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
The NanoLab 2018
Analysis of the Top 20

<table>
<thead>
<tr>
<th>Top 20 PIs by Dept</th>
<th>Δ</th>
<th>Financial</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS</td>
<td>11</td>
<td>↑1 All Academic</td>
<td>-$132 K</td>
</tr>
<tr>
<td>Mech Eng</td>
<td>3</td>
<td>↑1 Top 20 Academic</td>
<td>-$177 K</td>
</tr>
<tr>
<td>Chemistry</td>
<td>1</td>
<td>-1 All BNLA</td>
<td>-$6 K</td>
</tr>
<tr>
<td>Physics</td>
<td>2</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>MSE</td>
<td>1</td>
<td>-1 Top 10 Academic</td>
<td>&gt; $75K each</td>
</tr>
<tr>
<td>UCSF BioE</td>
<td>1</td>
<td>↑1</td>
<td></td>
</tr>
<tr>
<td>UC Davis EE</td>
<td>2</td>
<td>0 Top 10-20</td>
<td>&gt; $32K each</td>
</tr>
</tbody>
</table>
## Lab Members Historical Analysis

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

* ~25 service accounts removed from member count
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.

- 2\textsuperscript{nd} unit was \textit{completely} 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 < 4 months

They have ordered a 2nd system
### MLA150 System Specifications

<table>
<thead>
<tr>
<th>Writing performance</th>
<th>Write Mode I *</th>
<th>Write Mode II *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum structure size [μm]</td>
<td>0.6</td>
<td>1</td>
</tr>
<tr>
<td>Linewidth variation [3σ, nm]</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>Global 2nd layer alignment [3σ, nm]</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Local 2nd layer alignment [3σ, nm]</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Backside alignment [3σ, nm]</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Exposure time 405 nm laser for 4” wafer [min]</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>Exposure time 375 nm laser for 4” wafer [min]</td>
<td>35 6”: 78min</td>
<td>20</td>
</tr>
<tr>
<td>Max. write speed 405 nm laser [mm²/min]</td>
<td>285</td>
<td>1100</td>
</tr>
<tr>
<td>Max. write speed 375 nm laser [mm²/min]</td>
<td>285</td>
<td>500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System features</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Light source</td>
<td>Diode lasers: 8 W at 405 nm, 2.8 W at 375 nm, or both</td>
<td></td>
</tr>
<tr>
<td>Substrate sizes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable: 3 x 3 mm² to 6” x 6”</td>
<td>Optional: 8” x 8”</td>
<td>Customizable on request</td>
</tr>
<tr>
<td>Substrate thickness</td>
<td>0 - 12 mm</td>
<td></td>
</tr>
<tr>
<td>Maximum exposure area</td>
<td>150 x 150 mm²; optional: 200 x 200 mm²</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th># of tools</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Background information for a toolset Vacuum / Evap / Etch / SEM / EBL</td>
</tr>
<tr>
<td>51</td>
<td>Simplest tools. Any qualified member can qualify you</td>
</tr>
<tr>
<td>49</td>
<td>Tools that need a superuser signoff before you are qualified</td>
</tr>
<tr>
<td>82</td>
<td>Tools that have an online exam before you can request qualification</td>
</tr>
<tr>
<td>8</td>
<td>Tools with special requirements Read the manual for detailed procedure</td>
</tr>
</tbody>
</table>
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”

![Graph showing the learning curve with maximum, standard deviation, average, and minimum number of qualified tools over hours in the lab.](image)
Learning Curve – Academic vs BNLA

Learning Curve Academics

Learning Curve BNLA
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 20 hours labtime, average member is qualified on 14 tools

Analysis thanks to Allison Dove
Sample Information at a Glance
The NFPA Diamond

Hazardous Materials Classification

Health Hazard
4 — Deadly
3 — Extreme danger
2 — Hazardous
1 — Slightly hazardous
0 — Normal material

Fire Hazard
Flash Points
4 — Below 73 F
3 — Below 100 F
2 — Below 200 F
1 — Above 200 F
0 — Will not burn

Specific Hazard
Oxidizer OXI
Acid ACID
Alkali ALK
Corrosive COR
Use NO WATER
Radiation Hazard

Reactivity
4 — May detonate
3 — Shock and heat may detonate
2 — Violent Chemical change
1 — Unstable if heated
0 — Stable
Introducing the Berkeley NanoLab Wafer or The BNW

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

Si

Determines dopants & contamination controls

Substrate Definition:

- **Persistent**
  Special Containment Required
  Unresolved by Standard Process

- **Kinetic**
  Uncontainable and/or Unresolvable

- **Reactable**
  Self-Containing OR Standard Processes Immune

- **Organic**
  Minimally interactive Easily decontaminated
Kinetic Contamination

Contamination that moves!

