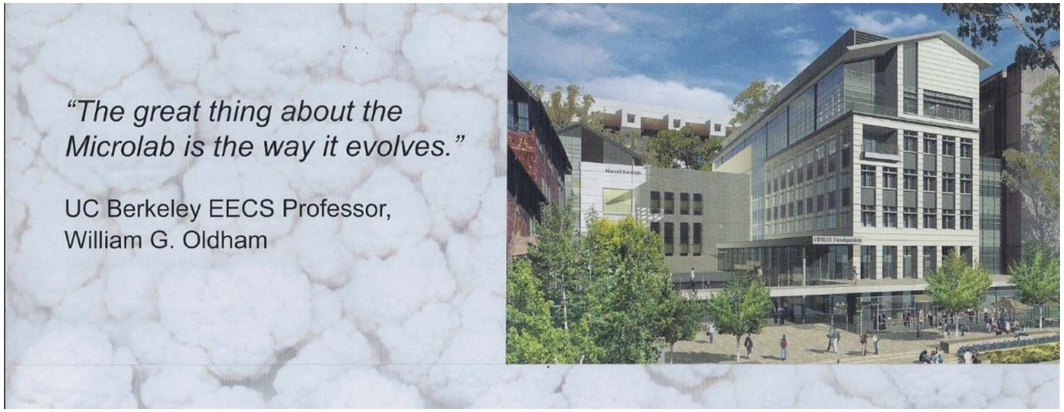
Marvell
Nanofabrication
Laboratory

2019 Principal Investigators Meeting



"The great thing about the Microlab is the way it evolves."

UC Berkeley EECS Professor,
William G. Oldham

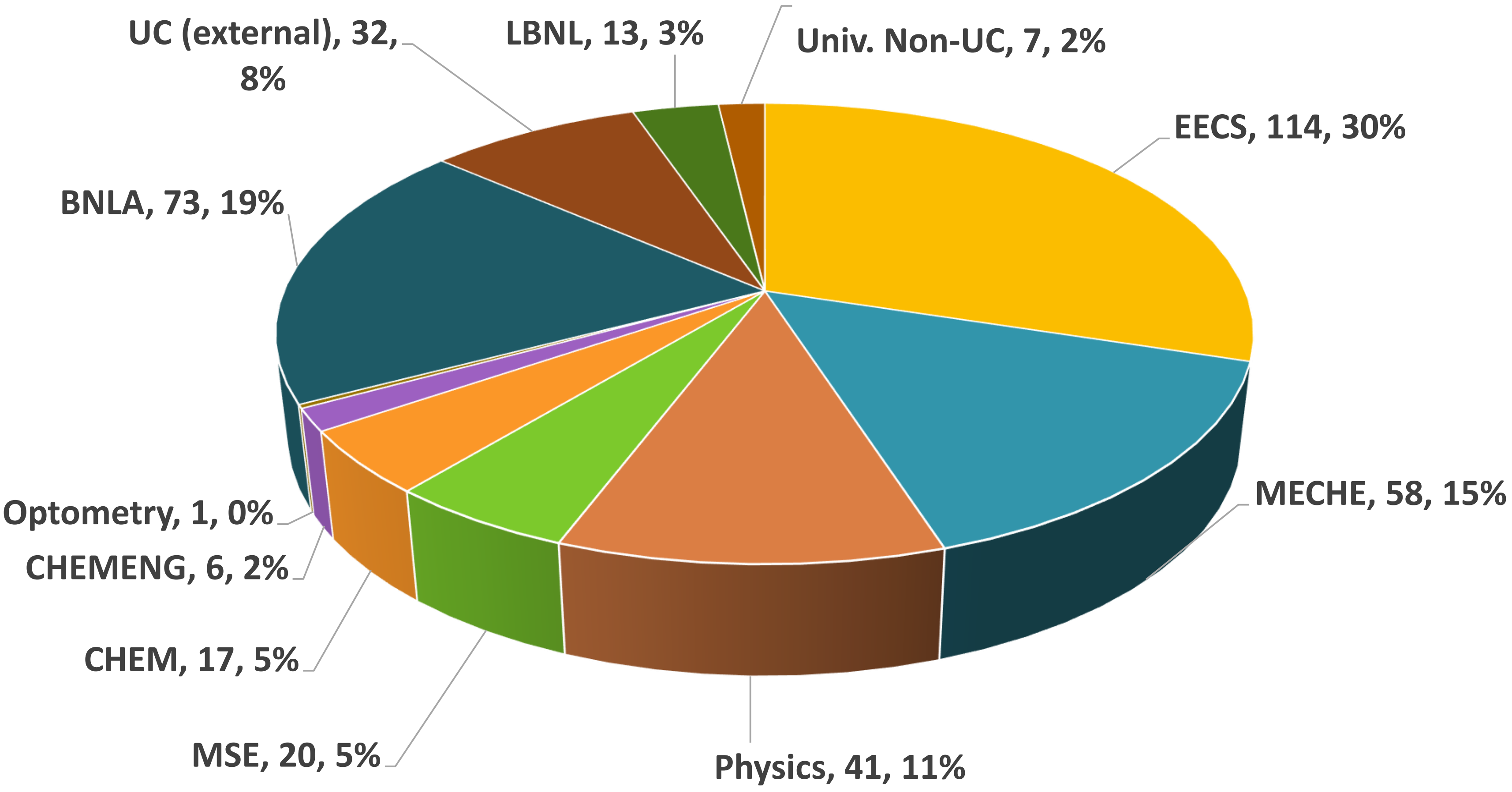
Professor Connie Chang-Hasnain — **Faculty Director**

Dr. Bill Flounders — **Executive Director**

Agenda

- Membership Status, Internal / External Usage Trends
- Staffing Status
- New Equipment / Capabilities
- Summary of Support from VCR's Office
- Equipment Qualification
- FY 18/19 Rates Overview

Lab Members by Department FY 18 Total = 382



Fiscal Year	2014	2015	2016	2017	2018
Total	462	441	420	370	382
UCB	326	280	297	252	257
External	136 (29%)	161 (37%)	123 (29%)	118 (31%)	125 (32%)

