparation time, surface smoothness and quality, and ease of use.

2.0: Experiments

For this experiment several different samples of a Si wafer were obtained for lapping and polishing experiments. The wafer pieces were cleaved into 10 mm x 20 mm rectangles as well as smaller 5 mm x 5 mm die sized squares. Each of these samples were then mounted onto a Model 155 Lapping Fixture using a low melting point wax (MWH 135) after being heated on the hot plate. The samples were affixed to the mounting block and then measured prior to lapping and polishing. The samples were mounted onto the Model 920 and held into place on the lapping machine using the Model 92002 Workstation. Below is an image showing the setup used for preparing the specimens.



Figure 1: Setup used for lapping and polishing specimens in this experiment. A Model 920 Lapping and Polishing Machine is shown equipped with a Model 92002 Workstation and Model 155 Lapping and Polishing Fixture. The Model 155 is shown captured in the Model 92002 and is continuously rotated counter-clockwise. The lapping wheel also rotates counter-clockwise and is variable speed up to 600 rpm.

Two primary stages of preparation were used in this experiment: lapping the surface to a desired thickness and polishing of the specimen to a specular surface. Different lapping wheels and abrasive sizes were used to examine the surface and determine any detrimental effects imparted to the specimen. Several polishing cloths were used also to find the best combination of consumables and parameters for preparing specimens of this type.

2.1: Lapping

Lapping was first done using a relatively hard metal lapping plate composed of cast iron (meehanite). The hard metal plate is covered with an abrasive slurry which rolls between the specimen and the plate. Two different plate configurations were used in this experiment. One plate was a flat, smooth surface and the other consisted of fine grooves machined in the surface of the plate. Grooved plates are used when large, flat specimen surfaces are lapped to prevent specimen stiction. Below are two simple illustrations of the plate surface used for the experiment.

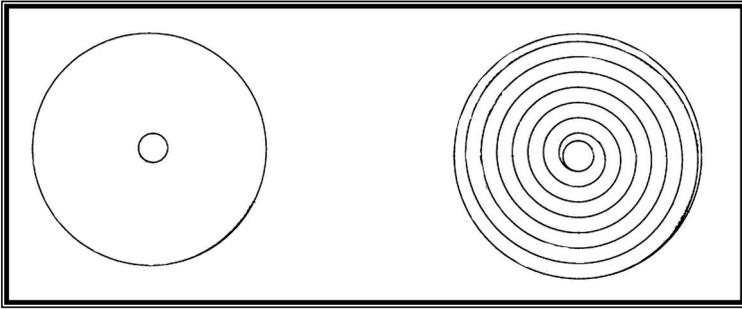


Figure 2: Illustration of the two lapping plates used for lapping. The plate on the left is a standard flat lapping plate and the plate on the right consists of machined spiral grooves in the plate.

Lapping the Specimen

Specimens were lapped using several different abrasive grits. The following abrasive grits were used for the lapping process:

- 14 μm Boron Carbide: Mixed in a weight ratio of 1 part powder: 1 part water: 4 parts glycerine. Boron carbide has a light density compared to most abrasives (density of 2.5) and stays in suspension well. It's blocky crystal shape is well suited to lapping, providing a greater amount of edges used in material removal.
- 8 μm Boron Carbide: Mixed in the same ratio as the 14 μm abrasive.
- 8 μm Silicon Carbide: Mixed in the same ratio as the boron carbide abrasives. SiC is much more dense than boron carbide (density of 3.2) and therefore does not stay in suspension as long as boron carbide. However, it does break down into finer particles and will sometimes yield a slightly better surface finish.

Specimens were lapped using an initial load of 50 grams and a lapping wheel speed of 100 rpm (2 on dial). The workstation speed used was 21 rpm (5 setting on the dial). Lapping of the specimen using the SiC abrasive proved to be less efficient primarily due to difficulty in the use of the abrasive slurry. The abrasive does not stay suspended as well as the BC abrasive does which tends to be more efficient in material removal. Below are images showing the various surfaces of the silicon specimens following the lapping process using different abrasive media.

