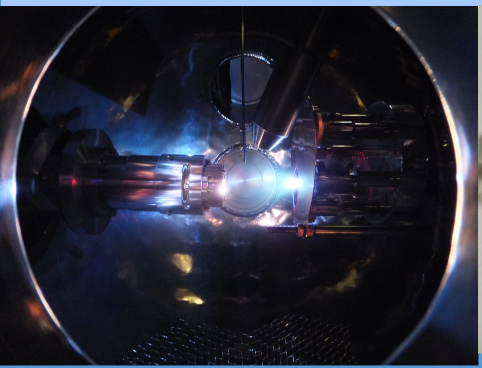
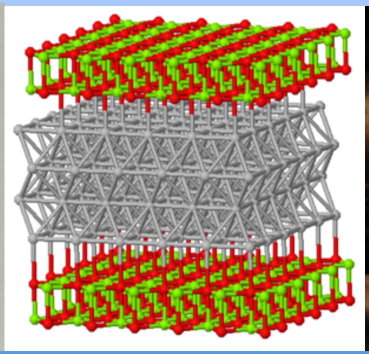
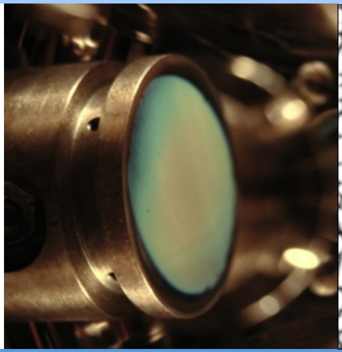
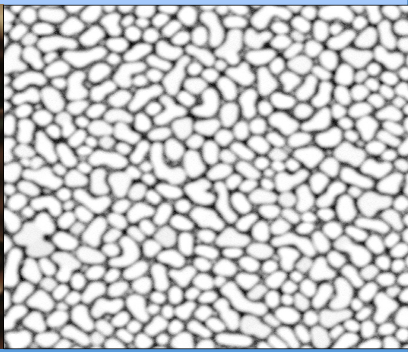
EWPAA – Berlin 2017

Photocathode design using condensed matter methods



John Zasadzinski, Jeff Terry, Linda Spentzouris, Zikri Yusof, Eric Wisniewski, Károly Németh
Mark Warren, Daniel Velázquez, Katherine Harkay, Jiahang Shao, Wei Gai, John Power
Noah Samuelson, Zhengrong Lee, Adam Denchfield, Rachel Seibert, Javier Cardenas

Argonne NATIONAL LABORATORY

ILLINOIS INSTITUTE OF TECHNOLOGY

Hybrid Superconducting Photocathodes on Niobium for higher QE

Two Approaches:

1) Superconductor/Normal metal thin film to exploit proximity effect (Nb/Mg)

Advantages:

- Proximity effect, should look like Nb
- Robust in air, can make replaceable plug
- Sharper electron pulse with metal

Disadvantage

- QE ~0.1% (still high for a metal)

2) Superconductor/Semiconductor thin film - Exploit RF transparency of semiconductors (Nb/Cs_2Te)

Advantages:

- Starting with QE ~ 13%
- Can reduce thickness to < 15Å or lower

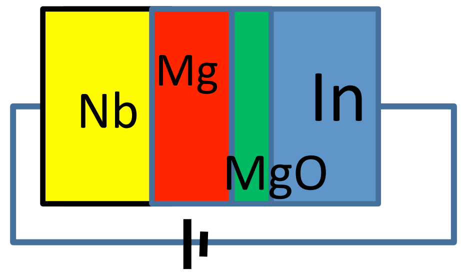
Disadvantage

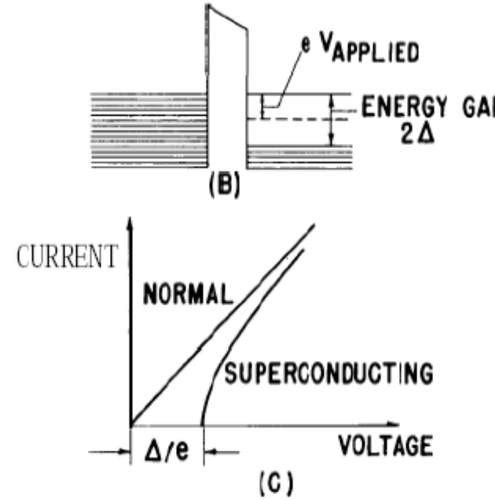
- Cannot expose to air

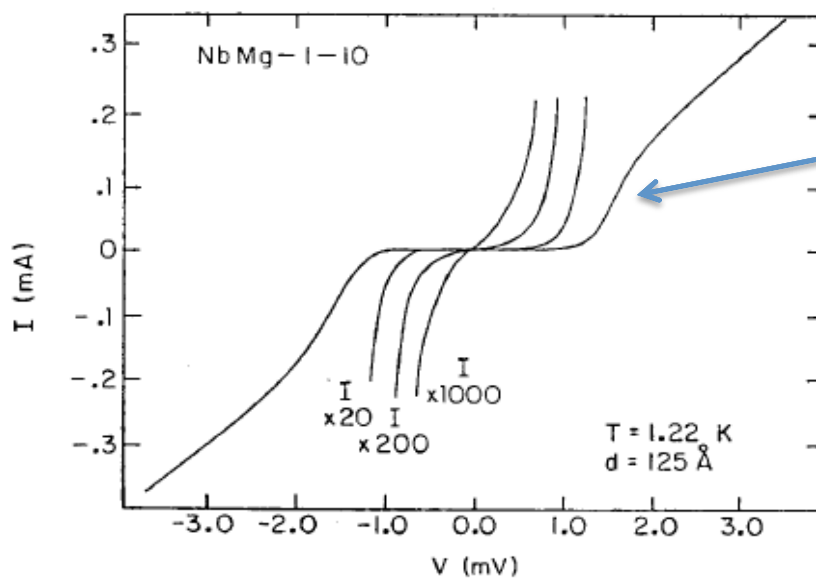
M. Warren, Z. Yusof, J. Zasadzinski, L. Spentzouris, N. Samuelson, A. Denchfield, W. Gai, E. Wisniewski, J. Shao., Proceedings of SRF2017, Lanzhou, China, MOPB065 (2017).