The NanoLab 2018

Analysis of the Top 20

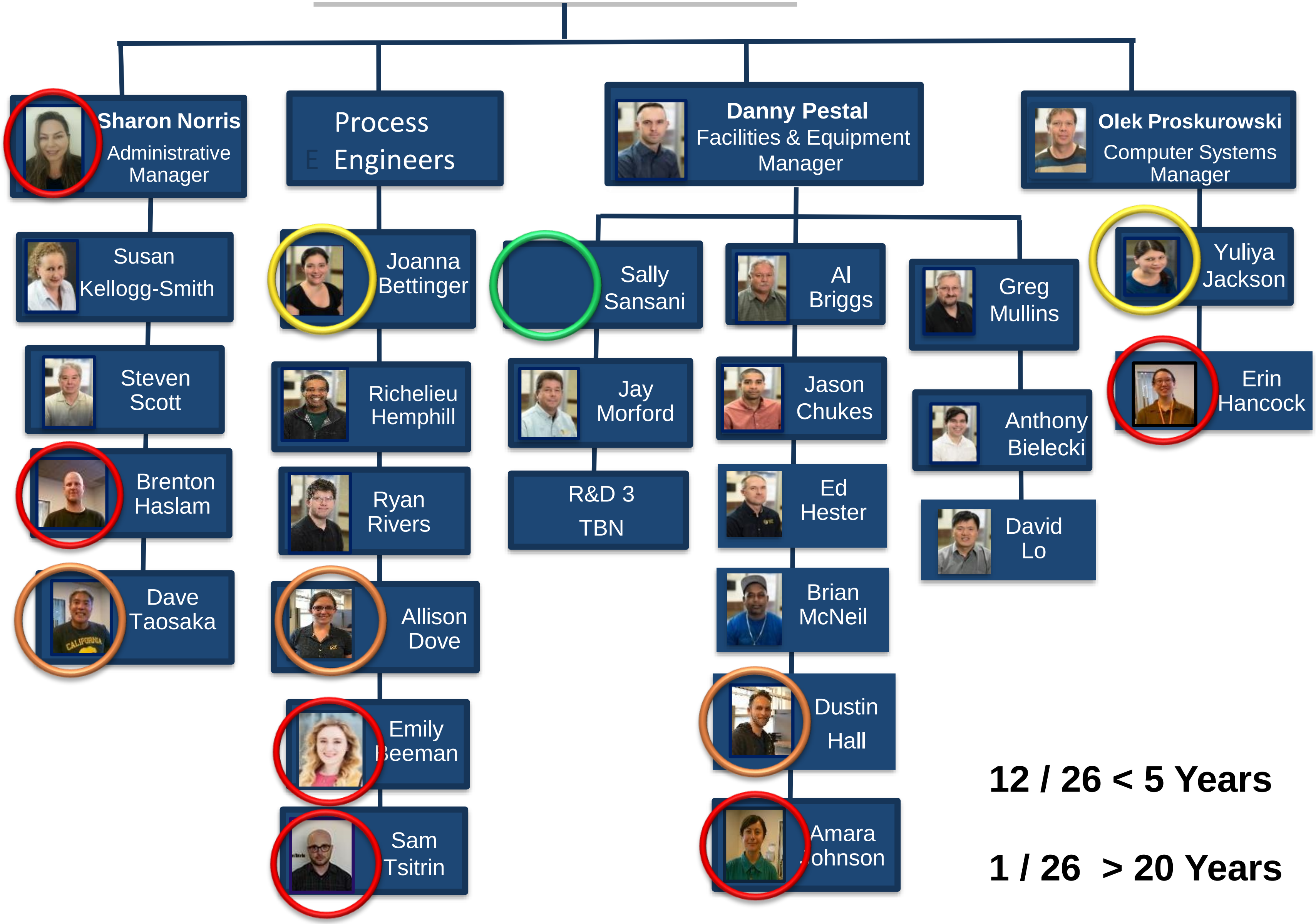
Top 20 PIs by Dept		Δ	Financial		Δ
EECS	11	↑1	All Academic	$1.95 M	-$132 K
Mech Eng	3	↑1	Top 20 Academic	$1.64 M	-$177 K
Chemistry	1	-1	All BNLA	$1.91 M	-$6 K
Physics	2	-1			
MSE	1	-1	Top 10 Academic	> $75K each	
UCSF BioE	1	↑1			
UC Davis EE	2	0	Top 10-20	> $32K each	

Lab Members Historical Analysis

FY	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total	466	474	497	471	462	441	420	370	382
UCB	367	353	370	340	326	280	297	252*	257
Ext Acad	48	67	68	59	66	87	55	49	52
BNLA	51	54	59	72	70	74	68	69	73
EECS	122	132	138	126	139	135	142	125	114
Mech Eng	102	99	106	95	87	59	62	46	58
Physics	42	36	45	39	35	31	38	36	41
MSE	21	27	31	23	21	23	17	16	20
BioEng	12	10	7	8	4	4	4	1	1
Chem/ChE	65	47	42	49	30	28	34	27	23

* ~25 service accounts removed from member count

Staff Organizational Chart



- **Sharon Norris**
Administrative Manager
  - Susan Kellogg-Smith
  - Steven Scott
  - Brenton Haslam
  - Dave Taosaka
- Process Engineers
  - Joanna Bettinger
  - Richelieu Hemphill
  - Ryan Rivers
  - Allison Dove
  - Emily Beeman
  - Sam Tsitrin
- **Danny Pestal**
Facilities & Equipment Manager
  - Sally Sansani
    - Jay Morford
    - R&D 3 TBN
  - Al Briggs
    - Jason Chukes
    - Ed Hester
    - Brian McNeil
    - Dustin Hall
    - Amara Johnson
  - Greg Mullins
    - Anthony Bielecki
    - David Lo
- **Olek Proskurowski**
Computer Systems Manager
  - Yuliya Jackson
  - Erin Hancock

1

2

3

4

12 / 26 < 5 Years

1 / 26 > 20 Years

Additional ebeam evaporator

Toshiba Donation May 2016. Released Sep 2017

NanoLab / Machine shop provided:

- Rebuilt pump package
- Rebuilt 6 pocket e-gun
- Ebay planetary rotation susceptor
- Spare QCM
- Custom 6” and 4” wafer holders

~ Spare parts, good shopping, gradual attention and ~$35K yields:
New high performance box coat system for evaporation of oxides

This is From Last Year’s Update - but it had a brother…

A Custom 3 target sputter deposition system

Toshiba Donation May 2016. Released Sep 2018

Received 2 ebeam box coaters

- one overhauled and released as 6pocket e-beam in Sep 2017.

- 2nd unit was <u>completely</u> rebuilt as an exploratory sputter system
- replaces 45 year old "randex"

NanoLab / Machine shop provided:

- 3 new Lesker sputter guns/flange ($18K)
- new AJA custom heated chuck ($25K)
- 3 spare power supplies
- rebuilt pump package
- used ion gun for pre clean

