Chapter 7.51

Pi Scientific 6” Ion Beam Mill

(ionmill6) (584)

1.0 Equipment Purpose

1.1 Ionmill6 is a 6 inch ion milling tool. A divergent ion beam source accelerates argon ions toward a water-cooled 2-axis rotation stage protected by a movable shutter.

1.2 Ionmill6 accepts 6” wafers or smaller pieces mounted on a 6” wafer.

2.0 Material Controls & Compatibility

2.1 Ionmill6 is used to etch materials via physical sputtering and can etch nearly any material. Very poor selectivity to masking materials should be expected.

2.2 Most materials are allowed except for materials with high vacuum incompatibility

2.2.1 Hardened photoresist is OK

2.2.2 Other organic materials must be approved by process engineer 1 for use in the tool.

3.0 Training Procedures & Applicable Documents

3.1 This tool requires members to pass the Nanolab Plasma Etch Technology test (etchclass). Once you have passed a workshop, you do not need to retake it for any other tool it covers. Workshops typically never expire.

3.2 Timeline:

3.2.1 Take vacuumclass. Pass the vacuumclass online test. (If you have already passed the vacuumclass test, skip to etchclass)

3.2.2 Take etchclass. (If you have already passed the etchclass test, skip to training 3.2.4).

3.2.3 Pass etchclass online test in Mercury Web. (If you have already passed the relevant etchclass test, skip to training).

3.2.4 Get trained by any qualified member.

3.2.5 Arrange a qualification session with a superuser to show competency on the tool.

3.2.6 Estimated time to completion: 1 week.

3.3 Superusers and staff qualify members on this tool.

4.0 Definitions & Process Terminology

4.1 Ion milling: A process by which ions are accelerated toward a substrate and used to initiate sputtering of the surface of that substrate

4.2 Selectivity: The ratio of etch rates of two or more materials.

4.3 Beam Current: The ion flow (measured in milliamperes) from the beam source to the target

4.4 Beam Voltage: The accelerating voltage applied to the ions in the beam

4.5 Tilt: Angle of substrate relative to the beam source.

5.0 Safety

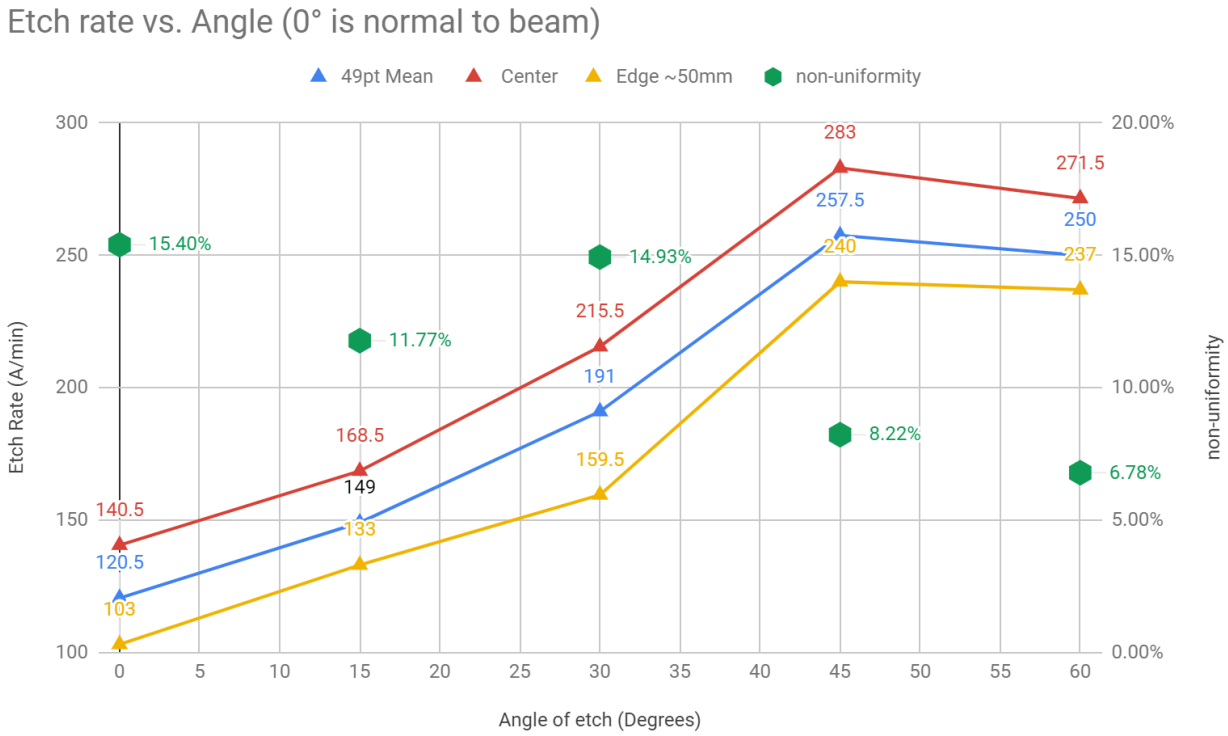
5.1 Follow general safety guidelines for the lab; the safety rules outlined in Chapter 1.01 - Marvell