Mg/Nb cathodes, proximity effect

- Mg is an ideal proximity effect candidate
- at 12.5 nm, Mg behaves like the Nb superconductor
- Ideal bulk Mg has a 0.1% QE which is higher than both Nb and Pb







Tunneling into Mg but Nb gap Observed (1.5 mV)

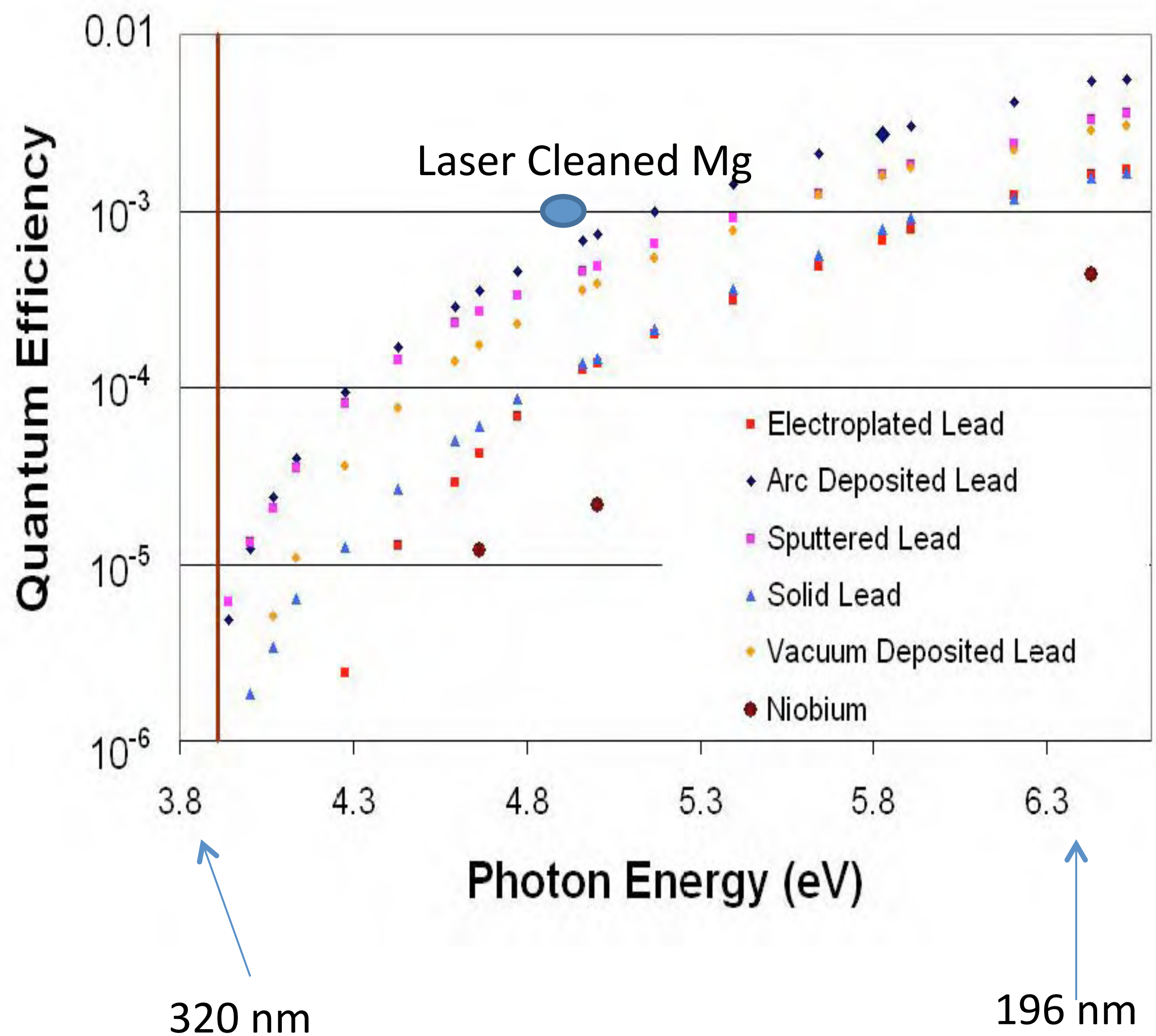
D.M. Burnell, E.L. Wolf, J. Low Temp. Phys., 58, 61 (1984)

Previous Work on SC photocathodes

- Pb has been studied
- We're looking for a PC with at least 0.1% QE at 250 nm (5 eV)
- Consider Nb/Mg

Nb-Pb SUPERCONDUCTING RF-GUN[1]

J. Sekutowicz, J. Iversen, D. Klinke, D. Kostin, W.-D. Möller, DESY, Hamburg, Germany
I. Ben-Zvi, A. Burrill, J. Smedley, T. Rao, BNL, Upton, NY 11973, USA



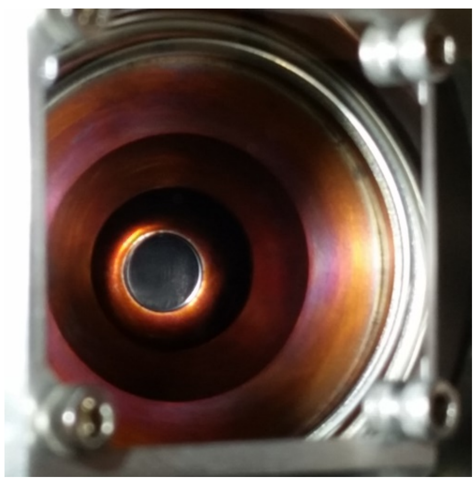
Fabrication of Nb Cathode with Mg Thin Film

High gradient measurements done at Argonne Wakefield Accelerator Facility test gun

3.0 mm thick Nb (99.95 purity)
UHV anneal at 600C for 10 hours
In-situ vapor deposition of Mg after cooldown
Mount Nb/Mg plug to Cathode test assembly