A Custom 3 target sputter deposition system

Toshiba Donation May 2016. Released Sep 2018

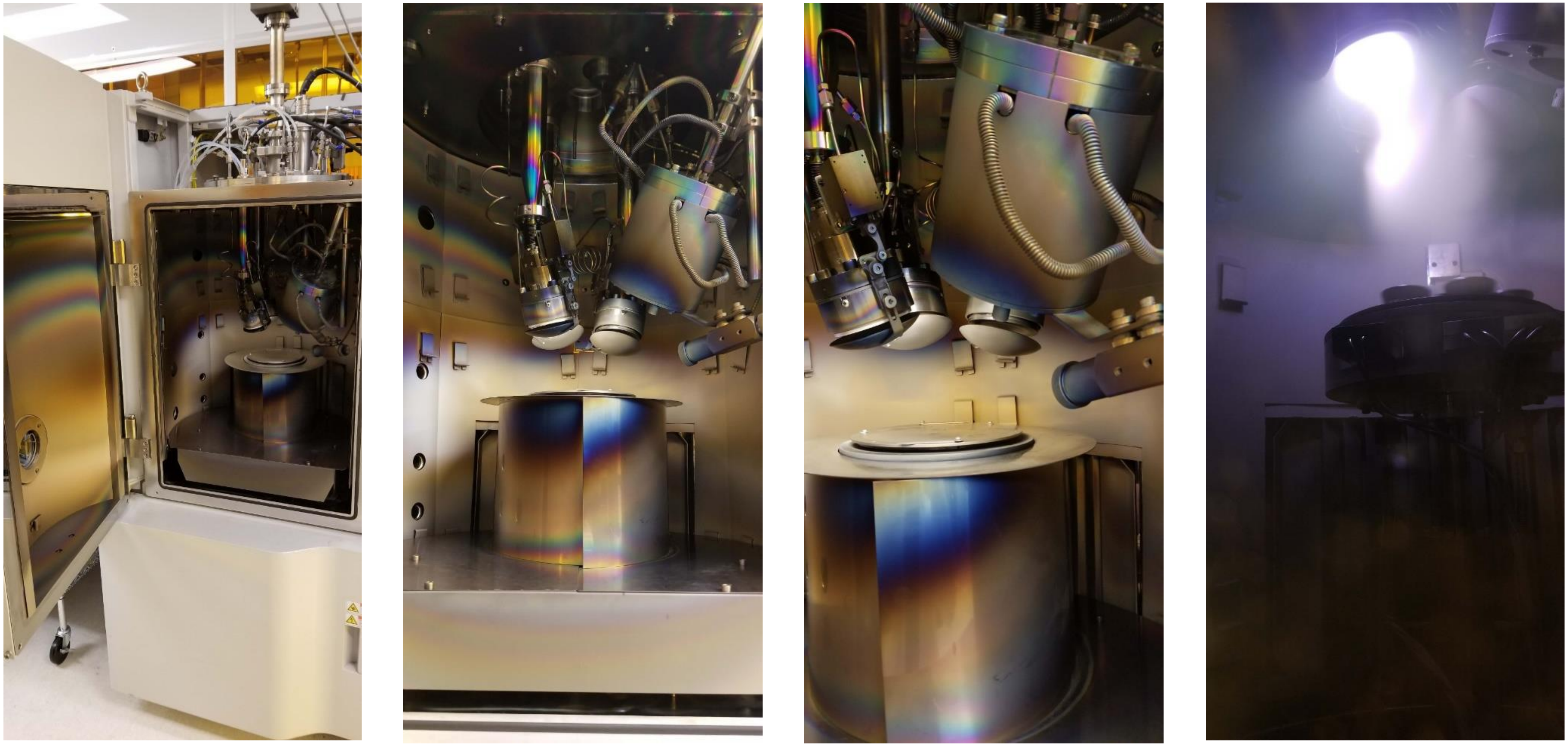
This is what complete rebuild looks like.

Donated chassis/chamber +
used and spare parts +
select new components +
machine shop +
PLC and programmer +
senior engineer =

~$110K ~ 1/3 cost of new

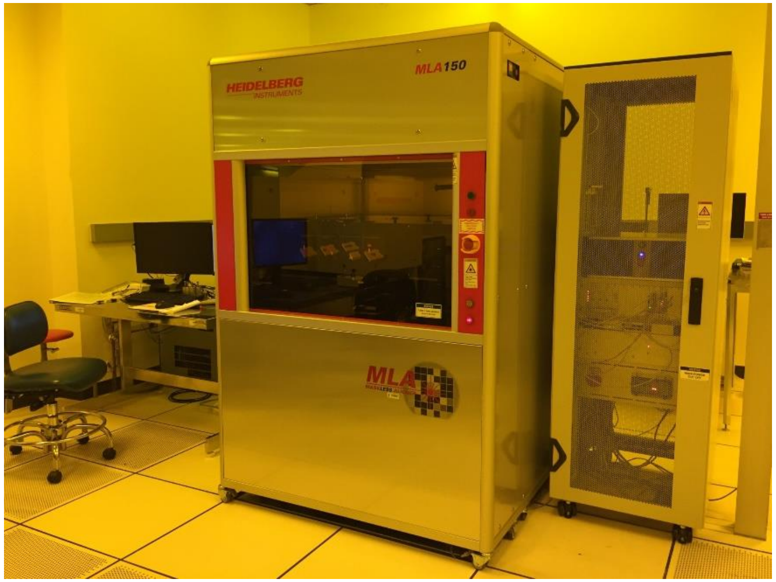
Targets – so far
Al, Cu, Cr, Fe, Ni, Nb, Si, Ti, TiW, W, Zr

