

Lapping and Polishing Basics

Lapping and
Polishing

1.0: Introduction

Lapping and polishing is a process by which material is precisely removed from a workpiece (or specimen) to produce a desired dimension, surface finish, or shape. The process of lapping and polishing materials has been applied to a wide range of materials and applications, ranging from metals, glasses, optics, semiconductors, and ceramics. Lapping and polishing techniques are beneficial due to the precision and control with which material can be removed. Surface finishes in the nanometer range can also be produced using these techniques, which makes lapping and polishing an attractive method for materials processing.

This paper describes some basics about lapping, including equipment setup, typical lapping techniques, and nomenclature.

2.0: Back to Basics

There are several techniques used for removing material from a particular workpiece (also called specimen in this discussion). Grinding, lapping, polishing, and CMP (chem.-mechanical polishing) are all techniques used for precise removal of material. A brief discussion of terms is needed to understand the basics of what is being referred to when these topics are discussed.

2.1: Grinding

Grinding can be defined as the rapid removal of material from a sample either to reduce it to a suitable size or to remove large irregularities from the surface. The grinding wheel or plate typically rotates at a high speed (around 200-1000rpm) and a coarse, bonded abrasive ($> 40 \mu\text{m}$) is used. Grinding is quick and relatively easy process but can cause deep subsurface damage in delicate materials. Typically grinding is applied to hard metals such as high carbon steels where rapid removal is essential and subsurface damage is not a critical parameter. For delicate materials the grinding process must be a balance of material removal and subsurface damage. In many cases it is advisable to initially cut the specimen with a gentle mechanical method such as a wire saw. A properly prepared wire saw cut sample can eliminate the grinding process altogether.

2.2: Lapping

Lapping is the removal of material to produce a smooth, flat, unpolished surface. Lapping processes are used to produce dimensionally accurate specimens to high tolerances (generally less than $2.5 \mu\text{m}$ uniformity). The lapping plate will rotate at a low speed ($< 80 \text{ rpm}$) and a mid-range abrasive particle ($5\text{-}20\mu\text{m}$) is typically used. Lapping removes subsurface damage caused by sawing or grinding and produces the required thickness and flatness. Although the lapping process is less damaging than grinding, there are two regimes of lapping: free abrasive lapping and fixed abrasive lapping.

Free Abrasive Lapping is when abrasive slurry is applied directly to a lapping plate (e.g. cast iron). This is perhaps the most accurate method for producing specimens and causes the least amount of damage. Free abrasive lapping is accurate because of the rigid lapping surface which can be tailored to suit a particular material. Fixed Abrasive Lapping is when an abrasive particle is bonded to a substrate as with abrasive lapping films and SiC papers. Abrasive lapping films have various particles bonded to a thin, uniform polyester substrate and are also capable of producing a very flat surface. SiC papers are much thicker than the film and create the potential for rounded edges on the sample.



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2.3: Polishing

Polishing is the removal of material to produce a scratch-free, specular surface using fine (<3µm) abrasive particles. Polishing is typically done at very low speeds using either polishing cloths, abrasive films, or specially designed lapping plates. Polishing with a cloth or lapping plate requires the use of free abrasive, and is a very low damage process when performed properly. Plate material and cloth material are critical when polishing a particular sample as the properties of these substrates are important in the final polish quality of the specimen.

Polishing with a lapping plate is a common process used in the case of metals and hard ceramic type materials. Polishing using copper composite plates or tin / lead lapping plates can produce high quality surface finishes with high removal rates. In many cases the use of a polishing cloth is required, and thus the selection of a proper polishing cloth is important. Polishing cloth properties needed depend on the application. If flatness is of primary concern, short nap cloths (such as Nylon) are used to maintain flatness. When the final surface finish is of primary concern, longer napped cloths (such as Rayon and Silk) are used. Many cloth materials today combine the best of both worlds, allowing flatness and surface finish combined to provide maximum performance. Polyurethane pads are commonly used for final polishing processes and produce excellent flatness and surface finish.

Polishing with abrasive films also produces excellent results. The flatness of the films combined with high removal rates makes them an attractive alternative to cloth and plate polishing methods.

2.4: Chem-mechanical Polishing (CMP)

Chem-mechanical polishing (CMP) is a technique that combines both chemical and mechanical polishing principles to achieve uniform removal rates of a highly composite specimen (such as integrated circuit device fabrication). CMP is typically done using a hard polyurethane polishing pad combined with a slurry of finely dispersed alumina or silica particles in an alkaline solution. CMP combines the selectivity of chemical polishing with the mechanical removal properties of standard mechanical polishing techniques. The two combined give excellent selectivity and planarity and can be tailored to many different materials.