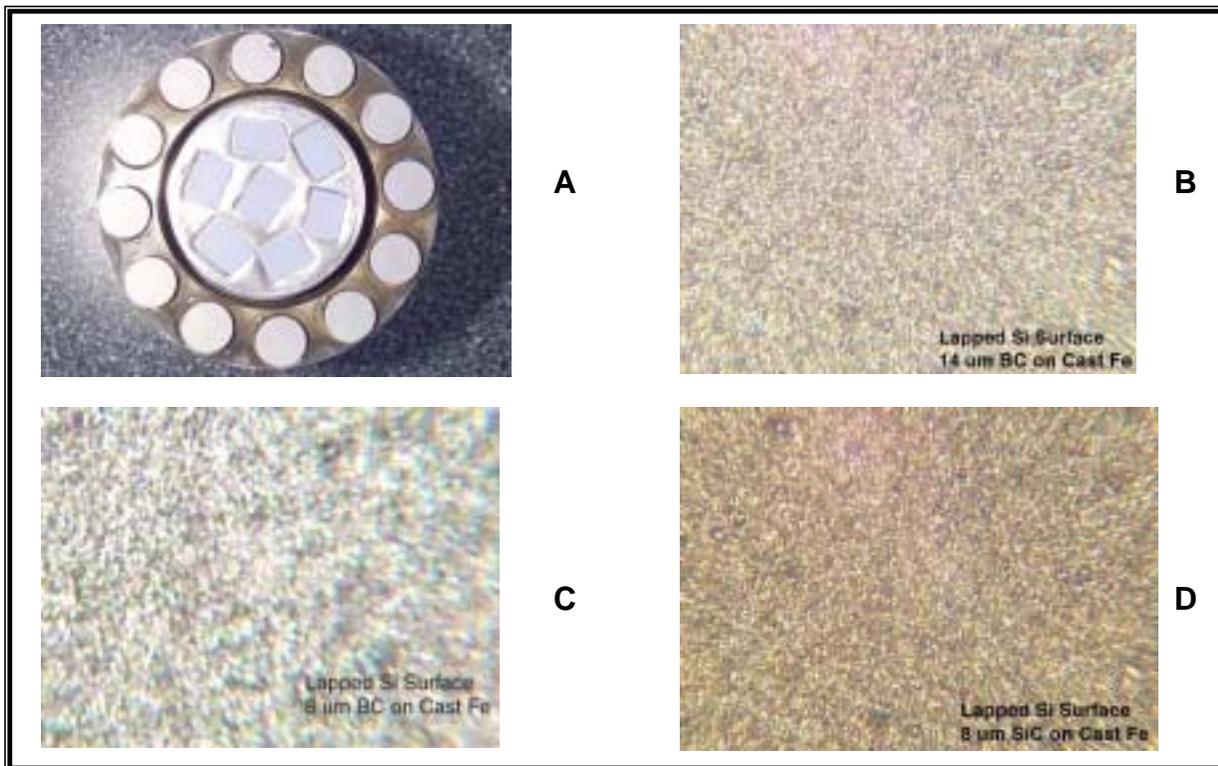


Figure 3: Images showing the surface of a Si specimen following lapping with various abrasive types and sizes on cast Fe lapping plate. In A) Macro image of die as mounted on the Model 155; B) 14 μm BC; C) 8 μm BC; D) 8 μm SiC .

2.2: Polishing the Specimen

Following lapping, the specimens were then polished using a diamond abrasive slurry on a variety of different polishing cloths. The use of fixed abrasives such as SiC papers were also attempted to demonstrate the differences in surface finish with the different techniques. The specimens were evaluated optically for surface finish and smoothness to ensure that the damage from the lapping process had been removed and to ensure a specular finish on the surface of the die was obtained. The following section describes the various results.

Abrasive Paper Polishing

To initially test the success (or lack thereof) in the use of abrasive papers for polishing, several different grades of SiC papers were used for rough and fine polishing of the Si specimens following lapping. Abrasive grits of 400 grit, 1000 grit, and 1200 grit were used to polish the specimen following lapping. The papers were used to remove the mechanical damage induced by lapping and to produce a specular finish on the specimens. Below are images taken of each grit size used.