Custom 3 target sputter deposition system

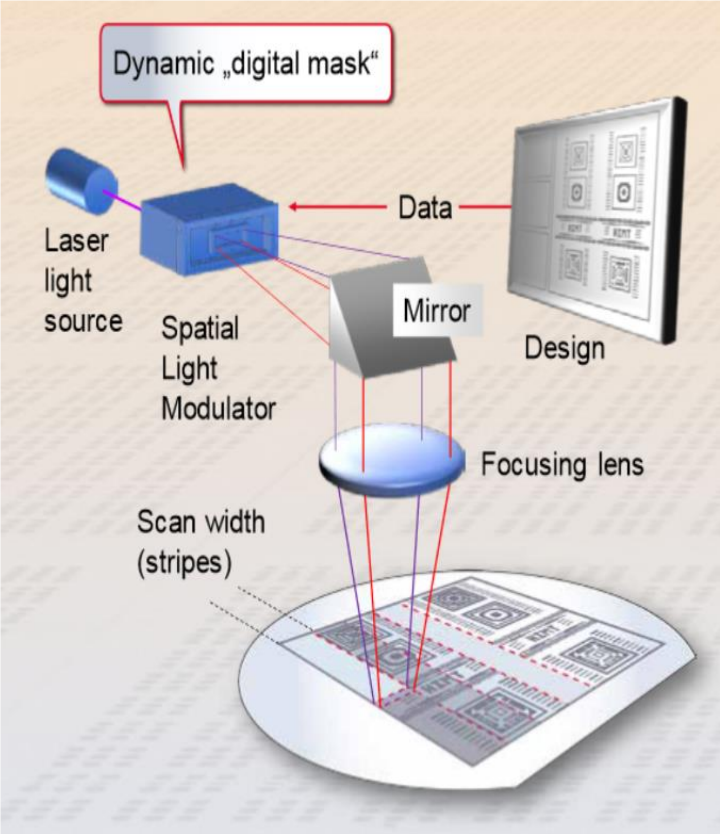


Direct Write Laser Writer = Maskless Aligner

On order April 2019; Delivery Oct 2019



Direct laser write with digital mirror array

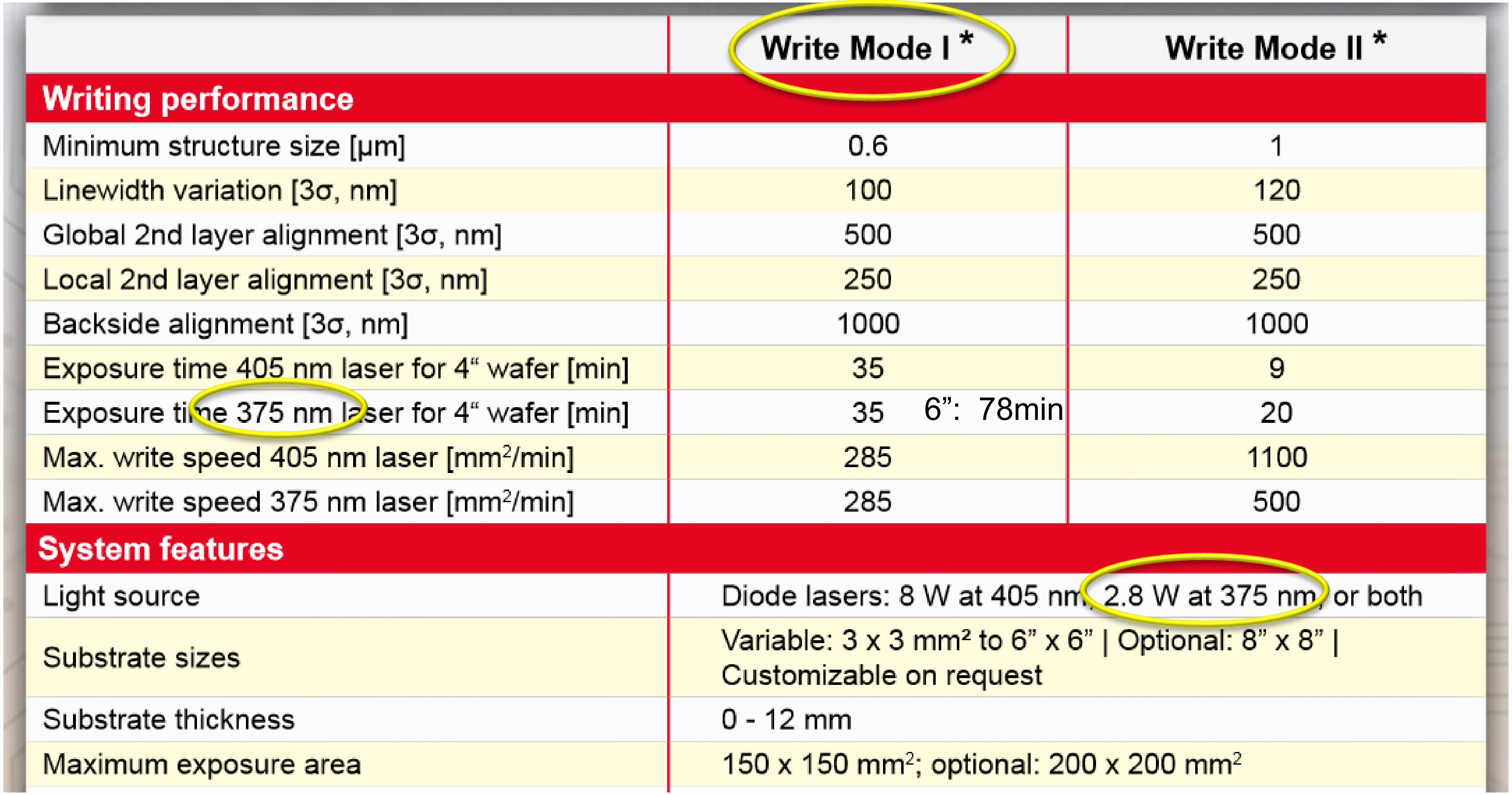


The MLA 150 at Stanford:

- Went from new to busiest tool in the lab in < 4months

They have ordered a 2nd system

MLA150 System Specifications



	Write Mode I *	Write Mode II *
Writing performance		
Minimum structure size [µm]	0.6	1
Linewidth variation [3σ, nm]	100	120
Global 2nd layer alignment [3σ, nm]	500	500
Local 2nd layer alignment [3σ, nm]	250	250
Backside alignment [3σ, nm]	1000	1000
Exposure time 405 nm laser for 4“ wafer [min]	35	9
Exposure time 375 nm laser for 4“ wafer [min]	35 6”: 78min	20
Max. write speed 405 nm laser [mm²/min]	285	1100
Max. write speed 375 nm laser [mm²/min]	285	500
System features		
Light source	Diode lasers: 8 W at 405 nm, 2.8 W at 375 nm, or both	
Substrate sizes	Variable: 3 x 3 mm² to 6” x 6” | Optional: 8” x 8” | Customizable on request	
Substrate thickness	0 - 12 mm	
Maximum exposure area	150 x 150 mm²; optional: 200 x 200 mm²	

Write time for direct write systems without DMA: pattern density dependent and 10- 20 X longer

Maskless Aligner and VCR Support

From VCR FY19	$ 80K
NanoLab Match (from BNLA)	$ 80K
From VCR FY18	$100K
NanoLab Match (from BNLA)	$100K
PI Support from BETR	$100K

Total MLA150 as specified	$460K

Prior VCR Investments (always matched)

FY17	100K	AFM
FY16	250K	150 to ebeam / 100 to wafer bonder
FY15	250K	2 chamber PECVD

New Equipment Qualification Categories

	# of tools In category	
Class	5	Background information for a toolset Vacuum / Evap / Etch / SEM / EBL
Member Qualify	51	Simplest tools. Any qualified member can qualify you
Basic Tool	49	Tools that need a superuser signoff before you are qualified
Exam Tool	82	Tools that have an online exam before you can request qualification
Specialty Tool	8	Tools with special requirements Read the manual for detailed procedure