2.5: Abrasive Types

There is a wide selection of abrasives to choose from when selecting a lapping and polishing process. Selecting an abrasive is dependent upon the specimen hardness, desired surface finish, desired removal rate, lifetime, and price. There are four basic types of abrasives that are used in lapping and polishing processes: silicon carbide (SiC), aluminum oxide or alumina (Al₂O₃), boron carbide (B₄C), and diamond (C). All of these abrasives have distinct properties and are used for different materials and applications.

- SiC:** SiC is hard and generally has a needle or blocky structure. SiC is used in many applications where rough lapping is required. It seldom is used for polishing or applications that require smooth surface finishes.
- Al₂O₃:** Al₂O₃ is relatively hard and has a sharp, angular structure. Alumina is commonly used where fine surface finishes are required as it breaks down over time and gives excellent surfaces during lapping and polishing. Alumina is also relatively inexpensive.
- B₄C:** B₄C is harder than most other abrasives (excluding diamond) and has a blocky crystal structure. B₄C provides excellent removal rates and is typically used when fast removal with moderate surface quality is needed.
- Diamond:** Diamond is the hardest material known and has a sharp, angular structure. Diamond is extremely useful in lapping and polishing due to its removal rates and surface finishing qualities. Diamond can produce excellent surface finishes combined with high removal rates.

| MATERIAL | HARDNESS (KNOOP 100) | DENSITY | STRUCTURE |
|---|----------------------|---------|------------------------|
| SILICON CARBIDE (SiC) | 2450 | 3.22 | BLOCKY, SOLID, SHARP |
| ALUMINA (Al ₂ O ₃) | 2000 | 3.97 | BLOCKY, SOLID, ANGULAR |
| BORON CARBIDE (B ₄ C) | 3000 | 2.51 | BLOCKY, SOLID, SHARP |
| DIAMOND (C) | 6000 | 3.51 | SHARP, ANGULAR, SOLID |

Table 1: Various Abrasive Materials and Associated Properties



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3.0: Lapping and Polishing Equipment

Equipment used for lapping and polishing can vary from application. Typically what is required for lapping and polishing are the following:

1. A lapping and polishing machine with variable speed.
2. A polishing jig for holding specimens precisely.
3. Various lapping plates for different applications.
4. Workstations for controlling lapping fixtures and conditioning equipment.
5. Conditioning equipment for maintaining plate flatness.

There are various methods available to accomplish these tasks. South Bay Technology, Inc. has developed a series of equipment designed for this purpose and is described below.

3.1: Lapping and Polishing Machines

Lapping and polishing machines vary extensively depending upon the manufacturer. SBT has designed a set of instruments that are specifically designed for universal lapping and polishing applications. The Model 920 Lapping and Polishing Machine incorporates a precision spindle assembly housed in a solid cast aluminum casting to provide stable operation in any laboratory environment. Stability when lapping is critical in producing flat, precisely controlled tolerances on a given specimen. The motor is a high torque, variable speed motor that allows a wide range of speeds to be employed. Flexibility in speed control allows the instrument to be used as a grinding machine, high quality lapping machine, or polishing machine. During grinding high speeds are required, whereas lapping and polishing applications are generally completed at low speeds. The Model 920 also incorporates workstations, which allow for the use of precise Lapping and Polishing Fixtures. Each workstation has its own speed control, allowing the user to precisely rotate the lapping fixtures or the conditioning ring. Lapping plates are held into place with three locating pins and are easily removable, allowing maximum flexibility in processing specimens. Various materials can be selected for the lapping plates, ranging from aluminum, cast iron, and glass.

Below is an image showing the Model 920 with a typical setup for lapping.



Figure 1: Model 920 Lapping and Polishing Machine for precise lapping and polishing applications.

3.2: Lapping and Polishing Fixtures

Lapping and Polishing fixtures are perhaps the most critical part of any lapping and polishing system. The lapping fixture is what holds the specimen during processing and ultimately will determine the final specimen quality. South Bay Technology has been a leader in the manufacture of precision lapping fixtures for any application. In general, the fixture typically performs like a piston, with a housing used for support of a dynamically sliding piston assembly. Specimens are attached to the base of the piston using vacuum mounting or wax mounting techniques. The piston movement is controlled with a precision dial micrometer at the top of the fixture, and thus allows the precise removal of material in various increments determined by the user.



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The base of the housing contains a wear resistant ring that supports the fixture, controls the flatness and parallelism of the specimen, and gives stability to the fixture.

Below is a basic image of a typical lapping and polishing fixture.



Figure 2: Model 164 Lapping and Polishing Fixture used for precision lapping and polishing of wafers and other materials.