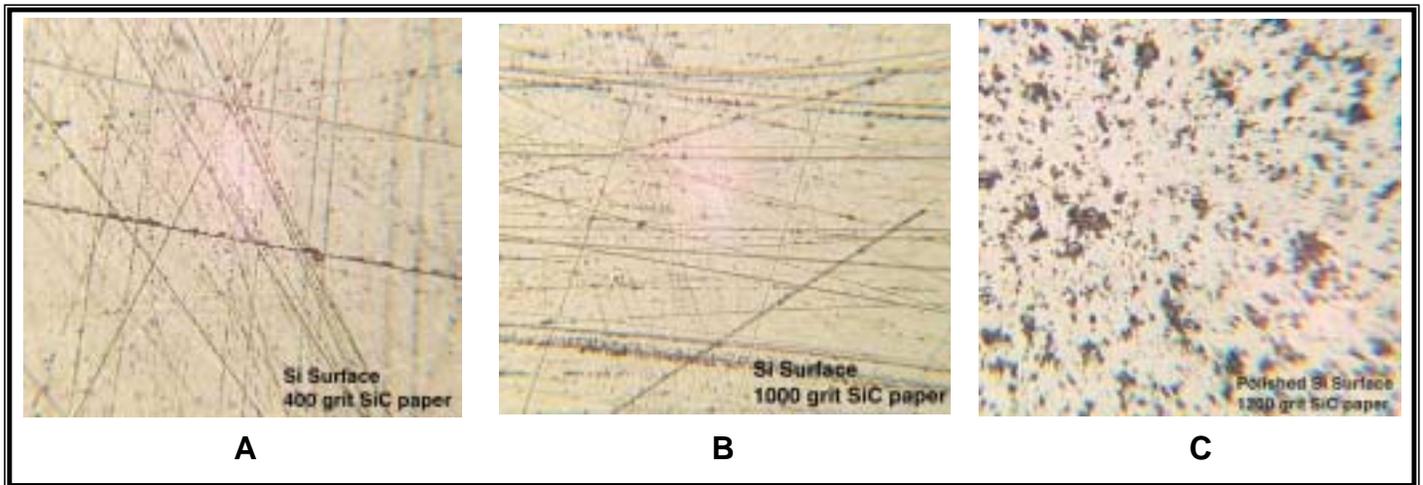


Figure 4: Images of polished Si surfaces using SiC abrasive papers. The specimens were polished following lapping on the cast iron lapping plate with boron carbide abrasives. In A) the specimen has been rough polished using 400 grit paper. In B) the specimen has been polished using 1000 grit paper and still has a large amount of scratching. In C) the specimen was polished using 1200 grit paper. The surface is severely pitted coupled with portions of polished areas. This shows that the mechanical damage from lapping has not yet been removed.

From the images above it is clear that the use of carbide papers for polishing following the lapping process are not sufficient to polish the specimen or to remove the mechanical damage imparted during lapping. The lapping process is shown to produce a slightly pitted structure as clearly seen in Figure 4C, primarily due to the rolling action of the abrasive particles used on a hard metal lap.

Cloth Polishing

The next step at producing damage free, specular surfaces is the use of a polishing cloth. Polishing specimens using a cloth is an economical, fast, and easy method for preparing polished surfaces of a variety of materials from metals to semiconductors. It is a commonly used technique in metallographic specimen preparation and can be used for other applications. Cloth polishing uses an abrasive slurry or paste suited to the material being polished applied to a specific type of polishing cloth. The polishing cloth is selected based on the desired surface quality, the type of nap or fiber used in manufacture of the cloth, desired flatness, removal rate, and lifetime.

Several different polishing cloths were used in this evaluation to determine the best method for polishing specimens following the lapping process. A table of different polishing cloths and their properties are listed below, describing the basic configuration and application of the cloths.

Cloth Type	Part Number	Description
ChemoTex 2000	PCX08A-10	Chemotextile cloth for both chemical and chem-mechanical polishing. Promotes high cutting rates when used with diamond compounds. Provides superior flatness and edge retention.
MultiTex	PMT08A-10	Superior fine polishing cloth for obtaining an optical quality finish. Use this cloth with diamond compounds, cerium oxide, aluminum oxide, or colloidal silica.
Cotton Fine	PCF08A-10	Used for rough diamond polishing of softer materials or other polishing grades of aluminum and chromium oxide.
ShaneyPol Medium	PSM08A-10	Used with diamond compounds for superior optical rough polishing. Also recommended for rough polishing of metals when flatness and edge retention are needed.
Nylon	PNY08A-10	A long life napless cloth used for rough polishing with diamond compounds. Useful for polishing most materials while maintaining flatness.

Each of these cloths were used in determining the best method for polishing the specimens following lapping. Each cloth is described individually below in terms of effectiveness.