Nb/Mg cathode

Gun without cathode



Preliminary Kelvin probe data

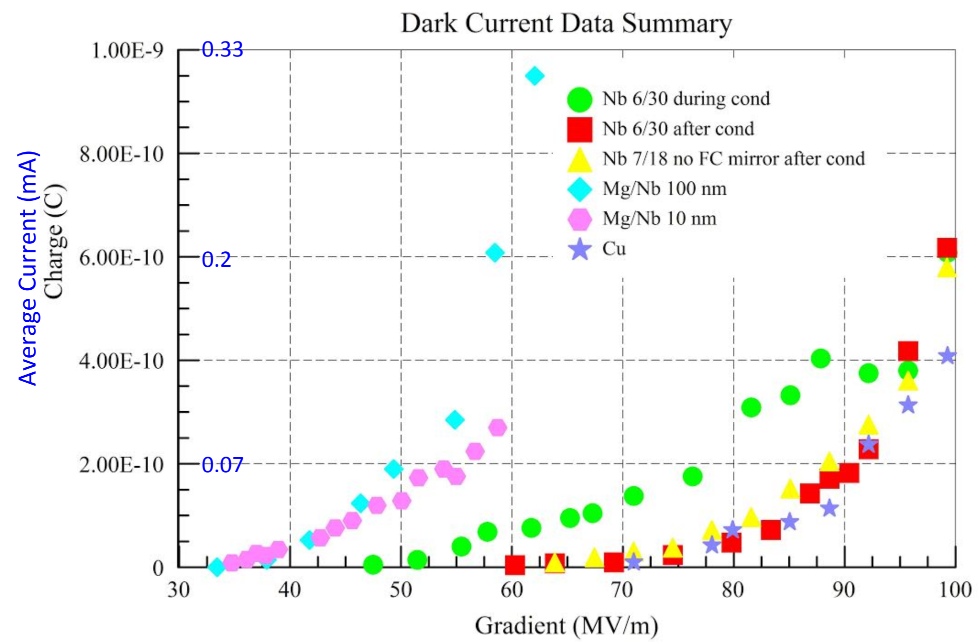
Table 1: Measured values of Nb/Mg

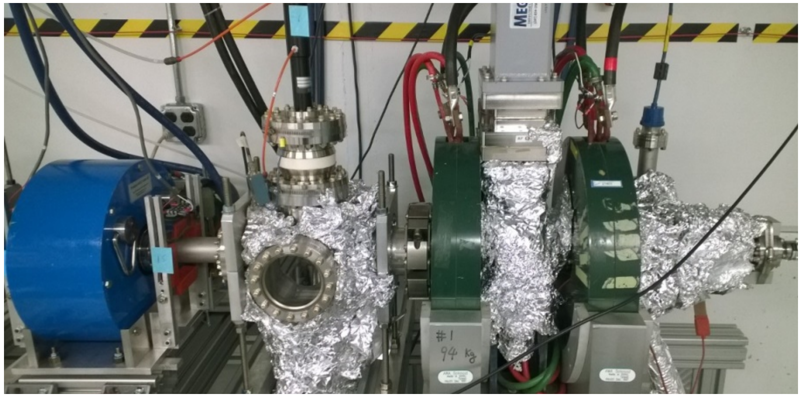
Mg Film Thickness (nm)	QE	Work Function (eV)
0*	1×10^{-6}	4.1
10	1.5×10^{-5}	3.81
100	9.0×10^{-5}	3.7

Thickness chosen for proximity effect
Two orders of magnitude better with no surface treatment

Dark Current Results for Nb and Nb/Mg

No Serious Degradation of Mg film up to 60MV/m



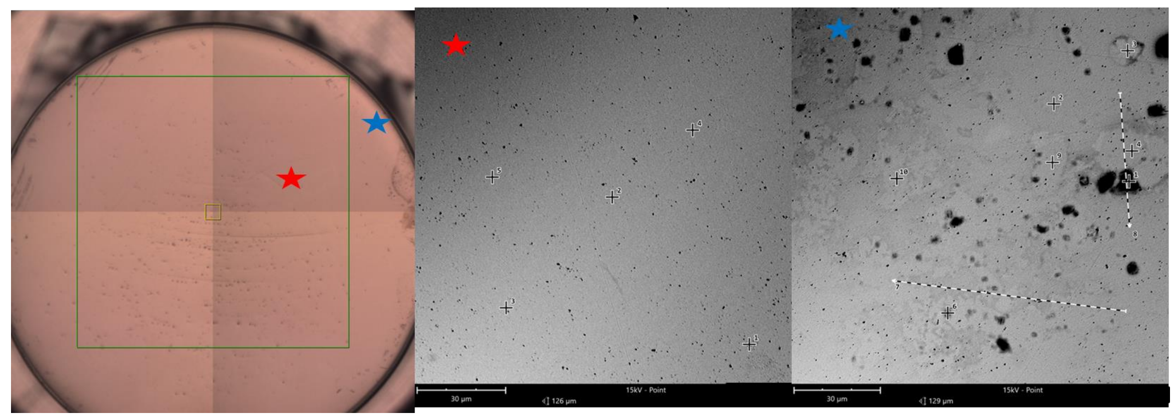


1.3 GHz gun
RF pulse length 5 μs
Effective pulse length several μs
Faraday Cup for charge measurement

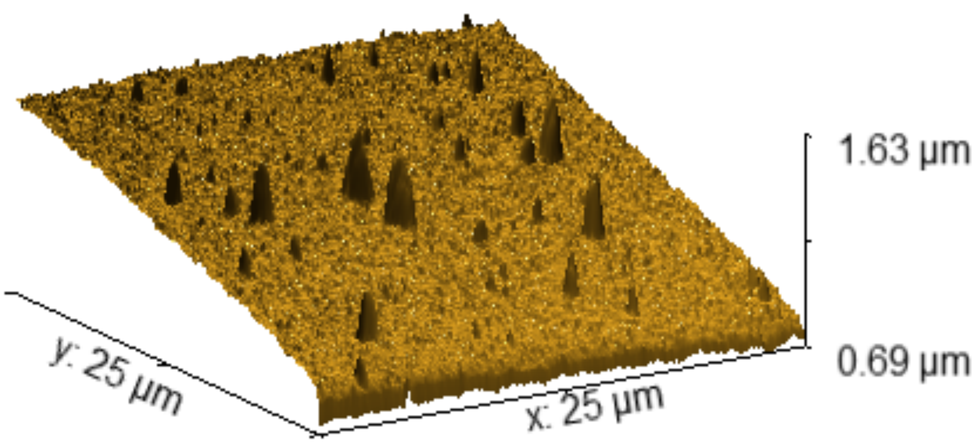
Improvement is straight-forward

Nb/Mg SEM Post-Conditioning

Much worse near edge (seam with gun)