NanoLab Chemical Hygiene Plan

5.2 Do not use an N2 gun to clean the chamber. Vacuum particles out instead

6.0 ***Process Data***

6.1 We are working on improving uniformity of a high-power etch for process specification. In the mean time the current data is available on the Process Specification page for ionmill6



6.2 Detailed Investigation into 6" wafer SiO2 etch uniformity can be found here. One example below:

6.3 Thermal load test December 2019:

6.3.1 B.V. = 700V, B.I. = 350mA for 10 minutes

6.3.2 For the parameters listed above expect a temperature rise to ~ 75°C

6.4 Sputtered Al etch test.

6.4.1 Substrate: Si wafer with 6000Å of sputtered Al from mrc944. Lithography: 1.2um of standard i-line process using 'lines and spaces' mask. Descum and Harbake follows developing.

6.4.2 Beam Voltage = 500V, Beam Current = 250mA

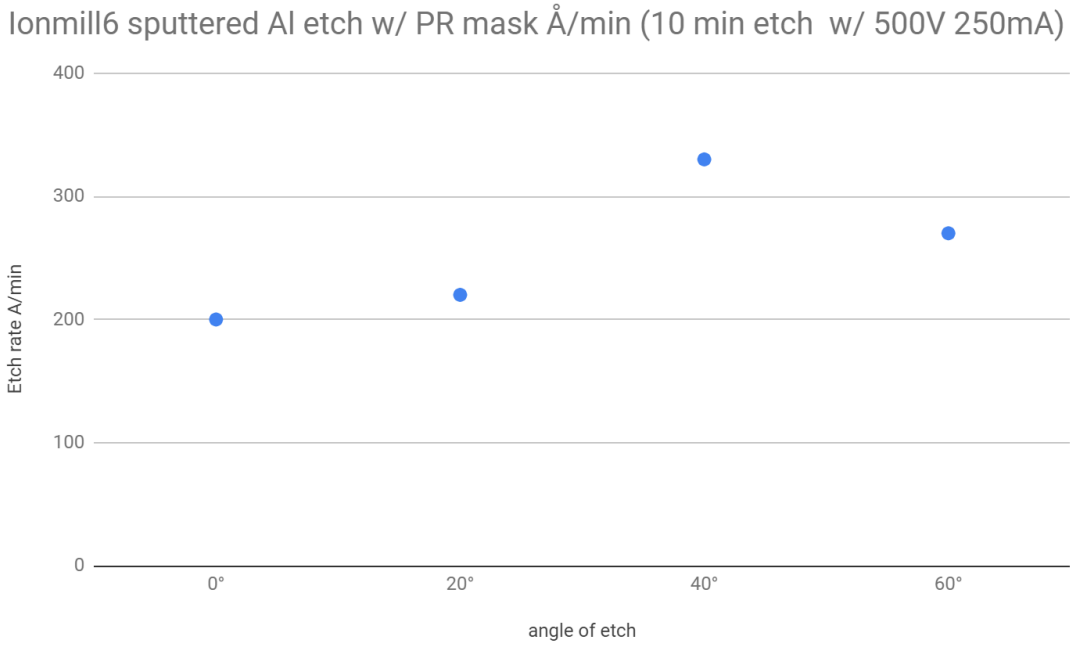
6.4.3 Spin =15

6.4.4 Time = 10min

6.4.5 Angle = 0° , 20°, 40°, 60°

6.4.6 Etch Rates for the center die are : 200, 220, 330, 270 (Å /min) corresponding to angles above as measured on alphastep after PR removal

