Fab Forum: 2/4/2019

Announcements

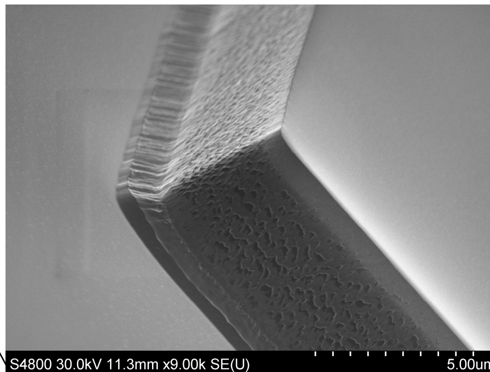
- ...
- Equipment Status: https://wiki.itap.purdue.edu/display/BNCWiki

AJA Ion Milling system with End Point Detection

Why have an ion mill?

- Dedicated tool for precision milling, first at BNC
  - Panasonic with Ar used up to now
- can mill ~nm or >μm
- mill at selectable angle to the sample
- sample stage rotates
  - helps remove sidewall-redeposited material
  - critical for tunnel barrier performance
- SIMS-based end point detector allows precise control of milling depth
- sample load lock

- Faculty in Charge: Bhave



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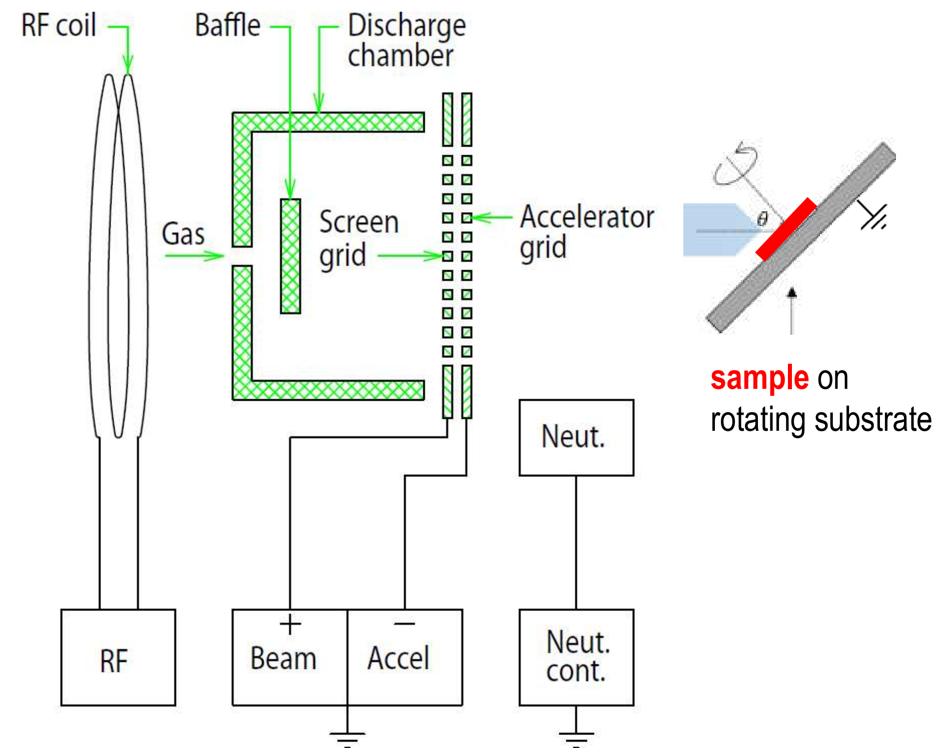
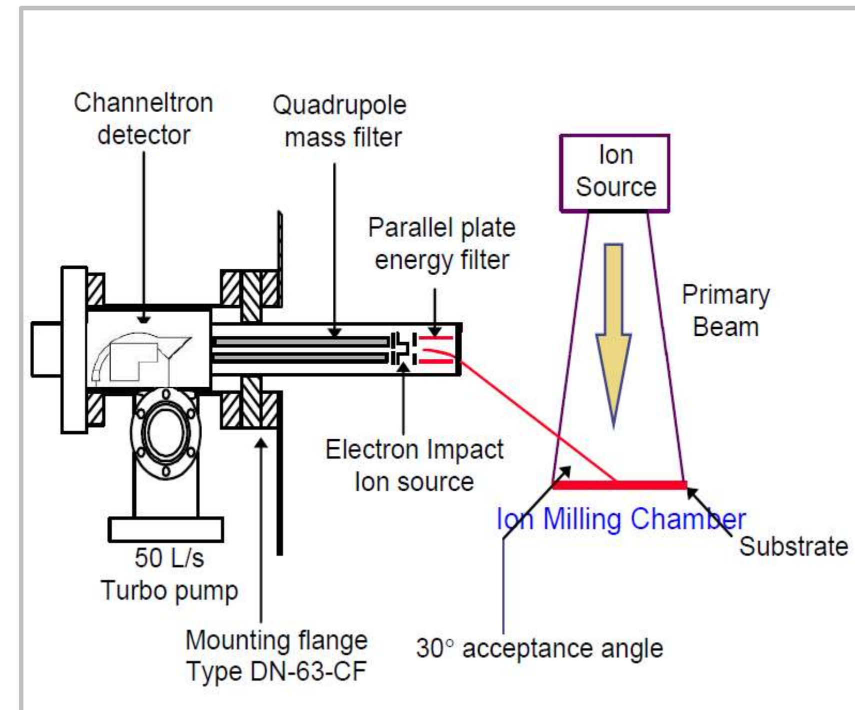
Ion Milling Basics