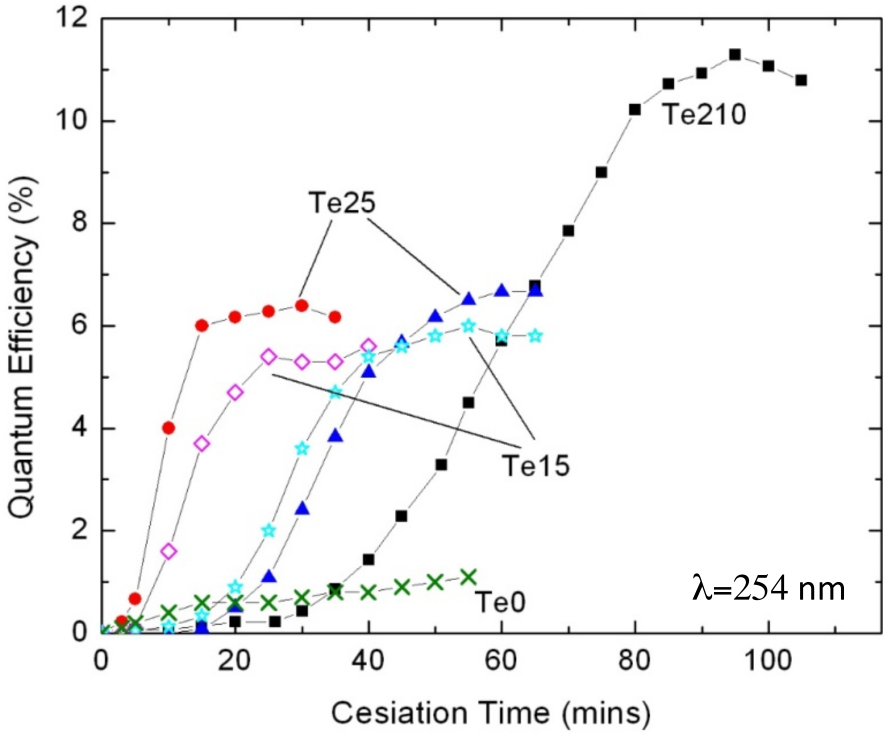
AFM Topography of Nb/Mg (10 nm)



Now: 1 μm diamond slurry polish
Future: Single crystal growth of Nb (or flat grained polycrystal) Followed by Mg deposition

Nb Foils in UHV resistively heated to melting point make large crystallites ~ mm to 1 cm.

Nb Coated with Cs_2Te



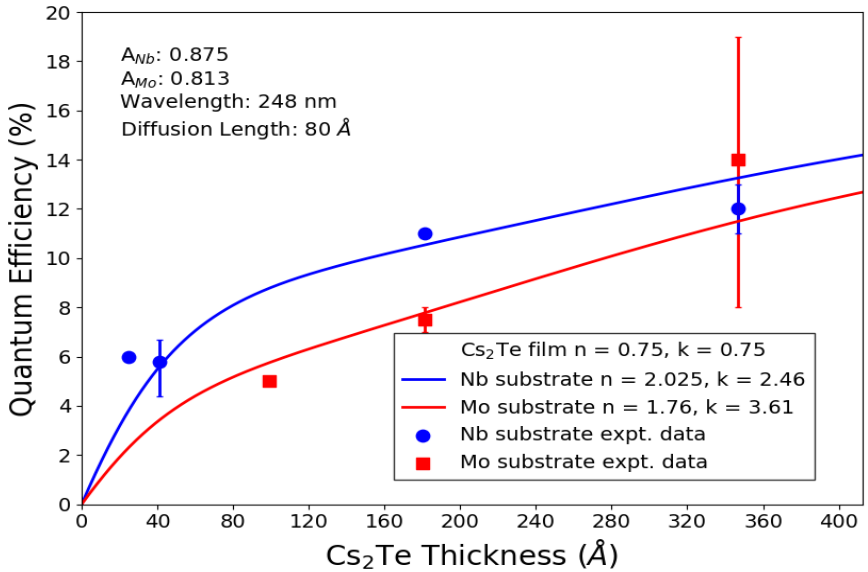
Te25 means Cs deposition performed on
a 25 Å tellurium film, and similarly for others

- **QE close to standard recipe of Cs_2Te on Mo**
- **QE maintains 5-7% for ultra-thin layers (1.5 nm)**
- **Cesiated Nb has QE<1%**

Semiconductors have low carrier density
-> skin depth is much greater than film thickness
-> very low loss in ultra-thin coating

Zikri Yusof, Adam Denchfield, Mark Warren, Javier Cardenas, Noah Samuelson, Linda Spentzouris, and John Zasadzinski (submitted: Phys.Rev.AB)

Modeling of QE vs. Cs_2Te Thickness



Phenomenological model based on Spicer 3-step model.

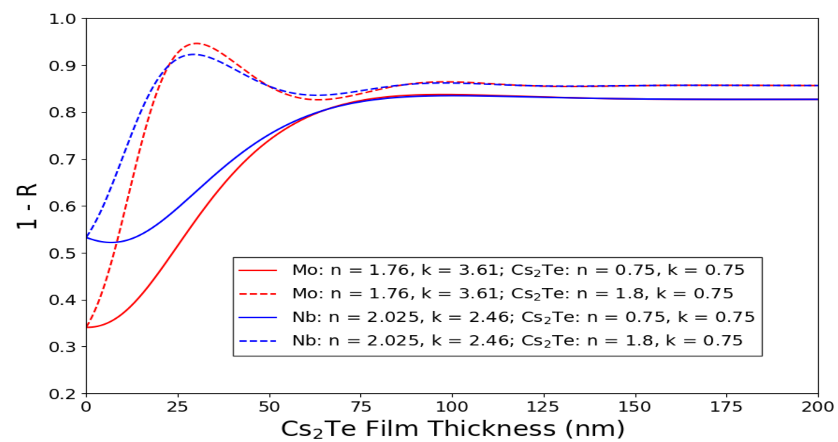
$$QE = A(1-R)\left(\frac{1}{1+\frac{1}{\alpha L}}\right)$$

$1/\alpha$=28 nm

If d<L, L=d : If d>L, L=8 nm

A=(α_{PE}/α)P_E : Adjustable parameter Obtained from fit

Transmission 1-R determined By Fresnel equations and Indices of refraction n+ik for Nb, Mo, Cs_2Te



Future work

Nb/Mg

- Change fabrication (single crystal Nb substrate) to improve emission.
- Surface treatments to improve QE.
- **Test in a superconducting gun! Takers?**

Nb/Cs_2Te

- Develop vacuum transport
- Investigate coating layers to make cathode more robust in air

Alternative superconductors

- Nb/Nb3Sn/Mg
- Investigate new bulk superconductors

  Desirable properties such as low reflectivity [large (1-R)],
  or low carrier density + high electron-photon coupling potential

Emission studies of multilayer structures

Goal: Improving emission by detailed control of fabrication

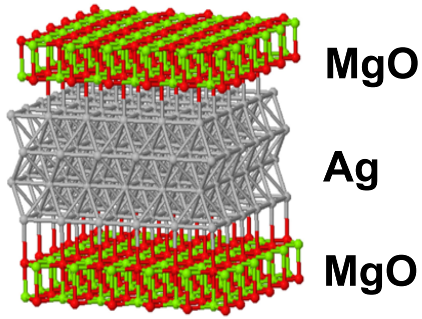
- DFT models indicate that, besides improving work function, MgO layers on Ag favorably influence shape of surface bands, and could impact intrinsic emittance

- Carefully fabricate MgO/Ag/MgO epitaxial surfaces of varying MgO thickness and compare emission parameters to predictions