6.4.7 Nonuniformity: etch rate for the Edge die was consistently ~10% less than the Center die



6.5 Pt etch reported by a member January 2020:

6.5.1 BV= 350V , BI= 175mA , 15RPM

6.5.2 7min at 25 degree etch + 2min at 65degree clean

6.5.3 Etch depth ~ 100nm

6.6 Nb etch reported by a member in 2025:

6.6.1 BV=500V, BI-150mA, 30 deg; Etch Rate = 120Å/min

6.7 PR etch at 500V / 250mA is on the order of 100A/min

6.8 MiR 701 etch at 300V / 150mA is on the order of 50-60 A/min

6.9 LiNbO3 thin film etch of a small chip on a carrier wafer:

6.9.1 750 BV, 300BI, with angle of 10deg. The etching rate is around 0.31~0.38nm/s depending on etch time

6.10 Old Process Data moved to the Appendix

7.0 ***Available Processes, Gases, Process Notes***

7.1 DO NOT ATTEMPT to run a Low Beam Voltage (<300V) / High Beam Current process without consulting staff.

7.2 Note that the system will automatically control the RF Ion source to accommodate the parameters entered.

7.2.1 For example, assume the starting conditions of BV=750V and BI=350mA.

7.2.2 If BI is raised to 400mA, the controller will increase the power to the RF source to create more ions, which are then accelerated by the constant 750V. More ions are being accelerated to the same speed as our initial conditions, therefore the flux passing through a plane normal to the beam is increased. More ions/sec means more coulombs/sec which is the definition of current.

7.2.3 If instead BV is raised to 800V, and BI is left at 350mA then the ions will be accelerated to a faster velocity. This again leads to more Coulombs/sec and higher current. The controller will decrease the RF source power to make less ions available, and will allow for only 350mA to flow.

7.3 The accelerator current represents the amount of current that is collected by the accelerator grid. This is NOT the beam current. The accelerator current represents current lost from the beam due to the accelerator grid. It should be as low as possible, and is not something that can be controlled from the panel. It is an intrinsic property of the grid construction. Do not adjust the accelerator voltage.

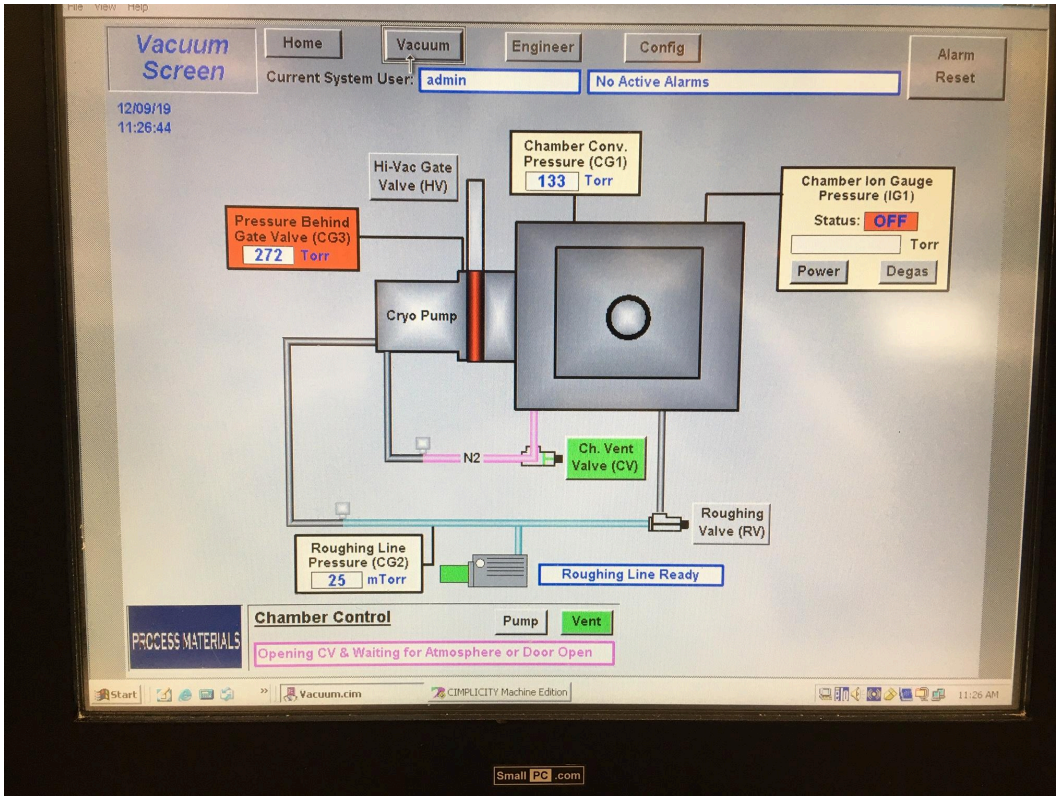
7.4 We are now collecting processing data to better gauge the health of the RF Source. There is a clipboard with a log sheet attached to the controller panel. Please write down your BV/BI parameters and note the FORWARD / REFLECTED power only after you press BEAM.

