GRAVITY PROBE PROGRAM

PROCESS SPECIFICATION

POLISHING PROCEDURE FOR QUARTZ ROTORS

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POLISHING PROCEDURE FOR GP-B ROTORS

I . Preparation of machine, slurry and rotor

A. Machines: Two machines can be used for polishing: Ed White (E) machine and Lindbergh (L) machine.

The E machine has speed controllers like the lapping machine. They should be set to 125 RPM. The direction of the four motors on the E-machine are controlled by mechanical cams which regularly change the direction of the motors. The sequence of the directions of the four motors, as shown in the attached diagram, is

Motor A (Upper)	+	-	+	-	+	-
Motor B	-	+	-	+	+	-
Motor C	-	+	+	-	-	+
Motor D	+	-	-	+	-	+

The L machine is run by computer at 100 RPM. The programs that run the L machine are Reset and Polisher. The procedures differ somewhat for the two machines and for two rotor materials: fused silica (FS) and single crystal silicon (Si).

1. Clean, lubricate and if necessary align the machine.
    - E machine: Use Lithium Grease (Lubriplate) for lubrication of shafts.
    - L machine: Use discarded Talyrond oil for lubrication.
2. Slurry delivery tubing should be washed before and after the polishing run. Leave the stirrer on continuously in order to avoid forming of conglomerates.

B. Laps:

For FS use phenolic laps or pitch laps.
For Si use pitch laps.
For E machine use phenolic laps or pitch laps.
For L machine use pitch laps (phenolic laps are not available for L machine).

C. Slurries: The choice of slurries is critical for the sphericity and surface quality of the rotors. The following three slurries are used for flight rotors.

(1) Big C from Universal Photonics (liquid) - Dilute with approximately 4 parts deionized, filtered water (Resisitivity 8-10 Megohm-cm) to 1 part Big C. This dilution is the same for both machines and may be adjusted slightly by observing whether the polishing compound is covering the surface of the rotor during polishing.

(2) H2000 from SPT (liquid) - Dilute with approximately 5 parts deionized, filtered water (Resisitivity 8-10 Megohm-cm) to 1 part H2000. This dilution is the same for both machines and may be adjusted slightly by observing whether the polishing compound is covering the surface of the rotor during polishing.

(3) Alumina Powder 0.3 and 0.1 micron form Baikalox (powder) in deionized water - Dilute according to manufacturers directions.

For FS, use Big C. For Si, use H2000 or Alumina.

1. Prepare polishing slurry.

2. For silicon rotors, adjust pH of polishing compound. For Si pH control is crucial. It should be kept between 6.65 and 6.7. The breaking of a slurry film indicates the successful runs.

a.) The pH of the polishing compound is measured with a Cole-Palmer Electronic pH Meter, model number 05669, using the Cole-Palmer combination pH electrode, catalog number 55500-10. Because of problems with clogging of the pH meter by the slurry, it is not possible to continuously measure the pH of the polishing compound. The pH should be measured, and then the electrode should be washed and stored.

b.) Adjust the pH of the slurry. Dilute polycrystalline citric acid (available from Stanford Biology Stores) twice with deionized, filtered water to approximately 200 parts water to 1 part citric acid. Add 5 to 10 drops of the diluted citric acid to the polishing slurry until the pH is approximately 6.7 (H2000 polishing slurry is slightly basic with a pH of approximately 7.5)

II. Starting Polishing:

A. Loading the Rotor Loading of the rotor is described in P0074. Care should be taken not to scratch the rotor during loading and unloading. Bring the laps in contact with the rotor one by one very slowly.

1. Before loading the rotor, spray wash both the rotor and the laps.
2. After loading, wet rotor with slurry.

B. Starting the Machines

1. Start the machine
   - E-machine: follow the same sequence as in P0074.
   - L-machine: Run RESET program, power up motors and slurry valve, load the rotor, wet rotor with slurry, check data and change if necessary. Set polishing time. Run the POLISHER program. (Current Versions: RESET 1.0, POLISHER 2.1)

III. During Polishing

1) Be sure that in all times the laps are wet and the supply of the slurry mixture is adequate.

What can go wrong:

- the magnetic stirrer could stop mixing the slurry.
- the delivery tubing could get clogged.
- the distribution of slurry over the four laps may not be uniform.

2) Be sure that the controllers work properly: check the display of RPM for E-machine. Adjust if needed.

3) Observe the motion of the rotor under the action of laps. The pattern should be regular and the axes of rotation correspond approximately to the three tetrahedron axes in between the low three laps.

What can go wrong:

- the motion may be irregular. This may happen if there is something impeding the smooth motion. Laps may have irregular contact, may not be completely wet with slurry or the rotor may have something on the surface which prevents smooth rotation. Usually this will result in a loss of sphericity and the cause of it should be found.

- the sphere may stick on one of the laps. This will result in polishing of all the surface except the small circle opposite the lap on which the sphere is stick. It may be caused by inadequate wetting or adherence to the lap by formation of very thin film between the lap and the sphere..