New Equipment Training Procedures

All training requests now tracked in equipment control program

Notification of reservation or enable by other members available

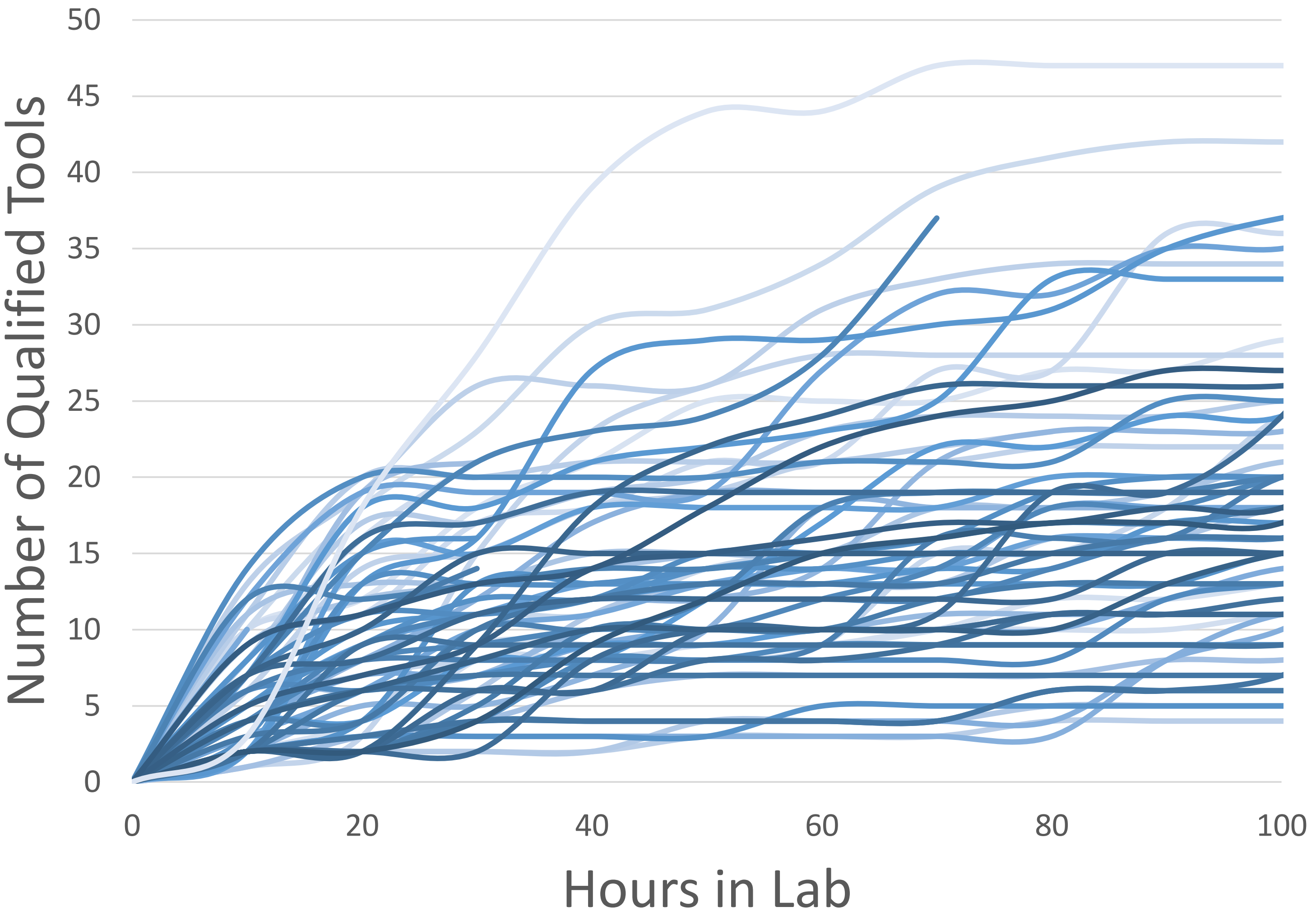
Immediate identification of requirements and who is qualified