8.0 ***Equipment Operation***

8.1 Enable the tool

8.2 Lab Members are limited to the VACUUM and ENGINEER tabs of the software. Please do not access CONFIG and CRYO tabs as those are for staff only.

8.3 Navigate to the vacuum screen - Figure 1. The PUMP / VENT operation is all automatic.



8.3.1 Press VENT in to vent the tool. The tool vents up and stops venting once reached atmosphere.

8.4 Mount your wafer on the chuck.

8.4.1 Try not to apply a lot of pressure to the chuck as you are placing the wafer on it.

8.4.2 If the wafer mat is relatively new it will be very sticky on its own and will not need the additional vacuum gun step described below.

8.4.3 Set the vacuum/pressure gun to vacuum, and connect the end to the small port on the side of the chuck.

8.4.4 Pump the handle to remove the void between the wafer and the conductive silicone rubber mat. Remove the vacuum/pressure gun.

8.4.4.1 The vacuum will dissipate immediately, a molecular bond between the wafer and mat is now holding the wafer tight.

8.5 Stage position and setup

8.5.1 Set the desired milling angle on the stage control touchscreen.

8.5.1.1 0 degrees is normal to the incident beam, 90 degrees is facing directly up, and -90 degrees is facing directly down. Stick to positive angles only or you risk damaging the rotating stage mechanism. Some shallow negative angle etches may be allowed. Check with process staff.

8.5.1.2 **NOTE: IF YOU EVER SEE THE STAGE ANGLE START TO BEHAVE ERRATICALLY,**

-especially going to negative numbers-

POWER DOWN THE STAGE CONTROLLER IMMEDIATELY AND NOTIFY STAFF

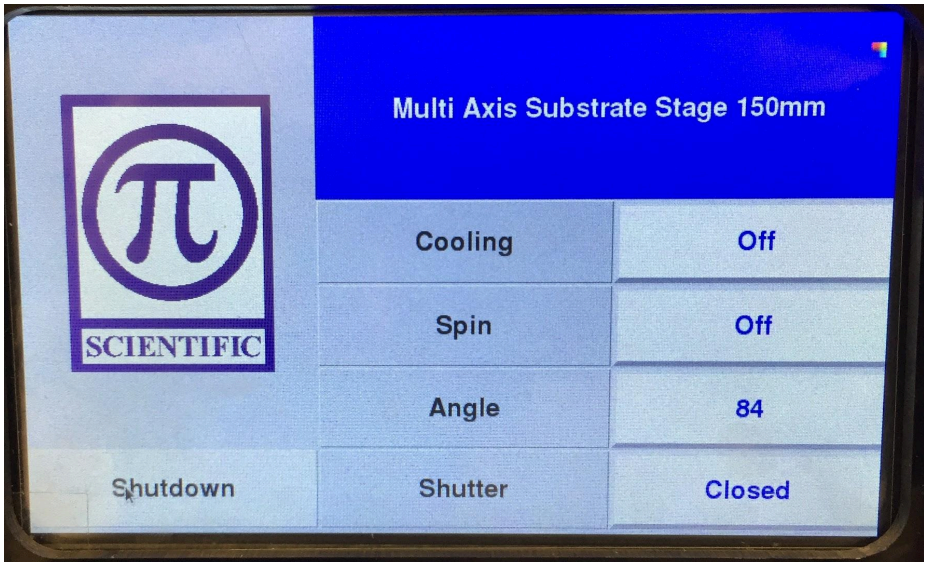


Figure 2. Stage Control Screen

8.5.2 Turn on the water cooling, start the stage rotation, and close the shutter.

8.6 Close and latch the chamber door.

8.7 Press the PUMP button. Foreline should turn blue.

8.8 After the system reaches crossover pressure the High Vacuum Gate Valve will open and the system will be pumped down by the cryopump.