- base pressure of system ~1e-8 torr
- Gas = argon, fed into glass discharge chamber
  - pressure ~1.5e-4 torr
- RF coil ionizes the Ar gas to produce plasma
- plasma raised to beam voltage $+V_B$ by beam grid
- Ar^+ drawn out of chamber by accel grid $-V_A$
- neutralizer produces electrons to neutralize Ar^+ to Ar
- broad Ar beam hits the sample at angle θ
  - rotating substrate



End Point Detection (EPD) Basics

- sensitive measurement of ions produced in milling
- discriminates by charge/mass ratio
  - elements
  - compounds
- energy filter at entry passes only a band of ion energies
- quadrupole mass filter (SIMS) passes only one e/m value
  - scanned to look at certain masses, e.g., Co, B, Mg, Ta
- ions which make it through will hit the channeltron
  - secondary electron multiplier (SEM)
  - amplified e- pulse hits detector



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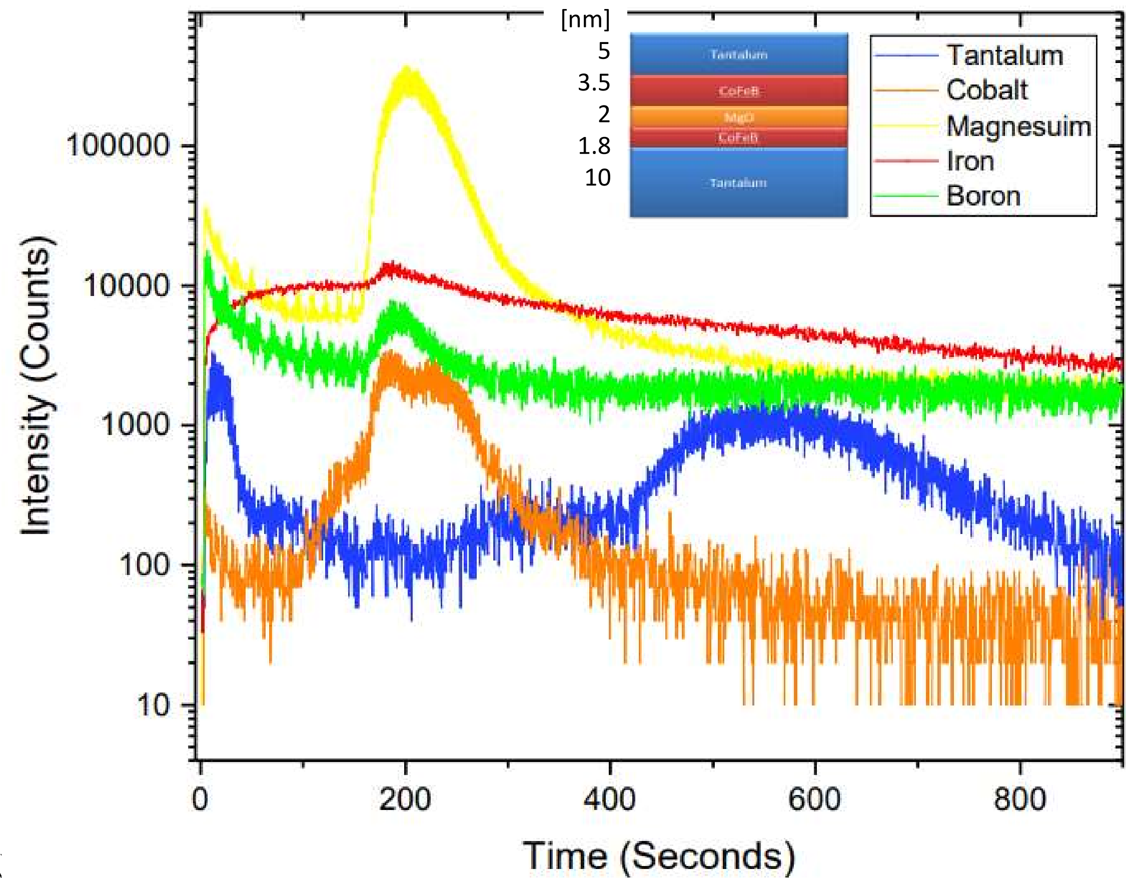
EPD example: CoFeB thin film stack for MTJ