MgO/Ag(001)/MgO: Modify emission properties via layer thickness

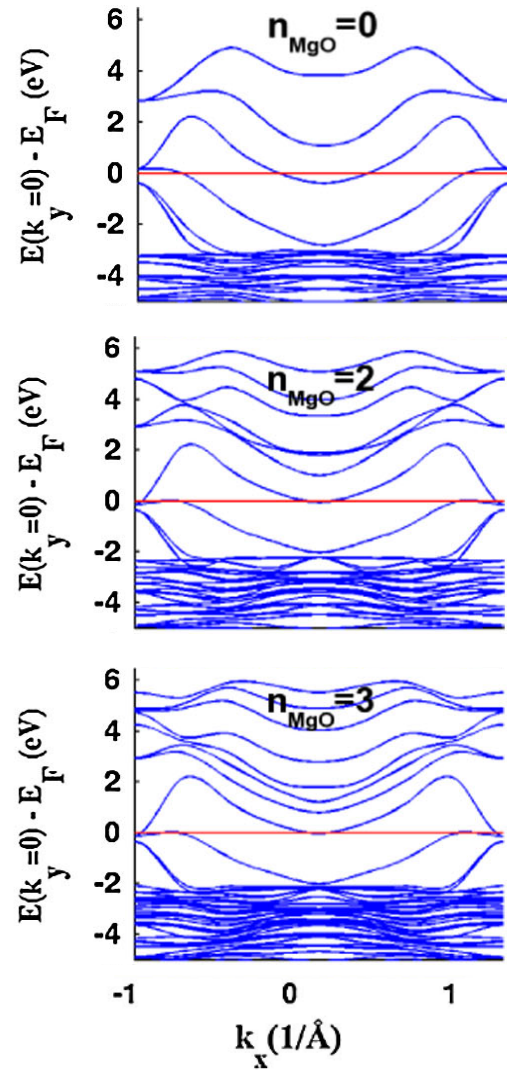
Model:
4 ML of Ag(001)
flanked
by *n* ML of MgO

1 ML ~ 0.2 nm

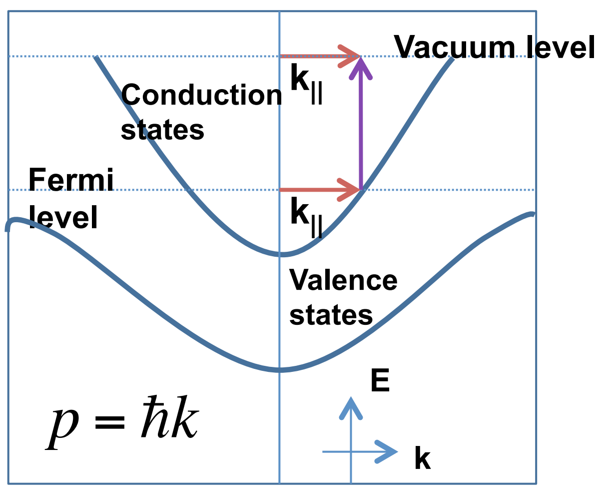


Courtesy K. Nemeth.

E_{band} versus k_x for n=0,2,3
Red line is Fermi level.



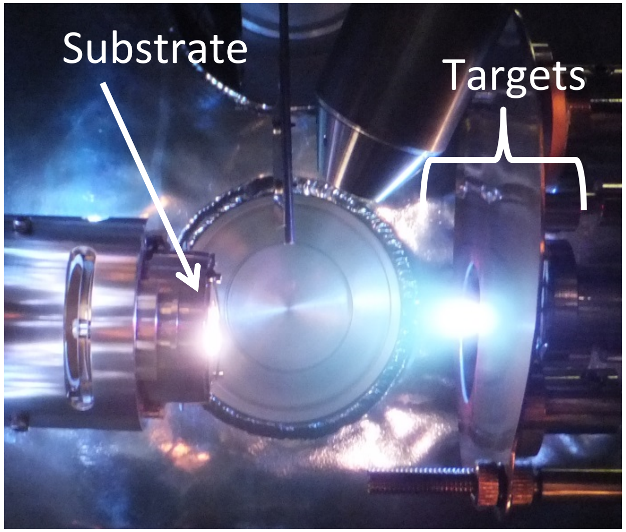
Band structure depends on MgO layer thickness:
The number *n* of monolayers modifies location in k-space where the valence band crosses the Fermi level.



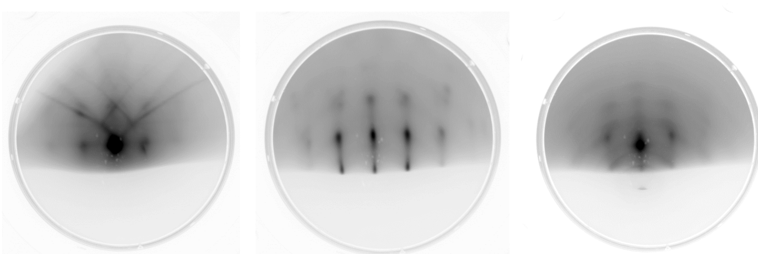
K. Nemeth, K. Harkay, M. Veenendal, L. Spentzouris, M. White, K. Attenkofer, G. Srajer, Phys. Rev. Lett. 104, 046801, 2010.

MgO/Ag(001)/MgO fabrication via Pulse Laser Deposition

Precision epitaxial deposition

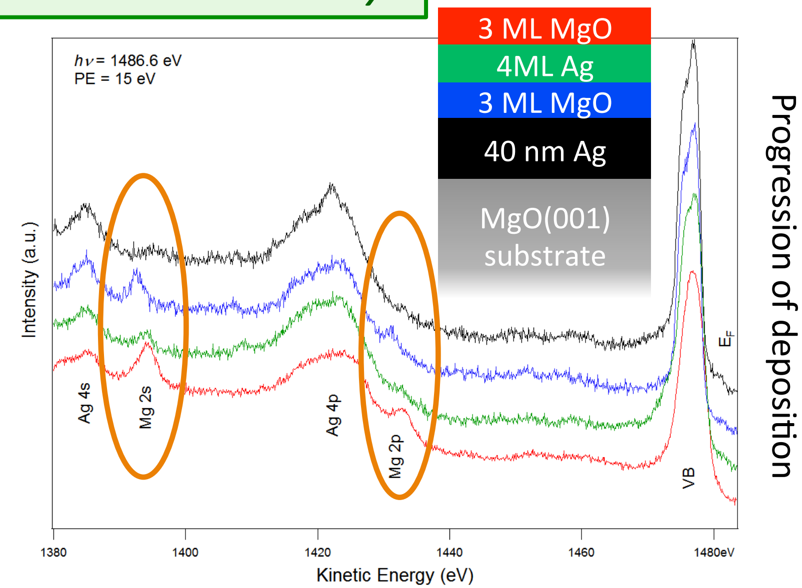


Calibrated Quartz Crystal Microbalance system to ***control deposition thickness*** to within a monolayer