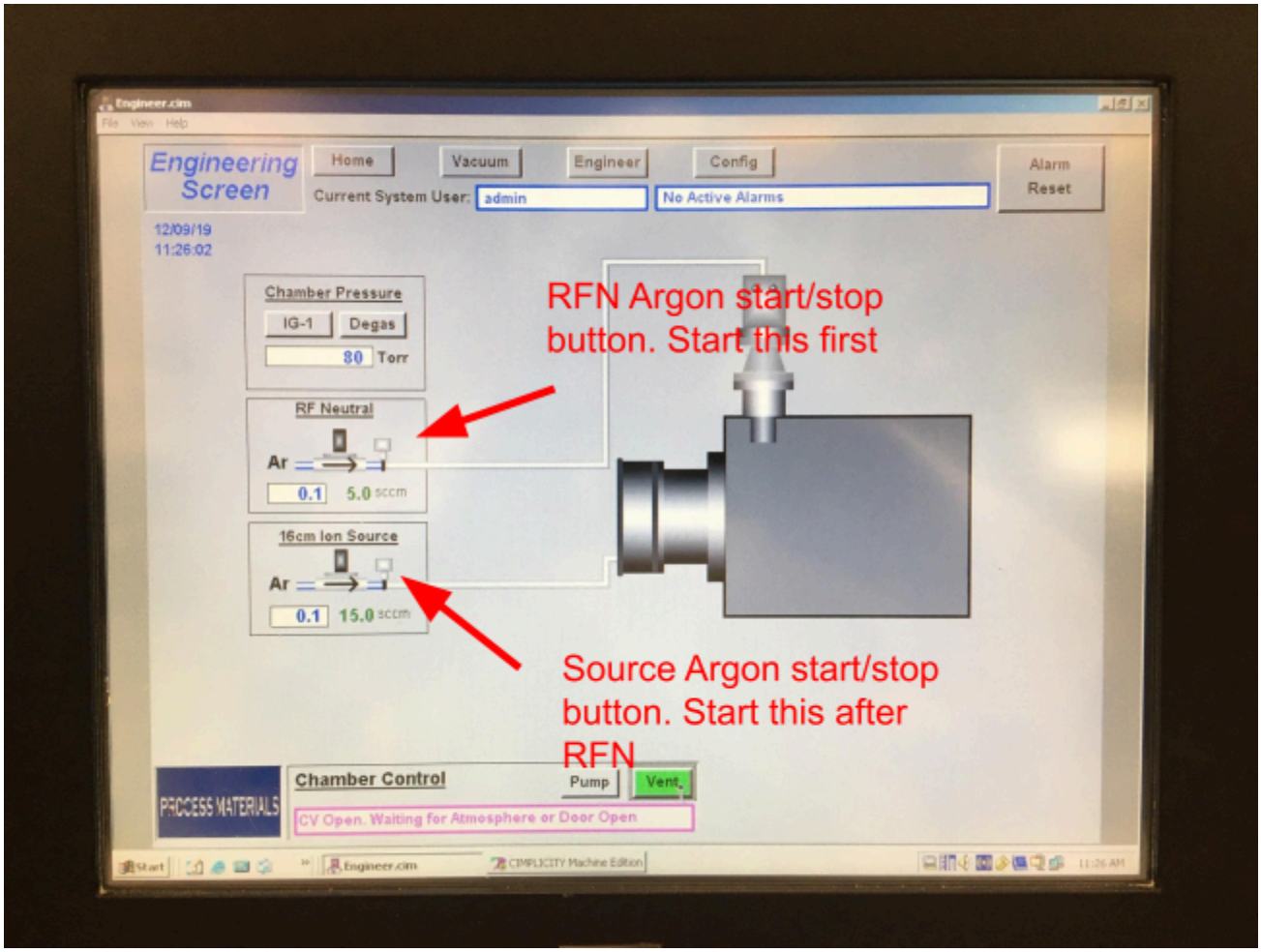


Figure 3. Engineer Control Screen

8.9 Once the chamber has achieved a base pressure of $at\ least\ 5 \times 10^{-6}$Torr, navigate to the "Engineer" Screen on the system touch screen.