- on Si:SiO2 substrate
- sputtered at BNC

EPD shutter open **closed**



Identifying the main components on Ion Mill

chamber opened

Transfer arm

Controller for subst. rotation and transfer arm

Load lock

Gate valve

Substrate tilt and rotation motors

Breaker for main chamber vent
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Breaker for load lock vent

Hiden EPD

(back of chamber) Ar^+ ion source

Pressure gauge controller

(back of chamber) Ebara turbopump

Ion source power supplies

Software control of processes

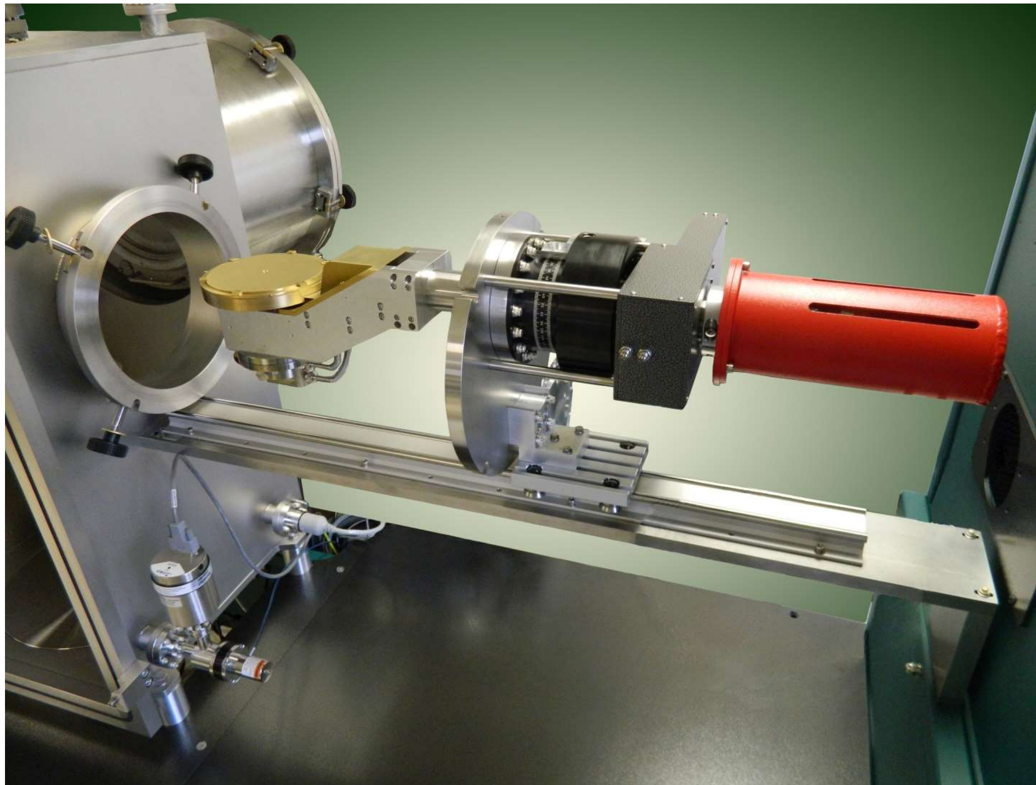
EPD pump controller

EPD controller

Load lock Pump controller

RF power for Ion source

water cooled / tilting / rotating substrate holder



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Main vendors involved in this system

- *Kaufmann & Robinson (KRI):* make ion source
  - RF discharge chamber (RF power supply from *Seren*)
  - collimated grids (beam, accel)
  - neutralizer
- *Hiden*: make SIMS-based EPD system
  - EPD probe
  - electronics for power, communication
  - software (`MASsoft`)
- *AJA*: integrate the above components into high vacuum chamber, adding
  - *Ebara* turbopump with *Kashiyama* roots backing pump
  - load lock with motorized transfer arm
  - tilting/rotating substrate stage with water cooling
  - shutter for ion source
  - shutter for EPD
  - pressure gauges
  - software (`Phase-IIJ`)

different etch rates and sputter yields for elements

K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
4.339	6.111	6.54	6.82	6.74	6.764	7.432	7.87	7.86	7.633	7.724	9.391	6	7.88	9.81