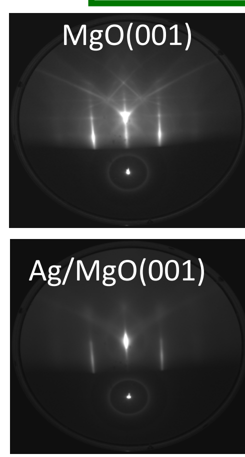


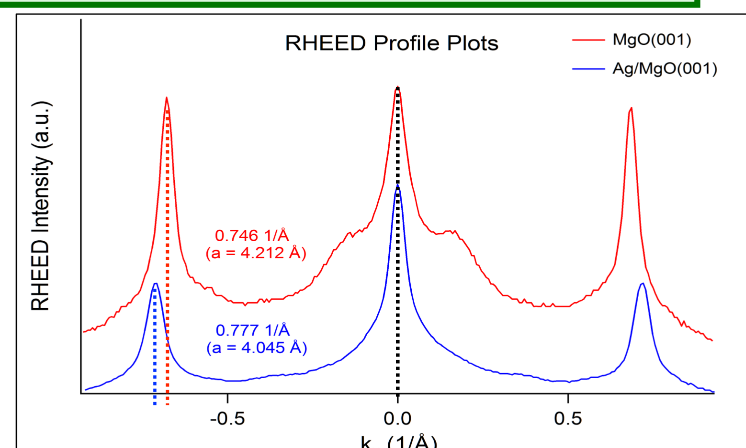
Mg(001) Ag-Mg(001) Mg-Ag-Mg(001)

XPS to check chemistry



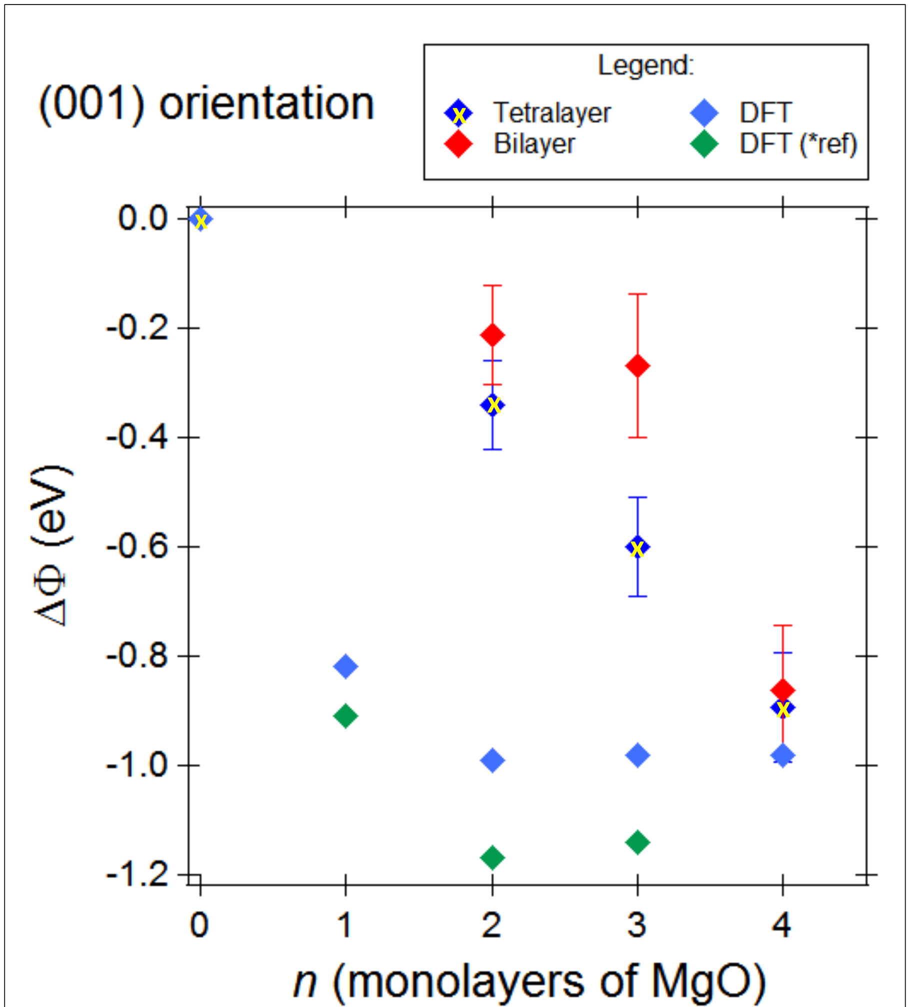
Diffraction monitors crystal growth





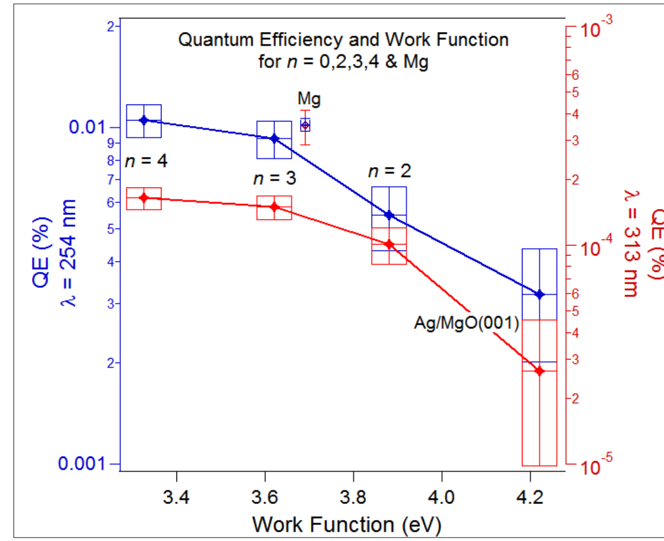
Work function and quantum efficiency versus MgO layer thickness

Kelvin (2mm) probe: Work function change vs. MgO thickness compared to uncoated Ag