8.9.1 On the left hand side there are two icons representing the mass flow controllers for the neutralizer and ion source argon lines.

8.9.2 Leave the default settings for the flow, and open the valves by pressing them directly on the touchscreen.

8.9.3 When gas is flowing, the gas lines should turn to a solid blue color. Let the gas flow for at least **5 minutes**, or until pressure stabilizes and additional 2 minutes. Failure to purge the RFN and Source with Ar will shorten the life of the tool and result in more frequent maintenance down time

8.10 Locate the RF2001 Ion Tech Controller just below the system control touchscreen.

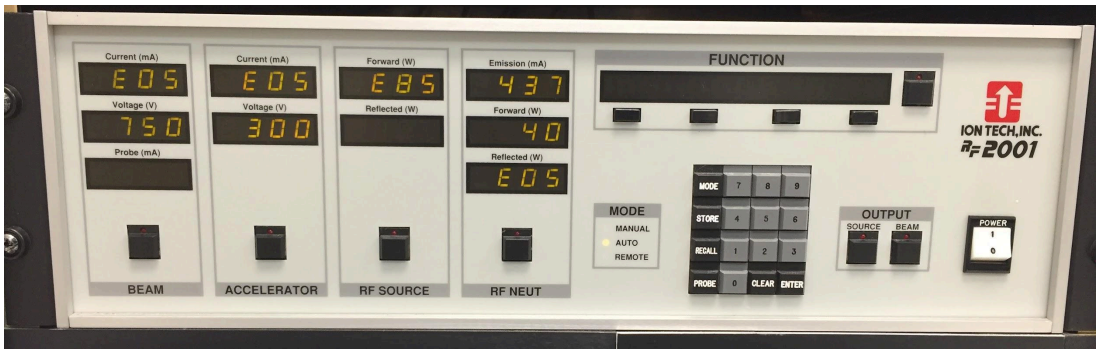


Figure 4. Ion Beam Controller

8.11 Press the “Beam” Button located at the lower left hand corner.

8.11.1 Not to be confused with the Output “Beam” button which turns on the ion beam

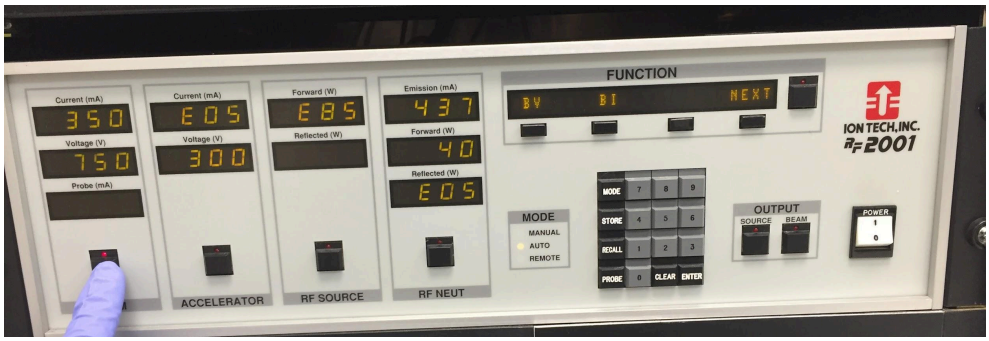


Figure 5. Beam control button (left side)

8.12 Two options will become available “BV” and “BI” corresponding to Beam Voltage and Beam Current respectively. Press the desired parameter and enter desired value.

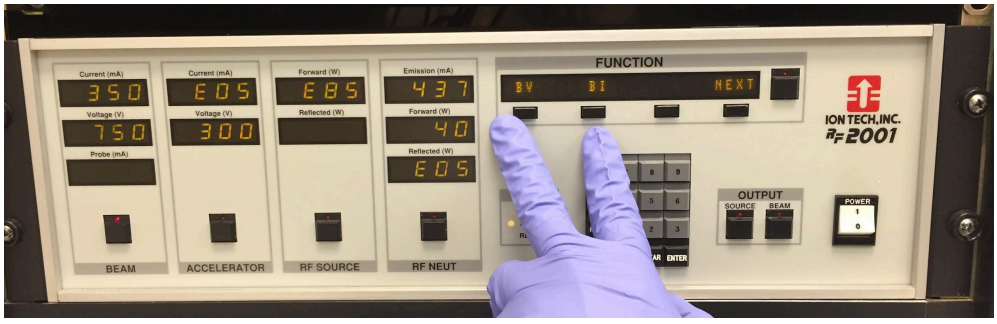


Figure 6. Beam voltage/beam current functions

8.13 Once desired operating setpoints are selected, start the ion source by pressing the “Source Button” located at the bottom right of the control panel in the OUTPUT box.