31.81	11.868	12.8	13.57	14.65	16.49	15.636	16.18	17.05	18.15	20.29	17.96	20.57	15.93	18.63
46	51.21	24.75	27.47	29.31	30.95	33.69	30.643	33.49	35.16	36.83	39.7	30.7	24.21	28.34
			330	310	530	870	350	450	530	880			920	
			0.50	0.60	1.2	1.9	0.80	1.1	1.3	2.0			1.1	
39.102	40.08	44.956	47.90	50.942	51.996	54.938	55.847	58.933	58.71	63.544	65.373	69.72	72.59	74.922
			655	518	450	459	441	412	410	441			848	

Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
4.176	5.692	6.38	6.84	6.88	7.10	7.28	7.364	7.46	8.33	7.574	8.991	5.785	7.342	8.639
27.5	11.027	12.23	13.13	14.32	16.15	15.26	16.76	18.07	19.42	21.48	16.904	18.86	14.628	16.5
40	57	20.5	22.98	25.04	27.13	29.54	28.46	31.05	32.92	34.82	37.47	28.03	30.49	25.3
4000		950	570	470	410		610	720	1100	1800			1200	3238
		0.77	0.63	0.7	0.70		1.2	1.4	2.0	2.8			1.2	
85.47	87.62	88.905	91.223	92.906	95.944	(98)	101.07	102.95	106.4	107.870	112.40	114.82	118.69	121.75
3090-4020		1237	872	674	584		506	516	550	639			1010	1131

Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83
3.893	5.21	5.61	7	7.88	7.98	7.87	8.5	9	9.0	9.22	10.43	6.106	7.415	7.287
25.1	10.001	11.43	14.9	16.2	17.7	16.6	17		18.56	20.5	18.751	20.42	15.028	16.68
35	35.5	19.17	23.2								34.2	29.8	[illegible]	25.56
			660	420	340	520	500	590	620	1080			2600	8800
			0.79	0.62	0.60	0.95	0.96	1.1	1.1	1.7			2.3	
132.905	137.34	138.91	178.49	180.948	183.85	186.1	190.2	192.2	195.09	196.967	200.59	204.37	207.194	
			833	675	592	551	524	533	565	635			1135	1333

Argon at 500 eV, normal incidence, 1 mA/cm2 current density
source: ionbeam.co.uk