Defined by mass transport mechanisms:
- Diffusivity in silicon $\geq 1E^{-15}$ cm$^2$/s @ 185 °C
  - Diffuses 100nm in ~15 minutes
- Maximum vapor pressure $\geq 1E^{-10}$ Torr at 594 °C
  - 1 Monolayer formed per 330 minutes @ 594 °C
    - (Aluminum used as reference material)
- Melting point $\leq 594$ °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

Detailed contamination Analysis
Allison Dove and Ryan Rivers
Persistent Contamination

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

Thermal Budget:
- Diffusivity in silicon grows beyond 1E-15 cm²/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 ($\leq 1E^{-10}$ Torr at $872 ^\circ C$)
- High melting point ($\geq$ 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 200°C
- Special Case: If brought above 250°C, 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

<table>
<thead>
<tr>
<th>Tool</th>
<th>Written Notation</th>
<th>Graphical Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate oxide tube</td>
<td>(Si,0.0.1.1)</td>
<td><img src="#" alt="Gate oxide tube" /></td>
</tr>
<tr>
<td>&quot;Semi-clean&quot; process tube</td>
<td>(Si,0.0.4.1)</td>
<td><img src="#" alt="Semi-clean process tube" /></td>
</tr>
<tr>
<td>Initial piranha clean</td>
<td>(Si,0.0.1.2)</td>
<td><img src="#" alt="Initial piranha clean" /></td>
</tr>
<tr>
<td>Photoresist strip bath</td>
<td>(Si,0.0.4.4)</td>
<td><img src="#" alt="Photoresist strip bath" /></td>
</tr>
<tr>
<td>Poly-Si gate etch</td>
<td>(Si,0.0.3.4)</td>
<td><img src="#" alt="Poly-Si gate etch" /></td>
</tr>
<tr>
<td>General-use plasma RIE</td>
<td>(*,4.4.4.4)</td>
<td><img src="#" alt="General-use plasma RIE" /></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>FY 2019</th>
<th>FY 2020</th>
<th>Academic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Fee per month</td>
<td>$123.60</td>
<td>$124.00</td>
<td>$84.00</td>
</tr>
<tr>
<td>General Laboratory Rate</td>
<td>$49.20/hr &lt;br&gt; <em>Cap: $2,450.00/month</em></td>
<td>$51.60/hr &lt;br&gt; <em>Cap: $2,500.00/month</em></td>
<td>+ 5% &lt;br&gt; + 2%</td>
</tr>
<tr>
<td>Special Equip Rate Tier 1</td>
<td>Tier 1: $21.00/hr &lt;br&gt; <em>Tier 1 cap: NA</em></td>
<td>Tier 1: $21.00/hr &lt;br&gt; <em>Tier 1 cap: NA</em></td>
<td>+ 3% &lt;br&gt; ----</td>
</tr>
<tr>
<td>Special Equip Rate Tier 2</td>
<td>Tier 2: $54.00/hr &lt;br&gt; <em>Tier 2 cap: NA</em></td>
<td>Tier 2: $54.00/hr &lt;br&gt; <em>Tier 2 cap: NA</em></td>
<td>0% &lt;br&gt; ----</td>
</tr>
<tr>
<td>Special Equip Rate Tier 3</td>
<td>Tier 3: $85.20/hr &lt;br&gt; <em>Tier 3 cap: NA</em></td>
<td>Tier 3: $89.40/hr &lt;br&gt; <em>Tier 3 cap: NA</em></td>
<td>+ 5% &lt;br&gt; ----</td>
</tr>
<tr>
<td>Special Equip Rate Tier 4</td>
<td>Tier 4: $186.60</td>
<td>Moved to Tier 3 ($89.40)</td>
<td>- 52%</td>
</tr>
<tr>
<td>Staff Services</td>
<td>$86.40</td>
<td>$87.00</td>
<td>+ 1%</td>
</tr>
</tbody>
</table>

*May 9, 2019*
### BNLA Annual Membership Fees

**No Change**

<table>
<thead>
<tr>
<th>FY 18/19</th>
<th>FY 19/20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lab Members Per Company</strong></td>
<td><strong>Annual Rates</strong></td>
</tr>
<tr>
<td>1</td>
<td>$18,500</td>
</tr>
<tr>
<td>2</td>
<td>$28,500</td>
</tr>
<tr>
<td>3</td>
<td>$38,500</td>
</tr>
<tr>
<td>4</td>
<td>$42,500</td>
</tr>
<tr>
<td>5</td>
<td>$55,000</td>
</tr>
<tr>
<td>6*</td>
<td>$65,000</td>
</tr>
</tbody>
</table>

**Non-Core Access Program**
- 6th member = restricted access
- max 20 hours/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 available, 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.

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

Thank you