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Processing YVO4 and Electro-Optic Crystals for Small Scale Fabrication

1.0: Purpose

Modern materials have provided the materials science community and industry with a broad ranging spectrum of applications. Today's telecommunications market has thrust optoelectronics and lasers into the forefront of materials research and development. Equipment to produce high quality devices for relatively low cost is critical in early design and process development. This paper outlines methods used for cutting and polishing yttrium vanadate (YVO_4) crystals using a variety of equipment to produce suitable devices. Cutting of oriented crystals and lapping and polishing of the final produced devices will be demonstrated using a series of equipment designed specifically for preparing optical crystal type materials.

2.0: Experiments and Procedures

Preparing optical crystals from bulk material requires several stages of preparation. The crystal ingot must first be mounted and sliced in a gentle, controlled manner that will produce suitable wafers from which devices can be fabricated. Many cutting methods are available to produce wafers from bulk material, including diamond wheel sawing and wire sawing methods. However, it has been found that for most brittle, fragile crystals, wire-sawing techniques are the most effective at producing a quality wafer without substantial mechanical damage to the crystal. After wafers are produced using wire sawing methods, they must be lapped and polished on both sides to produce a uniform wafer thickness. Following lapping and polishing, these wafers are then diced into small rectangular shapes to fabricate the devices. Edge polishing of the small pieces is the final stage of preparation, producing a high quality optical polish for device applications. Each stage of preparation is described in the sections to come.

2.1: Wire Sawing

A small ingot of yttrium vanadate material was obtained with a specific orientation (not provided) for cutting. The crystal was initially mounted onto a mounting block using mounting clay designed for wire sawing applications. The assembly was then placed into the Model 850 Wire Saw stage and adjusted such that the wire blade was oriented to cut parallel to the front edge of the crystal ingot.

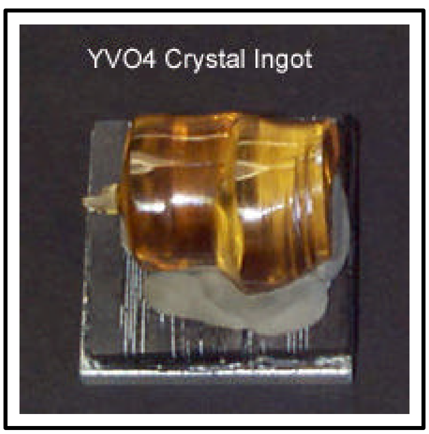

Figure 1: A single crystal ingot of YVO_4 material attached onto a mounting block prior to wire sawing on the Model 850 Wire Saw. The crystal is oriented to be approximately parallel to the wire blade to facilitate straight cuts.

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2.1.1: Wafer Slicing

Once the crystal is mounted, it is placed onto the stage of the Model 850 Wire Saw. The Model 850 consists of a loop of wire stretched across two pulleys that are driven by a motor. The entire arm assembly is brought into contact with the crystal using loading weights. The sample, attached to a micrometer stage, can be precisely rotated and moved in the direction perpendicular to the wire direction. This allows adjustment of the crystal to be cut into thin slices or wafers using the micrometer stage control. Adjustment of the crystal prior to cutting is critical to ensure that the proper orientation is obtained. Oriented crystal cutting accessories such as goniometers and alignment tools are available for use with the Model 850. A stainless steel wire of 0.010" diameter is used to cut the crystal and the tension is adjusted using a tensioning screw at the front of the arm. Guide wheel adjustments are made to allow the wire to move through the crystal with the maximum amount of support by the guide wheels. An illustration of the crystal ingot during a cut using the Model 850 Wire Saw is given below. Note the position of the guide wheels is in close proximity with the crystal ingot and the crystal is being cut with an abrasive slurry to produce a relatively smooth cut surface.

Figure 2: Illustration of the YVO_4 being cut with the Model 850 Wire Saw. Abrasive slurry is pumped onto the crystal area to be sliced and the wire cuts through the material based on a gravity feed mechanism. Small guide wheels are present to keep the wire straight and support the wire during a cut.

Cutting is most efficient when used with an abrasive slurry applied to the surface of the crystal during cutting. The Model 850 utilizes a recirculating pump system to pump abrasive onto the cutting area and continuously mix the abrasive, keeping it suspended for a longer period of time. Typical slurries used for cutting are boron carbide (B_4C), diamond, aluminum oxide (Al_2O_3), or silicon carbide (SiC). The size and concentration of the abrasive is tailored for specific applications, however the viscosity and the particle size are the two most important factors when performing a wire sawing operation. Specimen cutting was carried out using a variety of slurry sizes and types to obtain the most efficient cutting process. The cutting time, slurry concentration, and slurry type are given for reference. Several wafers were cut from the crystal ingot and were sliced in accordance with specifications set out for device requirements. This report uses a few different slurry mixtures, however the best results were obtained using the boron carbide slurry.