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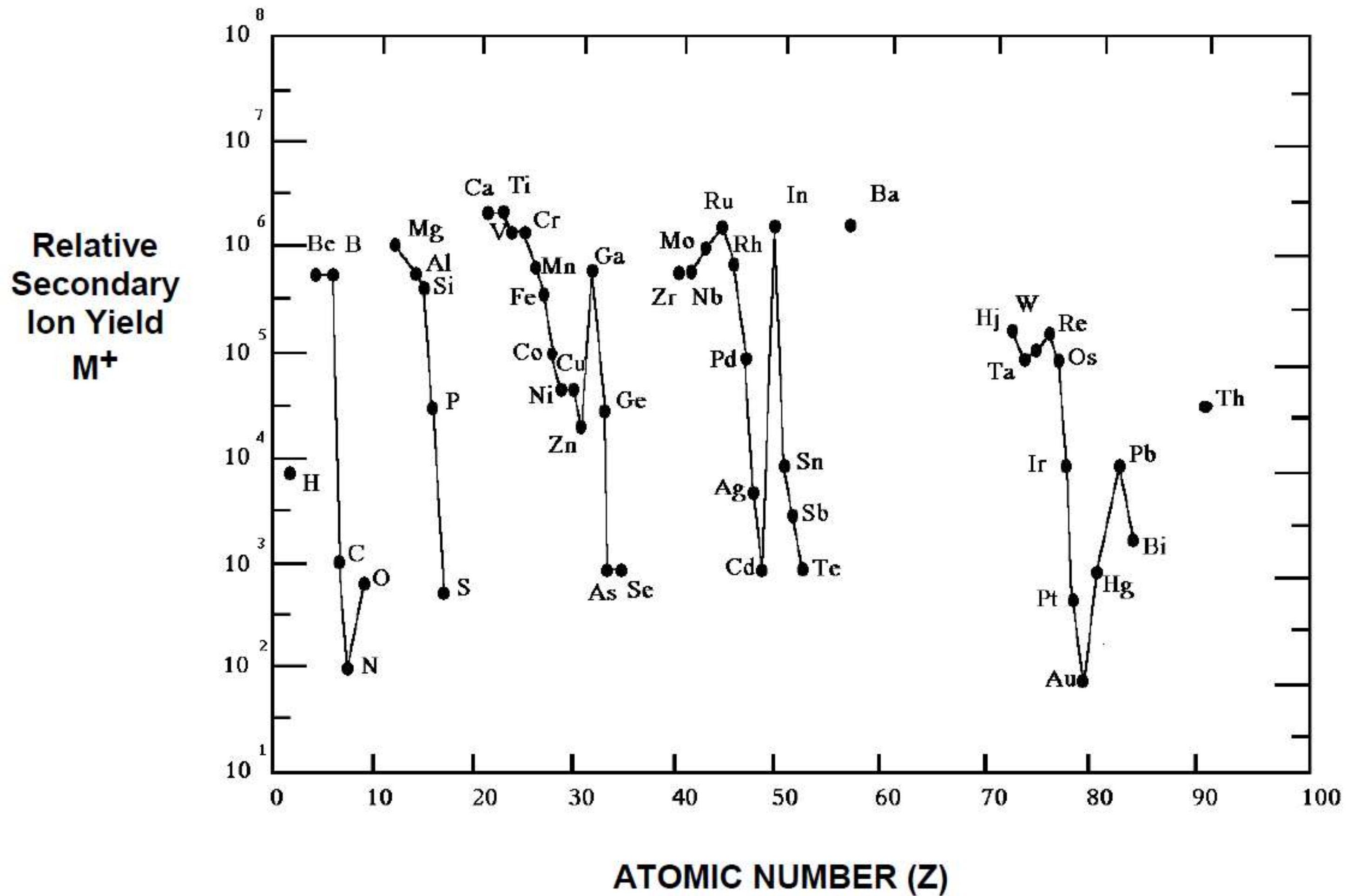
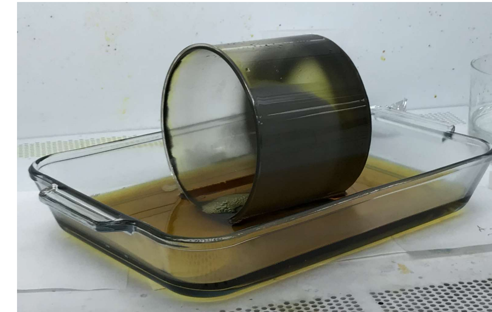
Some elements are harder to detect by EPD