Training request, completion, and qualification dates all captured

Quick Demo

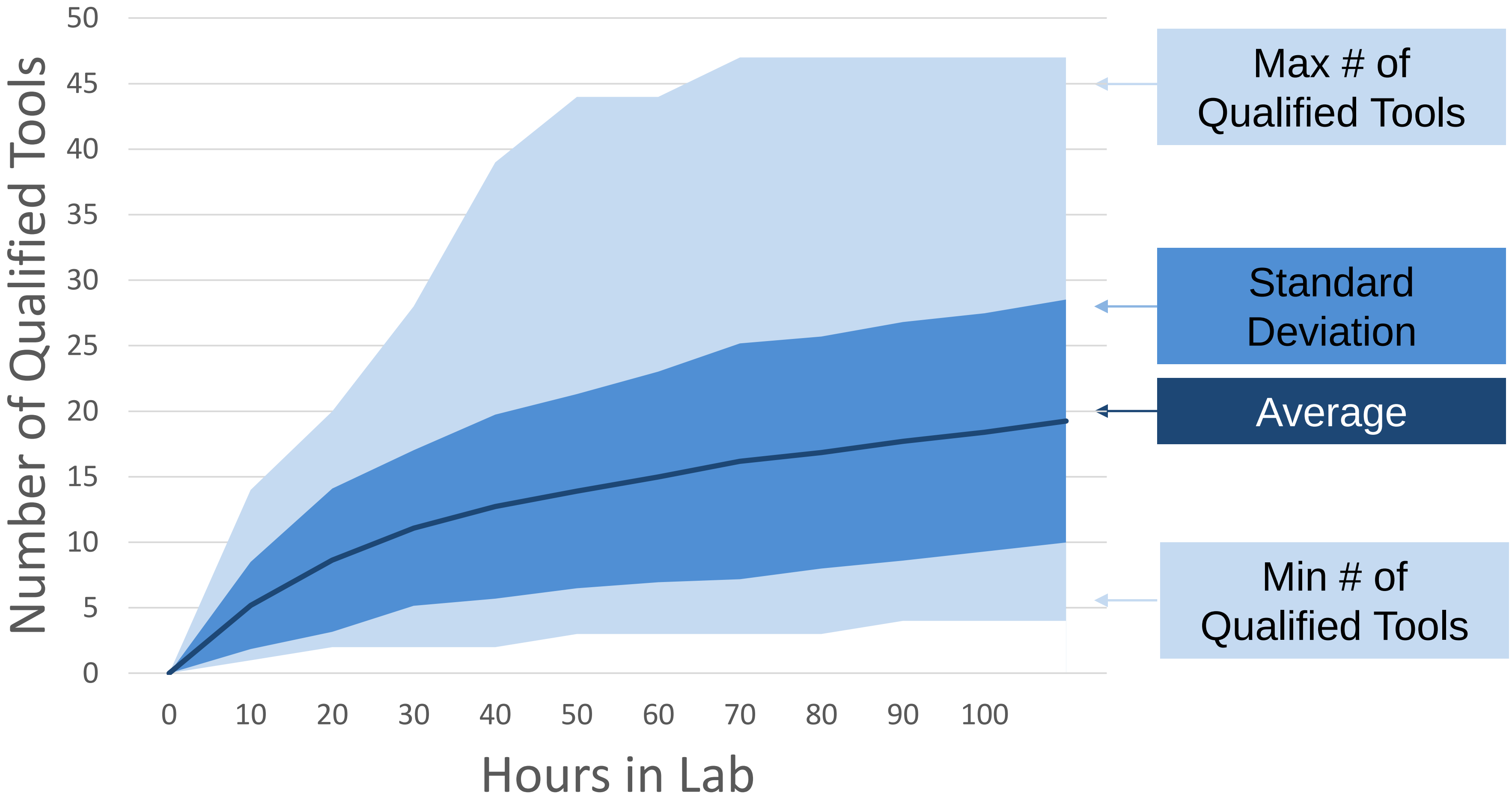
NanoLab Learning Curve

Cumulative sums of number of tools a given lab member is qualified on

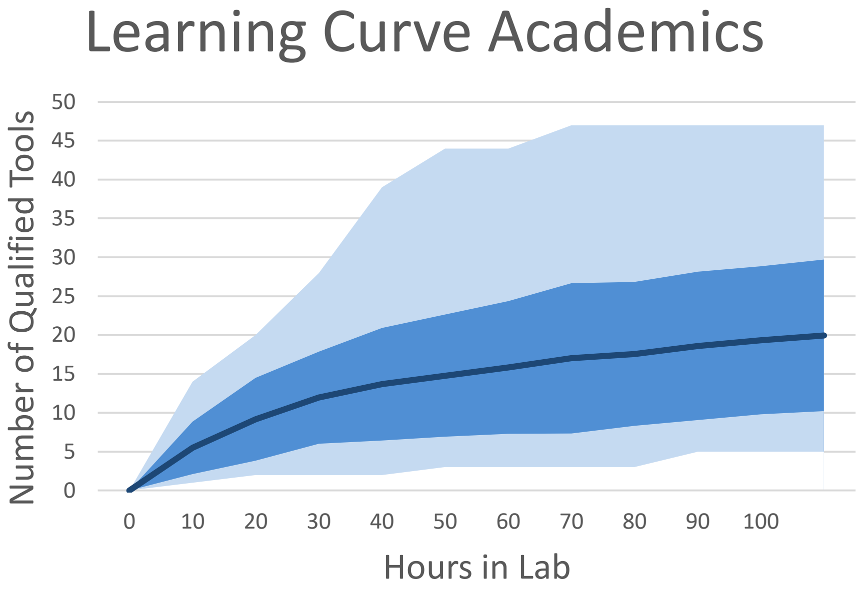


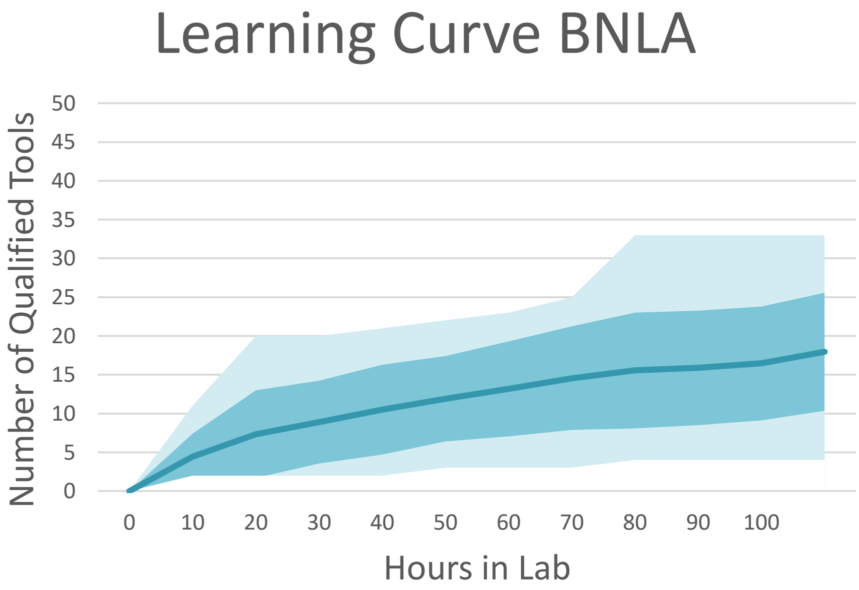
NanoLab Learning Curve

75 members' Lab History and Qualification Records examined to generate a lab-wide "learning curve"



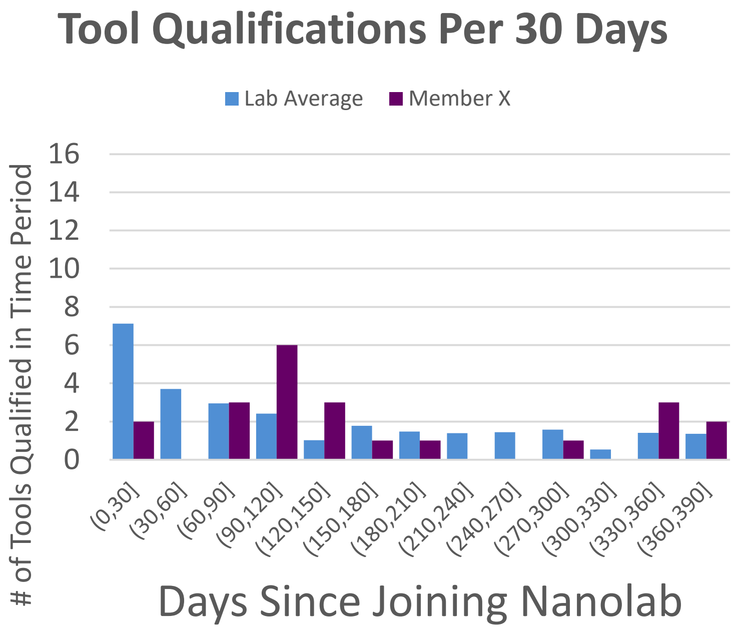
Learning Curve – Academic vs BNLA

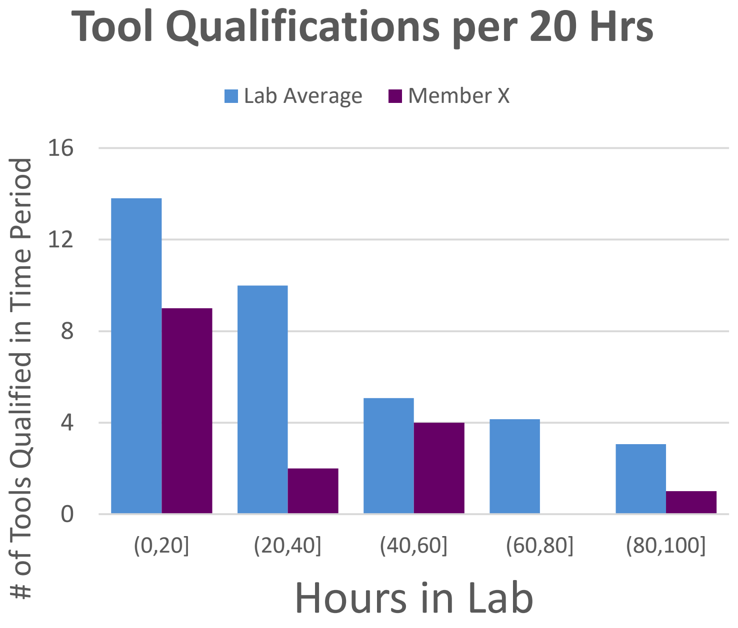




NanoLab Equipment Qualification - Bin Data

Number of qualifications in a given time period
Avg (N=75) and for Member X





Days since Orientation means little… time spent in the lab is the key

With only 20hours labtime, average member is qualified on 14 tools

Analysis thanks to
Allison Dove

Sample Information at a Glance
The NFPA Diamond

Introducing the
Berkeley NanoLab Wafer or The BNW

Persistent
Special Containment Required
Unresolved by Standard Process

Reactable
Self-Containing OR
Standard Processes Immune

Kinetic
Uncontainable and/or
Unresolvable

Organic
Minimally interactive
Easily decontaminated

Contamination Severity Level:
4 = Exposed Layer
3 = Contained Layer
2 = Residual Contamination
1 = Cleaned (after exposure)
0 = Never Present

Substrate Definition:

Determines dopants &
contamination controls

Kinetic Contamination

Contamination that moves!