3.3: Lapping and Polishing Plates

Lapping and polishing processes are performed on a hard, metal plate used in conjunction with abrasive suspensions such as diamond, silicon carbide (SiC), aluminum oxide (Al₂O₃), or boron carbide (B₄C). The metal lapping plate selected depends upon the desired material removal rate, the surface finish desired, the hardness of the specimen being lapped, and the flatness requirement.

Plate selection can play a critical role in the production of high quality specimens. Lapping plates can be flat or grooved depending upon the desired application. Grooved plates provide greater removal rates and prevent the abrasive from squeezing out from between the plate and the specimen.

Examples of some types are given below:

- Cast Iron (Fe):** Cast iron lapping plates are used for rough lapping and stock removal of materials. Specimens around 8-10 on the Mohs Hardness Scale can be lapped using cast iron plates. Cast iron produces a gray surface finish and provides high removal rates.
- Composites:** Composite plates are used for rough lapping and stock removal of materials. Specimens of 7-10 on Mohs Hardness Scale can be lapped on composite plates. These plates produce medium quality surface finishes with very high removal rates.
- Copper (Cu):** Copper plates are used for both rough and fine lapping of materials. Specimens around 9-5 on the Mohs Hardness Scale can be lapped using copper plates. They provide high quality surface finishes with intermediate removal rates.
- Tin/Lead (Sn/Pb):** Tin lead plates are used for fine lapping and polishing of materials. Specimens around 2-4 on Mohs Hardness Scale are lapped with tin lead plates. They provide high quality surface finishes with low removal rates.

Polishing can also be carried out using a polishing cloth attached to a substrate plate (either glass or aluminum typically) using aluminum oxide, colloidal silica, or diamond suspensions. Use of polishing cloths can be advantageous due to the high quality surface finish they produce. However, it must be noted that for extended polishing times the use of a cloth will sometimes lead to wavy surfaces and edge turning, which can be detrimental to the specimen quality. Proper selection of polishing cloths and process times is key in the successful use of a cloth for final polishing of specimens.

3.4: Plate Conditioning

Plate conditioning is a process by which the lapping plate surface is machined to maintain the flatness of the lapping plate and to “pre-condition” the lapping plate surface with the abrasive being used for the lapping process. Plate conditioning is important for lapping applications where flatness and parallelism of the specimen is critical. Specimen quality is a direct result of plate condition, and therefore proper maintenance of the lapping plate is crucial in preparing high quality specimens.

Conditioning of the lapping plate is affected by two primary parameters: a) position of the conditioning ring, and b) weight of the conditioning ring. The conditioning ring is generally a cast iron or stainless steel ring used with the abrasive desired or with diamond plated to the bottom of the ring. Conditioning of the lapping plate also helps maintain high removal rates during long lapping operations.

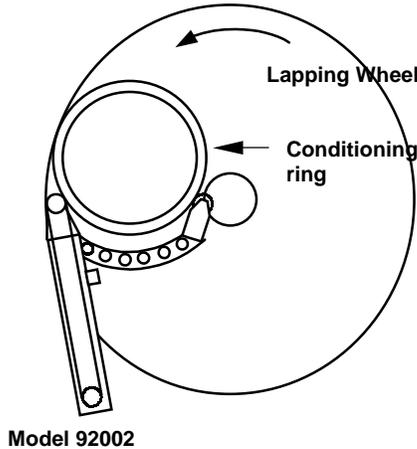


Figure 3: Schematic illustration of the conditioning process used on the Model 920. A workstation (Model 92002) is set up on the Model 920 and a conditioning ring is positioned on the lapping plate surface. The conditioning ring is used with abrasive slurry to make the plate flat.

3.4.1: Conditioning Basics

Proper positioning of the conditioning ring can help bring a plate back into flatness if the plate has become ‘out of flat’. Often times the plate will resemble a wavy shape due to the positioning of lapping and polishing fixture inside the radius of the lapping plate. If the lapping plate has become concave in shape, then the conditioning ring should be adjusted to the outer diameter of the plate. The extra work done on the lapping plate will then bring the plate back into flatness in a short time, provided the plate is not severely out of flat by more than 0.003” (75 μm). If the plate shape is convex, the conditioning ring should be positioned on the inner portion of the plate. Below are examples of this process.