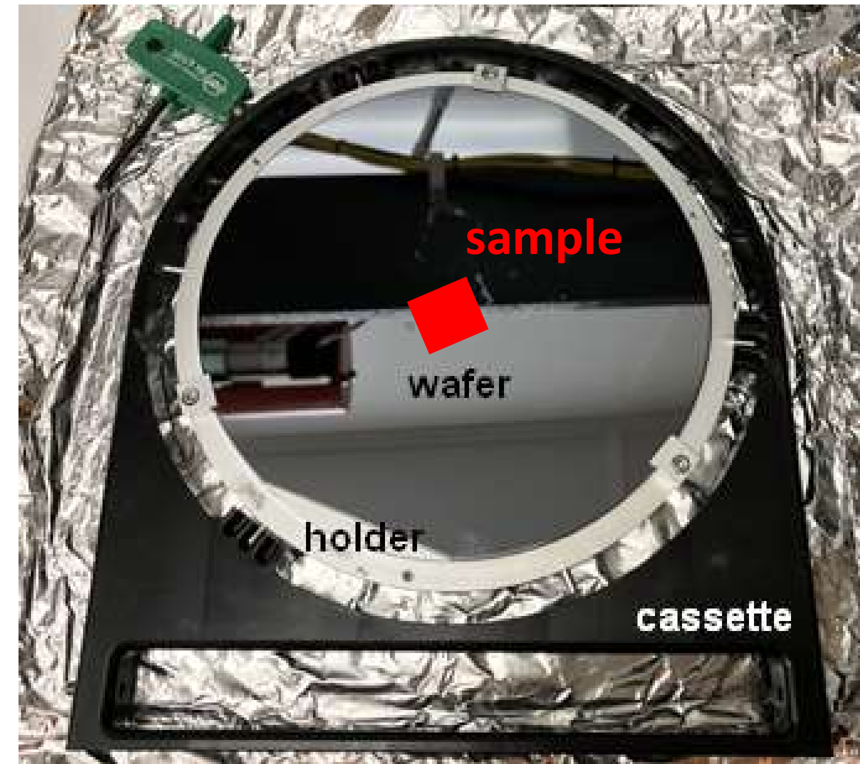
AJA Ion Mill: birthing pains at Purdue

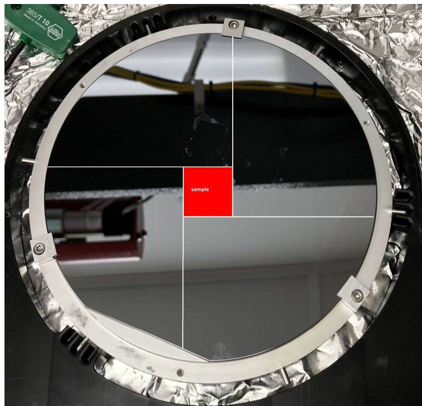


- tool was down most the time since May 2018 install
- ion source was shorted at HV, kept sputtering metal onto glass liner
  - problem since installation?
  - repeated 3 times before... **we found the reason** (Dec. 2018)
  - very rare problem (Kaufmann & Robinson, Inc.)
- AJA does not make/service the ion source **got to know KRI engineer!**
- stage rotation motor was intermittent **AJA repaired, works fine now**
- ion source parameters different from Cornell
  - etch recipes did not translate **Sen established new recipe here**