1 ML ~ 0.2 nm

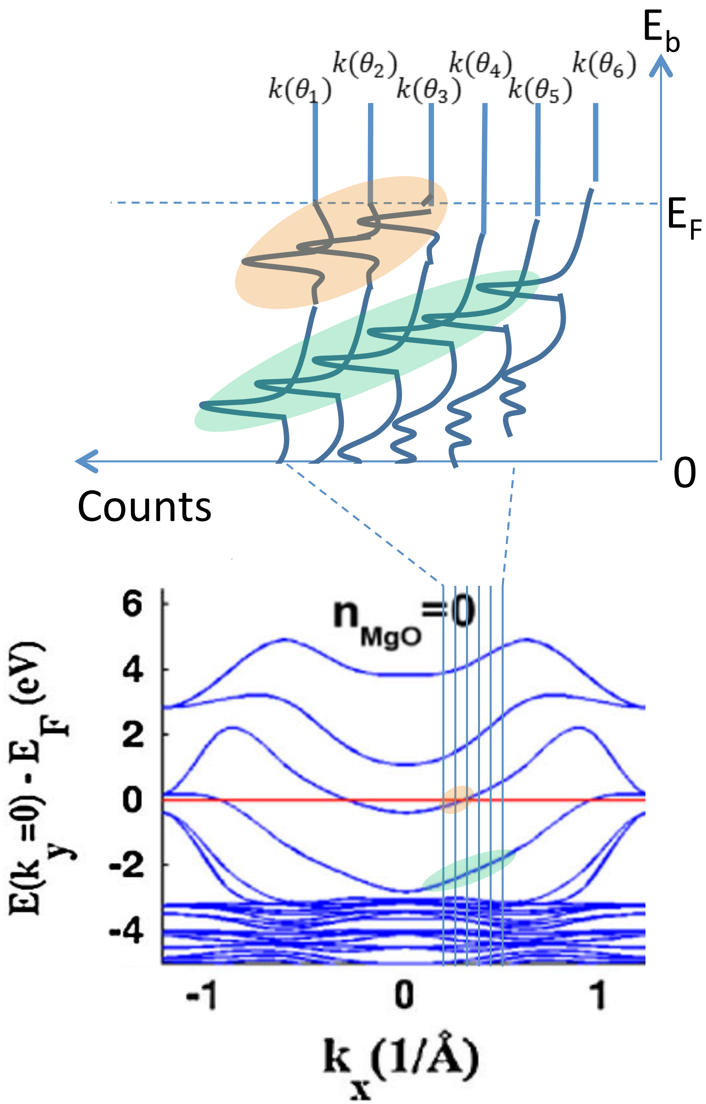
QE and work function for different MgO thickness



<- Work function drops more linearly on fabricated samples compared to DFT prediction.

D. Velazquez, R. Seibert, H. Ganegoda, D. Olive, A. Rice, K. Logan, Z. Yusof, J. Terry, L. Spentzouris, *Applied Surface Science*, **360**, p. 762-766, (2016).

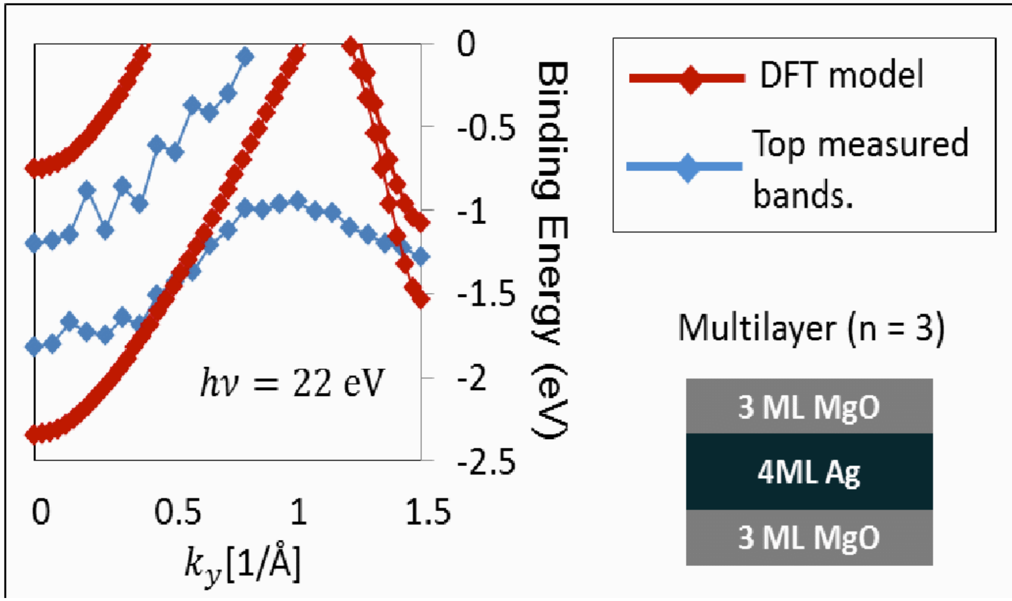
In quest of band structure and emittance:
Angle-Resolved Photo Electron Spectroscopy (ARPES)



Energy Distribution Curves taken at different angles are correlated with crystal momentum. Angle of emission gives surface parallel momentum of photoelectrons.

Band structure is formed by a cumulative of EDCs at different fixed angles/momenta

Band structure reconstruction from data (n=3)



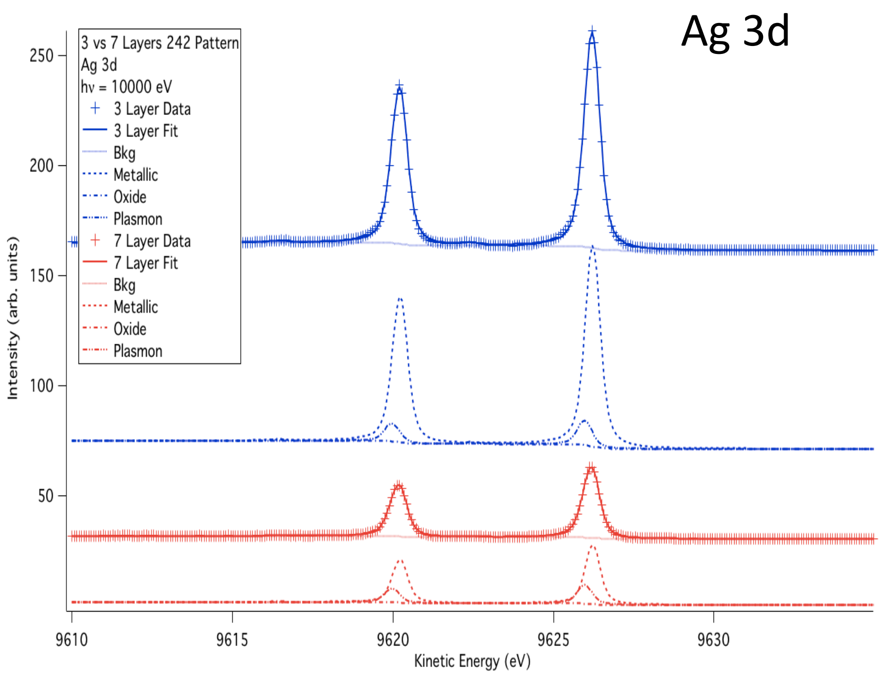
Hard X-ray photoelectron spectroscopy data on MgO/Ag/MgO