Defined by mass transport mechanisms:

- Diffusivity in silicon ≥ 1E-15 cm^2/s @ 185 °C
    - Diffuses 100nm in ~15 minutes
- Maximum vapor pressure ≥ 1E-10 Torr at 594 °C
    - 1 Monolayer formed per 330 minutes @ 594 °C
    - (Aluminum used as reference material)
- Melting point ≤ 594 °C
    - (Aluminum used as reference material)

Considerations for protecting tools:

- Total system separation required for process chambers - Kinetics are not capable of being contained reliably
- Consumable shielding can work for some tools
- Never, ever, allowed in a furnace without considering furnace permanently contaminated

Persistent Contamination

Materials that require engineering review.
Defined by falling into “grey areas”:

Thermal Budget:

- Diffusivity in silicon grows beyond 1E-15 cm^2/s between 185 °C - 461 °C
- 1E-10 Torr vapor pressure and melting point lands between Aluminum and Silicon

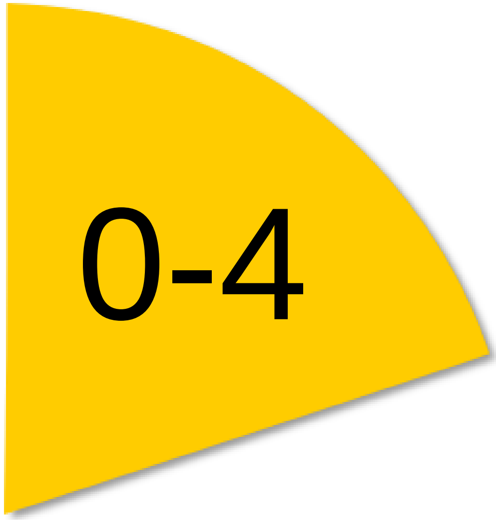
Chemical Resistance

- Difficult to remove reliably via cleaning processes

Considerations for protecting tools:

- Often viable to contain under layers of other material
- Secondary containment of process vessel can protect overall system
- Furnace exposure requires active engineering review and special process approval

Reactable Contamination



Materials that are safe for most processing

Defined by self-containment in standard processes

Thermal Budget:

- Low diffusivity in silicon at furnace temperatures
    - Typically form silicides and/or kick-out diffuse
- Low vapor pressure (≤ 1E-10 Torr at 872 °C)
- High melting point (≥ Silicon)

Cleanup:

- Easily neutralized via standard process in cleaning/etch
- Can be buried under standard process in deposition

Why they’re called out separately:

- Can still contaminate via bombardment mechanisms, still need to be buried in some scenarios.

Organic Contamination

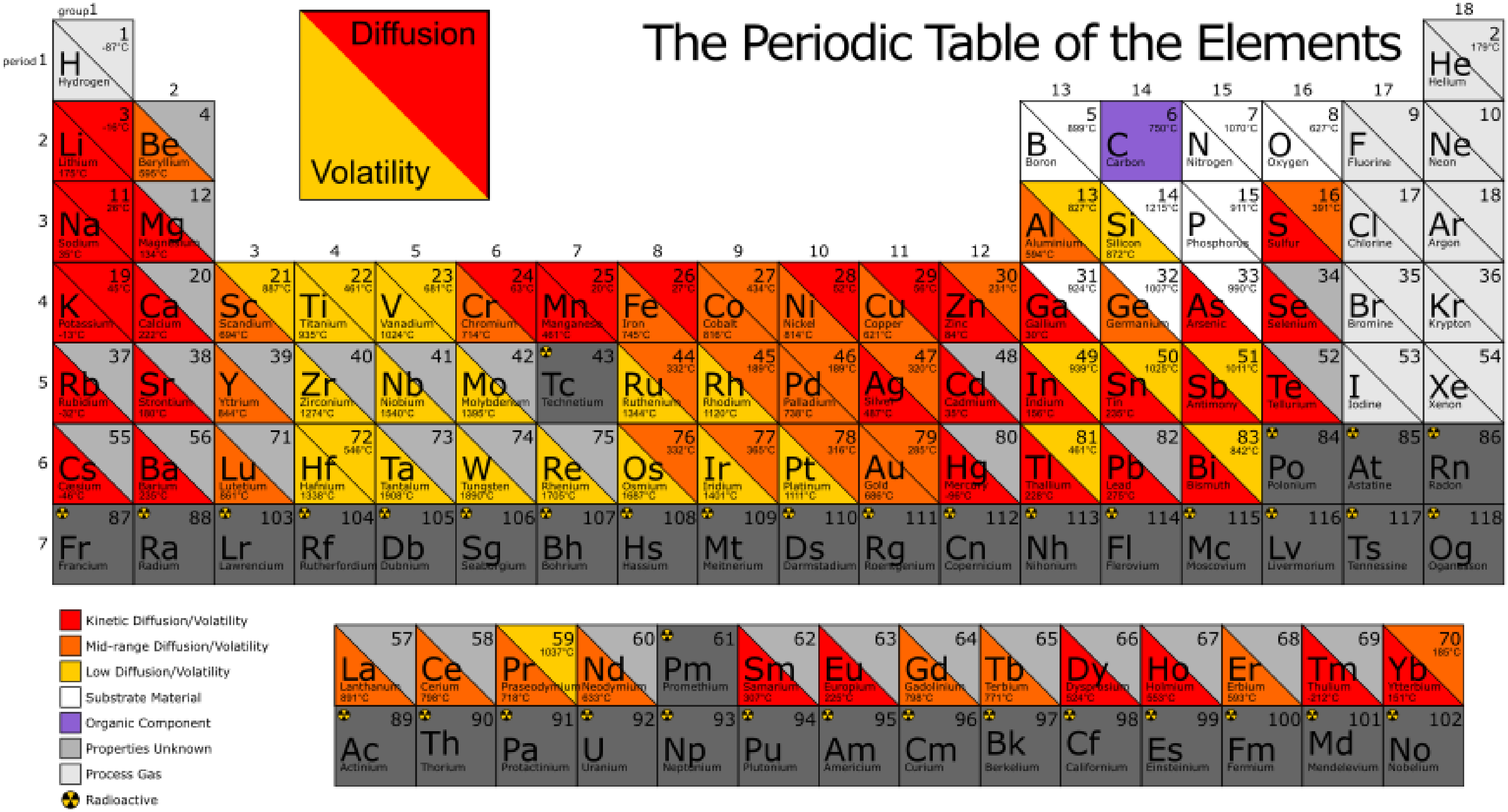
Materials primarily composed of carbon and weakly bonded

Thermal Budget:
- Generally kept under 200C
- Special Case: If brought above 250C, will decompose to graphite and potentially turn into serious Persistent contaminant

Chemical Resistance
- Easily removed by most solvents
- Removed by Oxygen plasma - Required for etch byproduct

Considerations for protecting tools:
- Never enter a furnace above a severity of 1
- Must be soft-baked prior to vacuum exposure
- If in doubt, clean the substrate. Organic cleans tend not to damage the substrate or pose substantial risk to tools.