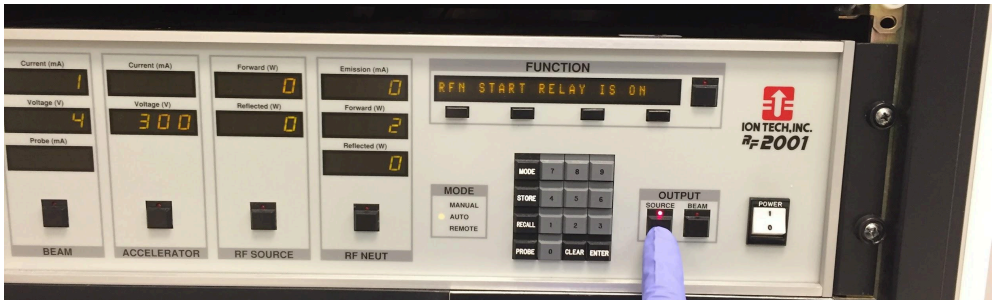


Figure 7. Source Button

8.14 **ATTENTION.** When the RF source has stabilized, a message “Source Is At Idle Power” will show to indicate that the beam is ready to be started. However do not start the BEAM until the RFN is warmed up sufficiently.

8.15 Forward power of the RF NEUTRALIZER will show a reading of 60-65W in the beginning while it is warming up. **After 5 minutes the Forward Power will go down to 40W and close to 0W reflected power.** You have to wait for these conditions before you start the BEAM output. Press the “Beam” button located at the bottom right corner of the panel.

Figure 8. Beam start button

8.16 Write down your process parameters and Forward / Reflected Power on the log sheet (clipboard).

8.17 Move back to the stage control touch screen and open the shutter when you want to begin milling. Simultaneously start a timer for your desired process time.

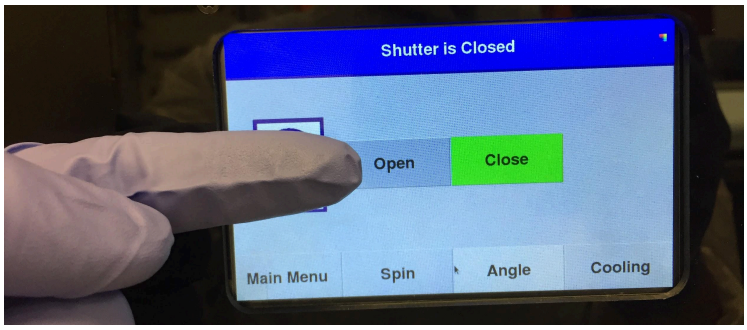


Figure 9. Shutter control screen

8.18 When your process time has elapsed close the shutter.

8.19 Press the lower right hand corner “Beam” and “Source” buttons to turn off the ion beam.

8.20 Allow the gasses to flow for **at least** another 5 minutes, then close off the Ion Source and Neutralizer argon gate valves.

8.21 Turn off Water Cooling

8.22 Press the VENT button. Wait for atmosphere and unload your sample.

8.23 Replace the ring and the screws, close the chamber door and press PUMP. You may now disable the tool

8.24 QUICK SUMMARY

8.24.1 Load Sample and set stage parameters

8.24.2 PUMP (~10-20minutes)

8.24.3 Open both Ar gas lines and flow for 5 minutes

8.24.4 Start RF Source and wait 5 minutes till RF Neutralizer Forward Power = 40W

8.24.5 Set BV/BI and start Beam

8.24.6 Open shutter and etch

8.24.7 Close shutter and turn off BEAM

8.24.8 When IDLE turn off Source

8.24.9 Wait 5 minutes with Ar flowing.

8.24.10 Close Ar and Turn off Cooling Water

8.24.11 VENT and Unload

8.24.12 PUMP the chamber and disable

9.0 ***Troubleshooting Guidelines***

9.1 If the stage controller screen goes dark or you accidentally press the Shutdown button. Open the door under the chamber and power off and on the PI Scientific controller box (M.A.S.S. CONTROLLER) with the black switch.