CUT #	ABRASIVE TYPE	ABRASIVE SIZE	SLURRY RATIO	TIME (MIN)
1	B_4C	23 ?M	1 POWDER: 3 WATER	13
2	B_4C	23 ?M	1 POWDER: 3 WATER	15:44
3	B_4C	14 ?M	1 POWDER: 1 WATER: 1 GLYCERIN	16:45
4	B_4C	14 ?M	1 POWDER: 3 WATER	19
5	B_4C	35 ?M	1 POWDER: 3 WATER	21
6	SIC	14 ?M	1 POWDER: 1 WATER: 2 WIRE SAW VEHICLE	38
7	B_4C	23 ?M	1 POWDER: 2 WATER	32
8	B_4C	8 ?M	1 POWDER: 3 WATER	55
9	B_4C	14 ?M	1 POWDER: 3 WATER	20
10	B_4C	14 ?M	1 POWDER: 3 WATER	45

Table 1: Cutting times of selected abrasives used for cutting wafers from the crystal.

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Wire cutting of the crystal was done in a manner to produce 2mm thick wafer sections from the bulk material. Each cut was done using the above process and averaged approximately 30 minutes per slice. Wafer uniformity following wire sawing operations can vary depending on several different factors. The efficiency of the abrasive suspension as well as the viscosity, wire tension, and cutting load all will effect the overall flatness of a given slice. Below is a chart illustrating the variation in thickness following wire saw cutting.

WAFER	LOW MEASUREMENT (MM)	HIGH MEASUREMENT (MM)	VARIATION (MM)
1	1.936	2.054	0.118
2	2.173	2.415	0.242
3	2.212	2.314	0.102
4	2.422	2.267	0.155

Table 2: Measured thickness variation of the as-cut wafers.

2.2: Lapping and Polishing

Following wire sawing, wafer lapping is required to create wafers to specific dimensions and to create flat, parallel surfaces onto which devices can be fabricated. Wafer lapping is typically carried out using a precision lapping machine coupled with a lapping and polishing fixture that is used for controlling specimen thickness and maintaining planarity during processing. Factors affecting the lapping process are the lapping plate material, hardness of the specimen being lapped, load applied during lapping, abrasive particle size and hardness, lapping wheel speed, specimen rotation, flatness requirement. Depending upon the hardness and properties of the material being processed dictates what type of lapping plates and abrasive materials are used. Hard lapping plates will tend to damage soft crystals that do not grind or polish well. However, softer lapping plates will cause flatness problems and planarity issues, and therefore a delicate balance of these parameters is required to obtain a high quality material.

Lapping and polishing was carried out using the Model 920 Lapping and Polishing Machine equipped with a Model 92002 Workstation. The wafers were held in place using the Model 147 Lapping and Polishing Fixture equipped with a Model 15001 Vacuum Accessory for holding the specimen by vacuum. A typical arrangement is shown in Figure 3 below.

Figure 3: Illustration of the lapping and polishing setup used for processing YVO_4. The Model 920 Lapping and Polishing Machine is shown with the Model 92002 Workstation and the Model 147D Lapping and Polishing Fixture. The system uses an 8” diameter lapping wheel combined with abrasive suspension or polishing cloth to produce a lapped, smooth surface.

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2.2.1: Lapping and Polishing Methods

Many techniques exist for producing polished samples from an as-cut wafer. This report used a system of mounting samples to a glass mounting plate, ¼" thick x 2" diameter. The glass plate was placed onto a hot plate and heated to 70° Celsius. Small amounts of wax (MWS052) were sliced into thin sheets and placed onto the glass plate. The wafers were then placed onto the plate and pressed down for uniformity with a Model 110 Sample Mounting Fixture. The assembly was allowed to cool for 30 minutes prior to lapping.

This particular wax was used along with a glass mounting plate arrangement to prevent cracking and wafer damage during thermal cycling. If the mounting wax used has a high melting point, or the mounting surface and specimen has a large difference in thermal expansion coefficient, specimen cracking will occur. Glass was used to match the coefficients as close as possible, and the low temperature curing wax helps ensure a minimum amount of thermal cycling.

Following mounting of the wafers they were inserted into the Model 147D and held in place using a GAST mechanical vacuum pump. A three step lapping and polishing process is used to produce the desired surface finish of the wafers and is discussed below.