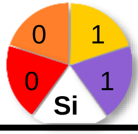
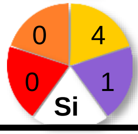
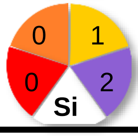
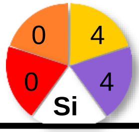
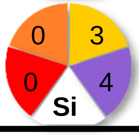
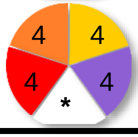
Now apply those criteria to all elements



Initial classification based on volatility and diffusivity (in Si).
Solubility in water also considered, but not used.

Q: What is the plan for this notation

A: Consistent ID for all equipment

Tool	Written Notation	Graphical Notation
Gate oxide tube	(Si,0,0,1,1)	
"Semi-clean" process tube	(Si,0,0,4,1)	
Initial piranha clean	(Si,0,0,1,2)	
Photoresist strip bath	(Si,0,0,4,4)	
Poly-Si gate etch	(Si,0,0,3,4)	
General-use plasma RIE	(*,4,4,4,4)	

Color Key:
Kinetic
Persistent
Reactable
Organic

Contamination Severity Number:
4 = Exposed Layer
3 = Buried Layer
2 = Residual Contamination
1 = Cleaned (after exposure)
0 = Never Present

Academic Recharge Rates

Fiscal Year	**FY 2019**	**FY 2020**	
Access Fee per month	**$84.90**	**$84.00**	**- 1%**
General Laboratory Rate	**$43.20/hr** *Cap: $1,400.00/month*	**$42.60** *Cap: $1,400.00/month*	**- 3%** **0%**
Special Equip Rate Tier 1 *wire bonder, HF vapor, polymer, metrology*	***Tier 1*: $21.00/hr** *Tier 1 cap: $200.00 / month* *Rate over Tier 1 Cap: $0/hr*	***Tier 1*: $21.00/hr** *Tier 1 cap: $200.00 / month* *Rate over Tier 1 Cap: $0/hr*	**0%** **0%** **0%**
Special Equip Rate Tier 2 *LPCVD, PECVD, DRIE, general purpose SEM*	***Tier 2*: $43.80/hr** *Tier 2 cap: $1,400.00/month* *Rate over Tier 2 cap: $5.70/hour*	***Tier 2*: $43.80/hr** *Tier 2 cap: $1,400.00/month* *Rate over Tier 2 cap: $5.70/hour*	**0%** **0%** **0%**
Special Equip Rate Tier 3 DUV, 50kV,130kV ebeam litho SEM, epi-SiGe	***Tier 3:* $61.80/hr** *Tier 3 cap*: $1,500.00/month *Rate over Tier 3 cap*: $19.00/hour	***Tier 3:* $ 60.00/hr** *Tier 3 cap*: $1,500.00/month *Rate over Tier 3 cap*: $19.00/hour	**- 3%** **0%** **0%**
Special Equip Rate Tier 4 130 kV ebeam litho	**Tier 4: $84.00**	**Moved to Tier 3 ($60.00)**	**- 28%**
Staff Services	**$86.40**	**$87.00**	**+ 1%**

BNLA Recharge Rates

Fiscal Year	**FY 2019**	**FY 2020**		**Academic**
Access Fee per month	**$123.60**	**$124.00**	**<1%**	**$84.00**
General Laboratory Rate	**$49.20/hr** *Cap: $2,450.00/month*	**$51.60/hr** *Cap: $2,500.00/month*	**+ 5%** **+ 2%**	**42.60** ***$1,400***
Special Equip Rate Tier 1 *wire bonders, HF vapor, polymer, metrology*	***Tier 1*: $21.00/hr** *Tier 1 cap: NA*	***Tier 1*: $21.00/hr** *Tier 1 cap: NA*	**+ 3%** **----**	**$21.00** ***$200***
Special Equip Rate Tier 2 *LPCVD, PECVD, DRIE, general purpose SEM*	***Tier 2*: $54.00/hr** *Tier 2 cap: NA*	***Tier 2*: $54.00/hr** *Tier 2 cap: NA*	**0%** **----**	**$43.80** ***$1,400***
Special Equip Rate Tier 3 DUV, 50kV, 130kV ebeam litho SEM, epi-SiGe	***Tier 3:* $85.20/hr** *Tier 3 cap: NA*	***Tier 3:* $89.40/hr** *Tier 3 cap: NA*	**+ 5%** **----**	**$60.00** ***$1,500***
Special Equip Rate Tier 4 130 kV ebeam litho	**Tier 4: $186.60**	**Moved to Tier 3 ($89.40)**	**- 52%**	
Staff Services	**$86.40**	**$87.00**	**+ 1%**	**$87.00**

BNLA Annual Membership Fees
No Change

FY 18/19		FY 19/20	
Lab Members Per Company	**Annual Rates**	**Lab Members Per Company**	**Annual Rates**
1	**$18,500**	**1**	**$18,500**
2	**$28,500**	**2**	**$28,500**
3	**$38,500**	**3**	**$38,500**
4	**$42,500**	**4**	**$42,500**
5	**$55,000**	**5**	**$55,000**
6*	**$65,000**	**6 ***	**$65,000**

** Non-Core Access Program
- 6th member = restricted access
- max 20hours/month 10am – 8pm
- unlimited non-core 8pm – 10am

High Profile NanoLab Tours This Year

TSMC Chairman **Mark Liu**

2017 Emp 47,000 Rev $32B

TSMC applied for BNLA membership

Applied Materials CEO **Gary Dickerson**

2018 Emp 21,000 Rev $17B

AMAT joined as CITRIS partner $150K

AMAT renewed commitment 2 tools for NanoLab

Lam Research SVP **Vahid Vahedi**

2017 Emp 9,400 Rev $8B

Request for Lam membership under development

Party Secretary, Shenzhen **Wang Weizhong**

2017 Pop 13M GDP $361B

TBSI / NanoLab TBD

Summary

- Academic Rates kept flat or decreased
  - Overall membership stable; BNLA balance considered a priority
  - EECS, Physics, Mech Eng, MSE Dept use steady
  - 3 of the top 20 PIs from UCD and UCSF

- Modest increases to BNLA
  - Non-core hour access program avaialable, not used

- VCR, BNLA, and BETR investment in MaskLess Litho purchase

- NanoLab continues to expand services and capabilities
  - Efforts to streamline training continue; mechanism to collect data defined
  - New sputter tool released and in heavy demand
  - New contamination control notation under development

- High Profile Visits help – Thanks Tsu-Jae and Connie

The NanoLab responds to your issues and works to control your costs.

Berkeley Fire Department Annual Tour

The shared lab model is alive and well thanks to your support.

Thank you