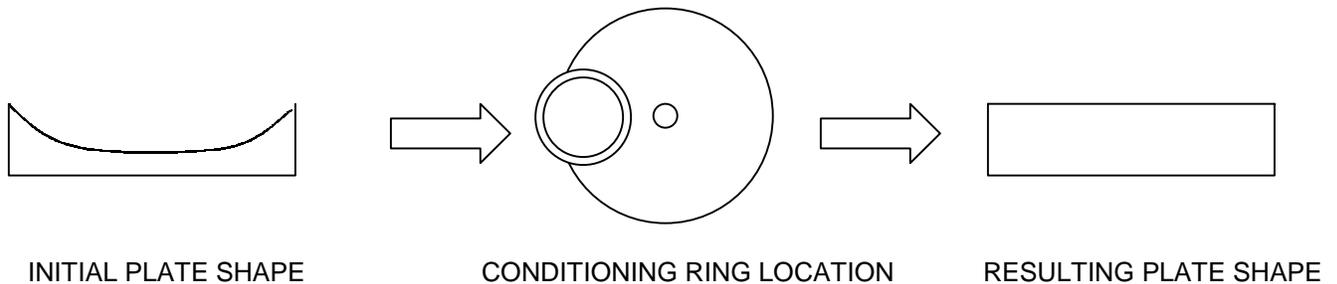


Figure 4: Schematic illustration of the conditioning process. The initial plate shape is a concave shape. Positioning the conditioning ring on the outer diameter of the plate will cause the highest point of the plate to be lapped faster than the inner portion, creating a flat plate surface.

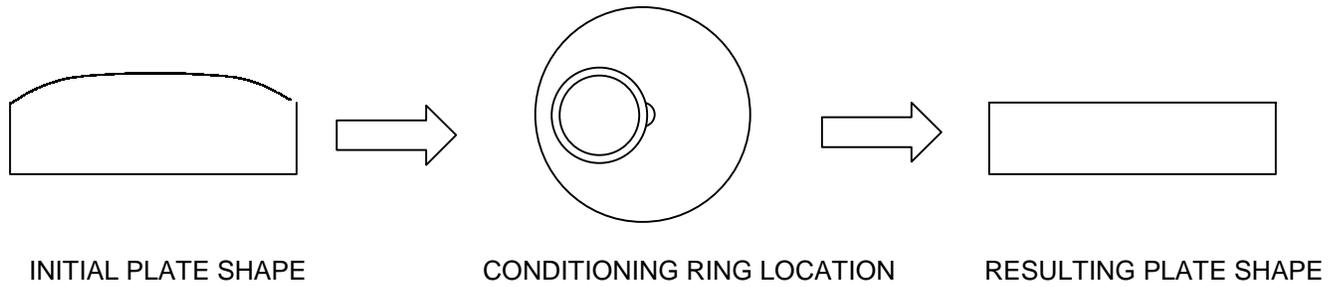


Figure 5: Schematic illustration of the conditioning process for the convex plate case. Positioning the conditioning ring to the inner portion of the plate will cause the high spot in the center to be lapped faster than the outer diameter, creating a flat plate surface.

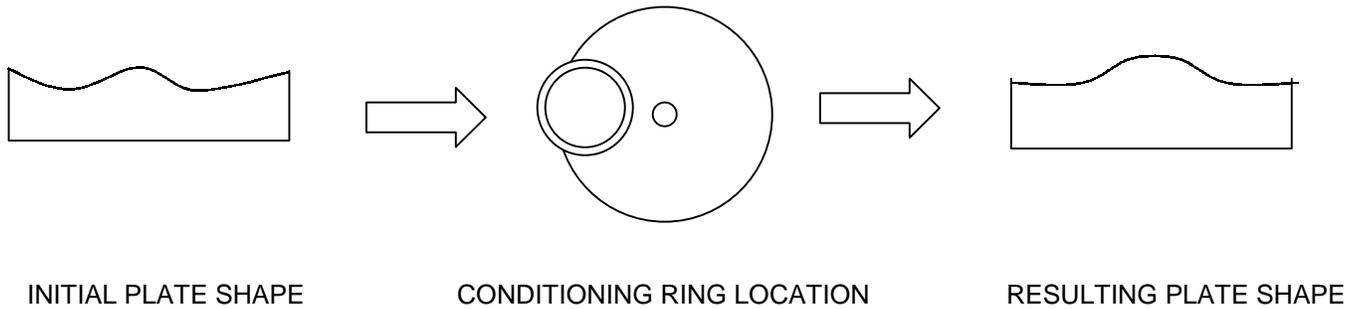


Figure 6: Schematic illustration showing a two step conditioning process. The top figure shows a plate with a wavy surface due to a small lapping fixture being used without a conditioning ring. The initial conditioning is completed with the conditioning ring on the outer diameter of the plate. Once the outer portion of the plate has been lapped down, the conditioning ring is moved to the center of the plate to lap it flat.

4.0: Conclusion

The line of SBT precision lapping and polishing equipment can be used for a wide range of lapping and polishing applications where precise, high quality specimens are required. Use of the Model 920 Lapping Machine combined with the SBT series of Precision Lapping and Polishing Fixtures enables the user to closely control the lapping process and create excellent specimens.

From MEMS wafer planarization to the edge polishing of electro-optical waveguides, SBT has a complete solution to fit any applications need.



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