Lapping

Lapping of the wafers to a specific dimension was first carried out to produce wafers that are 2mm in thickness and to remove some of the sawing roughness induced during the cutting process. Lapping was carried out using a copper composite lapping plate with 15µm diamond suspension. Suspension was applied to the lapping plate surface using a spray bottle, and 5 sprays per 5 minutes were used as the application rate. Lapping was done under the following conditions using the Model 920 Lapping and Polishing Machine, Model 147D Lapping and Polishing Fixture, and Model 92002 Workstation:

LAP SPEED:	1 on dial (65 RPM)
ARM SPEED:	8 on dial (20 RPM)
PLATE:	LP 920 A with copper composite plate attached
ABRASIVE:	15 µm diamond abrasive suspension
FEED RATE:	5 sprays / 5 minutes
LOAD:	600 grams
LAPPING TIME:	5 minutes

Rough Polishing

A two stage polishing process was used to produce the final surface finish of the material. The first step, termed Rough Polishing, was done using a 3 micron diamond suspension on the copper composite plate. The following conditions were used for polishing:

LAP SPEED:	1 on dial (65 RPM)
ARM SPEED:	8 on dial (20 RPM)
PLATE:	LP 920 A with copper composite plate attached
ABRASIVE:	3 µm diamond suspension (DS030-16)
FEED RATE:	5 sprays / 5 minutes
LOAD:	600 grams
POLISHING TIME:	5 minutes

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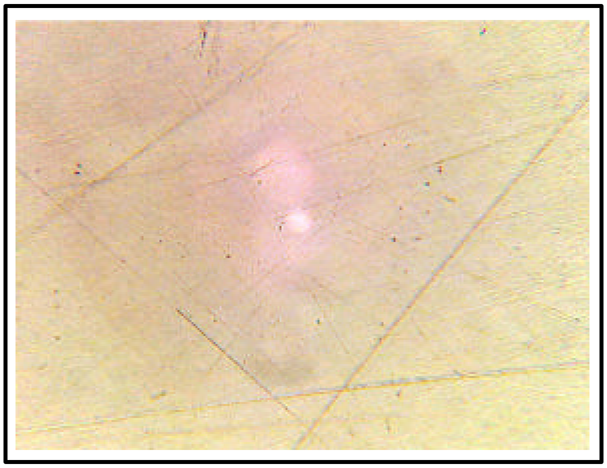

Figure 4: Optical microscope image of rough polished surfaced following polishing on Model 920. The damage from the lapping process has been removed and scratches remain from the rough polishing process. Inverted microscope, reflected light image, 200x magnification.

Final Polishing

The final stage of polishing was carried out using a 0.05 µm colloidal silica solution applied to a polishing pad. A black, polyurethane pad, called MultiTex™ (PMT08A-10), was used to produce a final polished surface that was smooth and uniform. The pad material is firm enough to maintain flatness and provide good optical quality as well. The following conditions were used for final polishing:

LAP SPEED:	1 on dial (65 RPM)
ARM SPEED:	8 on dial (20 RPM)
PLATE:	LP 920 M with Nylon Cloth (PNY08A-10)
ABRASIVE:	1 µm diamond suspension
FEED RATE:	5 sprays / 5 minutes
LOAD:	600 grams
POLISHING TIME:	10 minutes

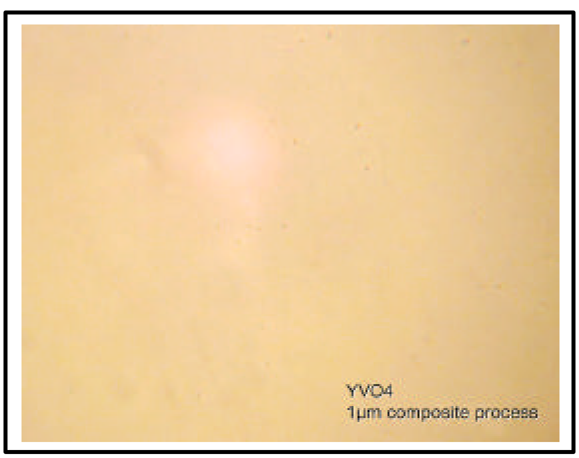

Figure 5: Optical microscope image of final polished surfaced following polishing on Model 920. The damage from the rough polishing process has been removed and scratches have been eliminated.
Inverted microscope, reflected light image, 200x magnification.

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3.0: Results

Following the cutting and polishing process the wafers were measured for flatness using an optical flat. The optical flat showed the surface to be flat within 1 µm across the wafer surface. This shows the efficiency of the lapping and polishing process as well as the relative ease with which these materials can be processed. A total processing time from beginning to end was found to be just over one hour for a single wafer. However, bulk cutting of wafers from the crystal ingot to produce multiple wafers for processing saves time in the long run. Also, this report illustrates only one lapping fixture being used during processing but the system can accommodate two simultaneously, doubling the throughput. The use of composite lapping plates vastly reduces the amount of time used for processing wafers and can ultimately save a great majority of time.

4.0: Conclusions

The processing of electro-optic crystals such as YVO_4 can easily be done using the SBT system of precision cutting, lapping and polishing machines. Wire sawing offers distinct advantages over diamond wheel sawing techniques, especially with these types of materials. The ability to cut oriented crystals using the Model 850 Wire Saw also improves the capabilities the equipment can achieve. Composite plate lapping is also an excellent way of lapping and finishing wafers of virtually any type but has extensive capability in this material system.