Nylon

The Nylon cloth was initially selected due to its manufactured properties. The cloth is a woven fiber cloth and provides high flatness for preparing extremely flat samples. The nylon cloth in this case was used with an 8 μm boron carbide abrasive slurry applied to the surface of the cloth. The sample was polished using a load of 150 grams and was prepared for a time interval of about 45 minutes. The cloth lifetime proved to be excellent, however the polishing rate obtained was quite poor. The removal of some mechanical damage from lapping can be seen in the image taken following polishing using this cloth. However, there are still a large number of surface pits present on the specimen and the surface finish is not polished.

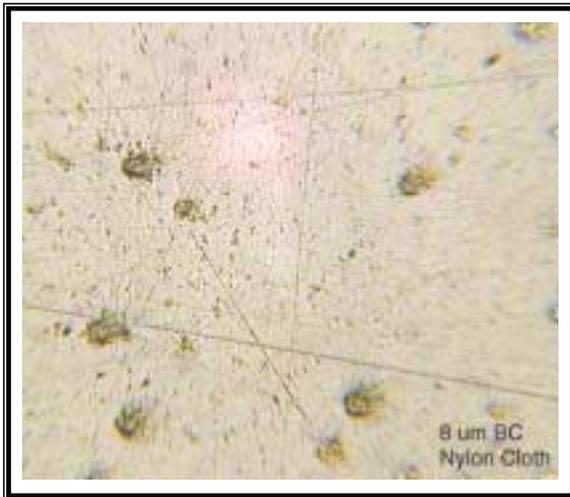


Figure 5: Image of polished silicon surface following polishing on Nylon polishing cloth. The surface exhibits a fair amount of polished area combined with a large number of surface defects and pits seen as dark spots across the surface. This is far from the ideal case of complete surface damage removal required of this intermediate step.

ChemoTex

The ChemoTex cloth was selected for similar reasons as the Nylon cloth, namely its propensity for keeping specimens extremely flat while providing a good removal rate at the same time. Two different abrasive media were used with this cloth, an 8 μm boron carbide slurry and a 6 μm diamond slurry. Polishing conditions were the same as with the Nylon cloth, including a 45 minute polishing period. From the first image it can be seen that the boron carbide slurry was largely unsuccessful in removing all of the mechanical damage imparted to the specimen during the lapping process. The resultant surface closely resembles that of the Nylon cloth polished sample. However, in the 6 μm diamond case, the mechanical damage for the most part has been removed, leaving mostly surface scratches from the abrasive media used. A few minor defects are still present on the surface of the specimen.

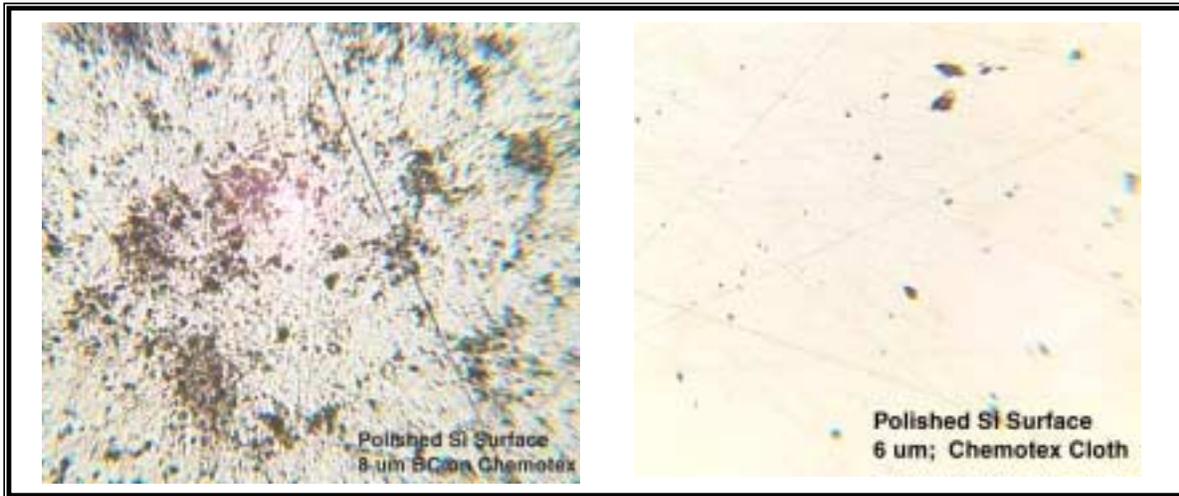


Figure 6: Images of the polished surface using a ChemoTex 2000 polishing cloth. The image on the left shows the surface following polishing using 8 μm boron carbide abrasive. The surface finish is poor, showing the presence of a large amount of surface defects still remaining from the lapping process. The image on the right shows a much improved surface although some surface defects still remain.