4) For Silicon rotors observe the breaking of the film. The wetting of the Si surface by the slurry depends on the subtle balance of various factors. Pure Si oxidizes very fast, but the action of polishing is removing the oxide. Empirically the good results in the sphericity were correlated with breaking of the film. The Si surface should appear shiny, not gray.

What can go wrong:

- pH may slip out of optimal range. This will enhance chemical action, which is preferential in some crystalline directions and consequently result in appearance of crystalline structure.
- Slight contamination may change the right surface condition.
- The slurry may not combine with lap material in creating the proper surface conditions.
- The oxide layer may be thick or otherwise there may be a surface condition that it may take more than one hour to obtain the breaking.

In order to keep conditions optimal the polishing process should be kept under constant surveillance.

IV. Unloading the rotor

Unloading has to be done with utmost care and control. There is ample possibility to scratch the rotor by touching e.g. lap border or some other machine part usually covered with some abrasive particles. The unloading is particularly difficult in L machine because the lack of adequate space. The best would be to try the unloading using rejected sphere until getting some dexterity.

V. Washing after the unloading and drying

The rotor should be washed immediately , first when the machine is stopped. Remove slurry delivery tubes and wash again. Lift the upper lap and remove it and wash immediately the upper part. Remove the rotor following the removal procedure, by disconnecting the laps one by one. Finally wash the rotor thoroughly and dry it. I use Kimwipes EX-L for drying but they leave a lot of lint. Other materials and suppliers were tested with no better results. Be careful not to cause the scratches by wiping the rotor.

VI. After each polishing run

It is necessary to execute a series of rigid controls so as to assure that the process did not diverge. This consists in measurements of sphericity, of the size and weight and in observation of the surface of the rotor for scratches and digs. The measurements are described in the procedures P0076 and P0077.
For silicon rotors the crystalline structure presents a special problem. The contribution is mainly in the L=4 spherical harmonic. In order to be sure that the L even is kept in specification, the only way is to measure complete 17 planes and find out if L even is in specification. This measurement is highly recommended.
The microscopic observation may reveal some problems with slurry, like the presence of large particles or contamination (specially when lapping is performed in the same time). Sleeks will indicate inadequate wetting or inadequate laps.

Note: It is recommended that the polishing be done at separate times from lapping in order to avoid possible cross contamination.

Suppliers:

Big-C, H2000, Baikalox and pitch:
Universal Photonics, Inc.
495 West John Street
Hicksville, NY 11801
Tel: 800-645-7173

H-2000:
Mr. Hastings
Selective Particle Technology
46 Herrontown Circle
Princeton, New Jersey 08540
Tel: 609-924-2720

Alumina Polishing Powder:
Baikowski International Corporation
1833-B CrossbeanDrive
Charlotte, NC 28217
Tel: 704-357-3770
Also,
Fusco Abrasive Systems (Distributor)
17899 South Susana Road
Compton, California 90221
Tel: 800-899-3872

Polishing Records

Polishing for all flight rotors, both FS and Si was performed by Frane Marcelja.
Flight rotor listed satisfy the specifications, except as noted.
For Si rotors pH was kept inside the indicated limits, but during the process pH continuously varies and is being adjusted, so it is not possible give a precise number for the pH.

Here is the list of the sucessfully polished rotors qualified for the coating procedure.

Sphere	**No.**	**Date**	**Machine**	**Slurry**	**Laps**	**Pass**	**except**
95FH	1	9/29/95	Ed	Big-C	phen.		
	3	11/15/95	Ed	Big-C	phen.		
	4	11/22/95	Ed	Big-C	phen.	L=2,	1.11
	5	2/27/96	Ed,L	Big-C	pitch		
	6	10/1/96	Ed,L	Big-C	pitch		
	7	9/25/96	Ed,L	Big-C	pitch		
	9	7/15/96	Ed,L	Big-C	pitch		
96FH	10	9/23/96	Ed,L	Big-C	pitch	even,	.74
	11	8/14/96	Ed,L	Big-C	pitch	even,	.74
	13	9/20/96	Ed,L	Big-C	pitch		
	14	in process	Ed,L	Big-C	pitch		
	15	in process	Ed,L	Big-C	pitch		
	16	6/17/97	Ed,L	Big-C	pitch		
	17	in process	L	Big-C	pitch		
	18	in process	Ed,L	Big-C	pitch		
93S	17	5/11/94	Ed	Alumina	phen.		
95S	24	12/22/95	Ed	H2001	pitch		
	25	1/16/95	Ed	H2001	pitch	even,	.84
	26	2/20/97	L,Ed	H2000	pitch		
	27	2/13/97	Ed	H2000	pitch		
96SN	29	in process,lapped					
	30	3/18/97	Ed	H2000	pitch		
	31	in process,lapped					
	32	not lapped					
	33	not lapped					