9.2 **problem of uncontrolled rotating stage.**

9.2.1 This problem can occur sporadically if the encoder loses its place. We have not figured out the exact reason for this fault yet.

9.2.2 This problem can also occur if the Stage Controller touchscreen is frozen and the user restarts the computer.

9.2.3 You should always watch the stage angle display while it is rotating to your set angle. If after changing the stage angle you notice the angle number display acting erratically AND/OR going into the negative number, you should

a) Turn off the stage controller immediately (the ON/OFF button on the computer under the chamber).

b) Do not turn the controller back on.

c) Call Sam Tsitrin or Jesse Merz.

d) Failing to reach staff, red fault the tool until staff can take a look.

9.3 Keep an eye on Accelerator Current. If the Source/Beam are on but Accelerator current isn't showing a number (2 - 4 are typical) there is a problem and you will need to restart your etch by restarting the Beam button. If that doesn't work report a yellow fault.

9.4 If the source fails to start (i.e. the RFN keeps cycling and trying to start but fails after multiple attempts)

9.4.1 Vent the chamber, pump the chamber and try again

9.4.2 Let Argon flow for 15 minutes total and try again

9.5 Cryo above 17K red message

9.5.1 As of 2024 we are ignoring this message and relying on the pressure gauge to tell us if the vacuum is good or not. See staff for explanation

10.0 Study Guide

10.1 Understand the Vent/Pump protocol

10.2 Know to wait for RFN to be sufficiently warmed up before beam output

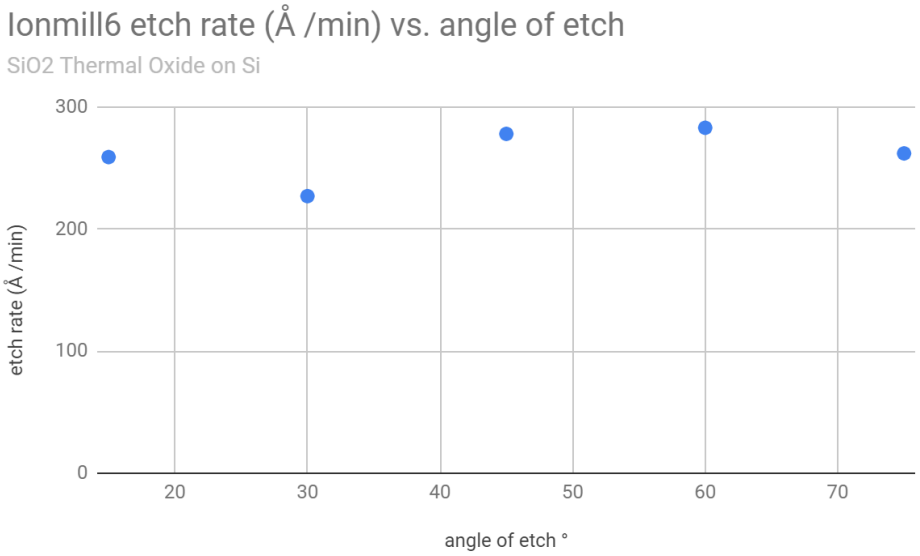
10.3 Know how to clean chuck and load sample

10.4 Know how to set up process parameters. Never run High Current/ Low Voltage process without consulting staff

10.5 Demonstrate shut down sequence

11.0 Appendices, Figures & Schematics

11.1 Thermal silicon dioxide etch tests - December 2019.



11.2

- **11.2.1** Beam Voltage = 500V, Beam Current = 250mA
- **11.2.2** Spin =15
- **11.2.3** Time = 4min
- **11.2.4** Angle = 15°, 30°, 45°, 60°, 75°
- **11.2.5** Etch Rates are : 259, 230, 278, 283, 262 (Å /min) corresponding to angle
- **11.2.6** Nonuniformity ~ 2%

11.3 Old Process Data (before the 12/2019 rebuild)

- **11.3.1** Au (evaporated) etch rate at 20° 100mA 500V ~ 60-70Å/minute
- **11.3.2** Cr (evaporated) etch rate at 20° 150mA 500V ~ 30Å/minute
- **11.3.3** PMMA C2 etch rate at 20° 100mA 500V ~ 70Å/minute