ShaneyPol

This polishing cloth has very similar properties to the ChemoTex cloth, although this cloth is slightly harder (firmer) than the ChemoTex cloth. This cloth should provide both high removal rates and long cloth lifetimes when used with a variety of compounds. The same polishing parameters were used for this cloth, with a reduction in preparation time to about 15 to 20 minutes. The abrasive media used for this specimen was 6 μm diamond slurry. The surface exhibits no subsurface damage remaining from the lapping process and shows only surface scratches imparted to the specimen from the 6 μm abrasive.



Figure 7: Image of the polished surface of silicon following polishing with the ShaneyPol polishing cloth and 6 μm diamond slurry. The surface of the specimen is free of mechanical damage from the lapping process and shows only surface scratches from the 6 μm abrasive media.

Cotton Fine

These polishing cloths are good for fine polishing and flatness retention and were selected for their high removal rates. The cotton cloths provide a good flat surface to start from and allows the specimen to become highly polished without edge rounding or damage to the specimen. Polishing using the Cotton cloth was carried out using the same parameters as the other polishing steps excluding the abrasive. 3 μm diamond slurry was used as the abrasive media and a polishing time of about 20 minutes was used. Below is the image of the final surface following polishing, exhibiting a well polished surface with only 3 μm scratches visible following the process.



Figure 8: Image showing the Si surface following polishing using the Cotton Fine polishing cloth and 3 μm diamond slurry. Note the scratches on the surface which correspond to the 3 μm abrasive size with no visible pitting or mechanical damage present from the lapping process.

MultiTex

The MultiTex cloth is commonly used in final polishing applications where specular, smooth surfaces are required. The MultiTex cloth closely resembles a polishing pad and therefore eliminates any edge rounding effects caused by large nap or fibrous cloths. It was selected due to its ability to produce finely polished surfaces on virtually any material type. Polishing was carried out with the same parameters as listed above in the previous steps using a 1 μm abrasive as the polishing media. Below is an image of the final polished surface illustrating the polishing quality obtained using this cloth.



Figure 9: Image of the final polished Si surface following polishing on MultiTex polishing cloth. The surface appears relatively smooth with a few small scratches present. The dark spots on the image is contamination on the objective lenses.

Once processing was completed the specimen was evaluated macroscopically and could be seen to have a highly polished, specular surface. The specimen appears to have a high quality optical polish free of any scratches and contamination from the polishing media.



Figure 10: Image showing the final polished surface of the silicon die following processing. Note the specular surface and the high polish quality obtained using this process.

4.0: Conclusion

Successful polishing of silicon can easily be accomplished from the proper selection of abrasive media, machine parameters, and processing times. Lapping the specimen using a hard metal plate and a free abrasive is highly successful in removing material in an efficient manner. Lapping times for removal of a few hundred microns of material were on the order of 10-20 minutes and was highly successful in reducing material. Polishing using silicon carbide papers following lapping proved to be largely unsuccessful in removing the mechanical damage (i.e. pitting) created by the lapping process, although some portions of the specimen were found to be polished.

Successful removal of mechanical damage from the lapping process was done the proper polishing cloths. Polishing of the specimen was successful using the following process:

- 1) Lap the specimen using a cast iron lapping plate with 14 μm boron carbide slurry.
- 2) Rough polish the specimen using a ShaneyPol Medium polishing cloth and 6 μm diamond slurry.
- 3) Fine polish the specimen using a Cotton Fine polishing cloth and 3 μm diamond slurry.
- 4) Final polish the specimen using MultiTex polishing cloth coupled with 1 μm diamond slurry followed by a final polishing solution of 0.05 μm colloidal silica solution (or equivalent).

Using the above process highly polished surfaces of lapped silicon specimens can be obtained in approximately 1 hour for small samples. This process should be equally applicable to other semiconductor materials such as GaAs or materials with similar mechanical properties as Silicon.