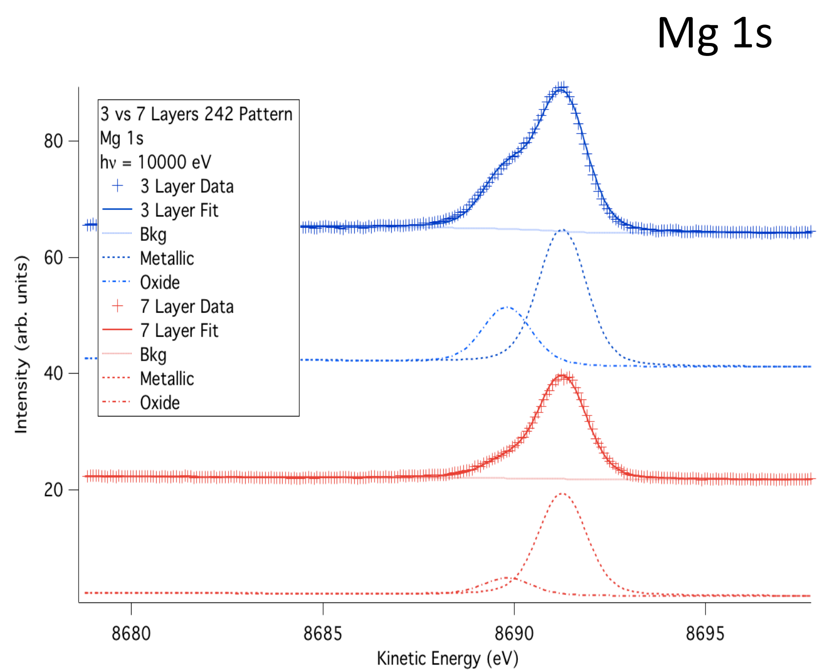
Can the chemistry/roughness of the interface explain the QE/WF data?
How does the chemistry of the interface depend on its roughness?

Blue: 3 monolayers of MgO
Red: 7 monolayers of MgO

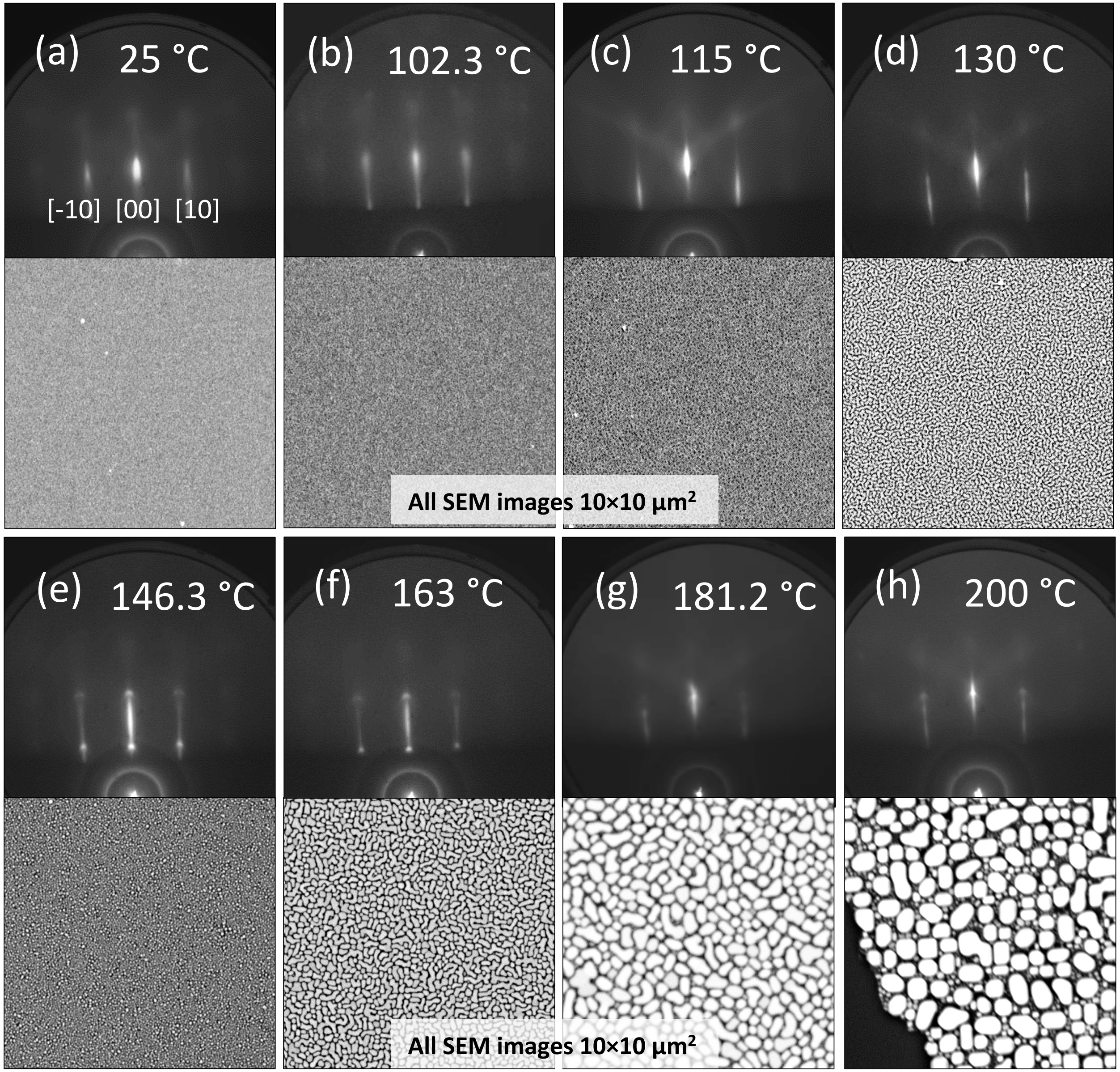
7 ml -> More silver-oxide bonds
Fewer Mg-oxide bonds

Diffusion?
Roughness?





Ag film growth at various substrate temperatures: Ag/MgO(001)



It is possible to control surface morphology reproducibly via substrate temperature (PLD fabrication)

Fundamental emission studies

- WF and QE vs. surface roughness (check against models)
- Interface chemistry vs. surface roughness
- Interface chemistry vs. layer thickness
- Thin layers at high gradients (dark current, survivability)
- Band structure and emittance vs. layer thickness