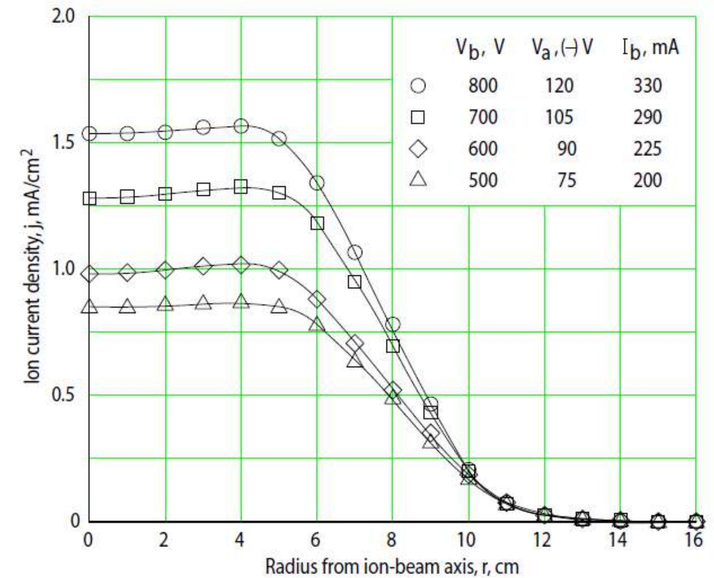
So, you want to use the Ion Mill…

- sample mounts on a 6” Si wafer
  - Al2O3 suggested also
- best to have cutout in Si for thermal contact to substrate
  - working on 4-piece “sandwich” design (below)
- please plan to use the load lock
  - unless deep etch, high heating needed in process





ion beam profile: put your sample in center of wafer



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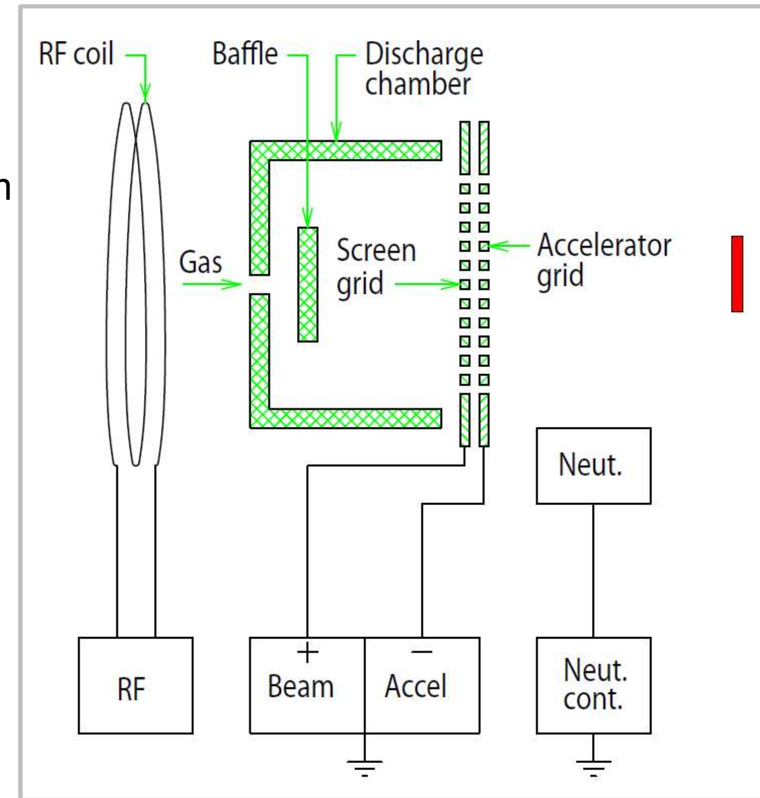
Developing recipe for your material / resist

- choose resist to withstand heat/damage of Ar beam
- determine beam voltage needed
  - VB = 150 V (prog #1) for CoFeB stack -- **20 nm**
  - VB = 600 V (prog #3) for LiNbO3 -- **1 um**
- substrate angle



Program #	
Flow [sccm]	
V_beam [V]	V_acc [V]
I_beam [mA]	I_acc [mA]
RF forward power [W]	

# 1	
11	
150	26
30	1000
85	

# 2	
15	
500	75
200	1000
280	

# 3	
16	
600	90
225	1000
310	

# 4	
20	
800	120
330	1000
440	

Ion Milling recipes being developed first

full recipes include photoresist and all milling parameters

- LiNbO3 deep etch (Bhave group)
- "MTJ stack": Ta / CoFeB / MgO / CoFeB / Ta (Appenzeller)

Timeline for roll-out of Ion Mill

- **February**: establish LiNbO3 recipe with existing user (Sen), train first batch of LiNbO3 etch users
- **March**: do same for CoFeB MTJ etch

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Questions and Open Discussion

WE ARE PURDUE. WHAT WE MAKE MOVES THE WORLD FORWARD.

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