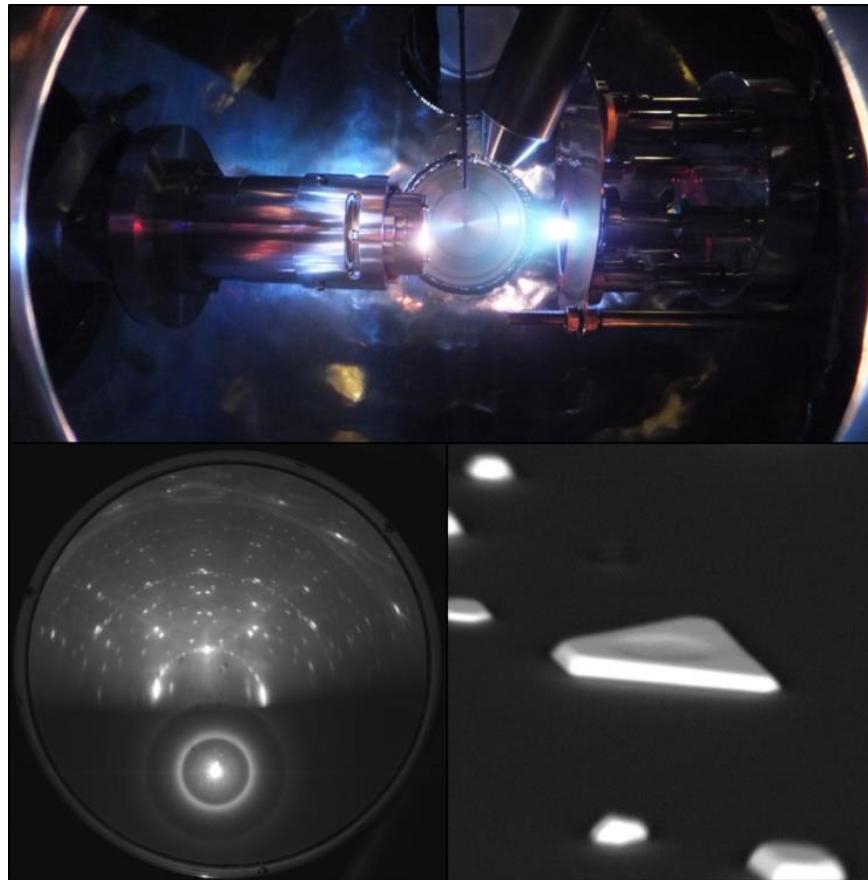




# Surface-Engineered Photocathode for Tunable Photoemissive Properties

Daniel Velázquez, Rachel Seibert, Zikri Yusof,  
Jeff Terry, Linda Spentzouris



# Program

## 1 Introduction

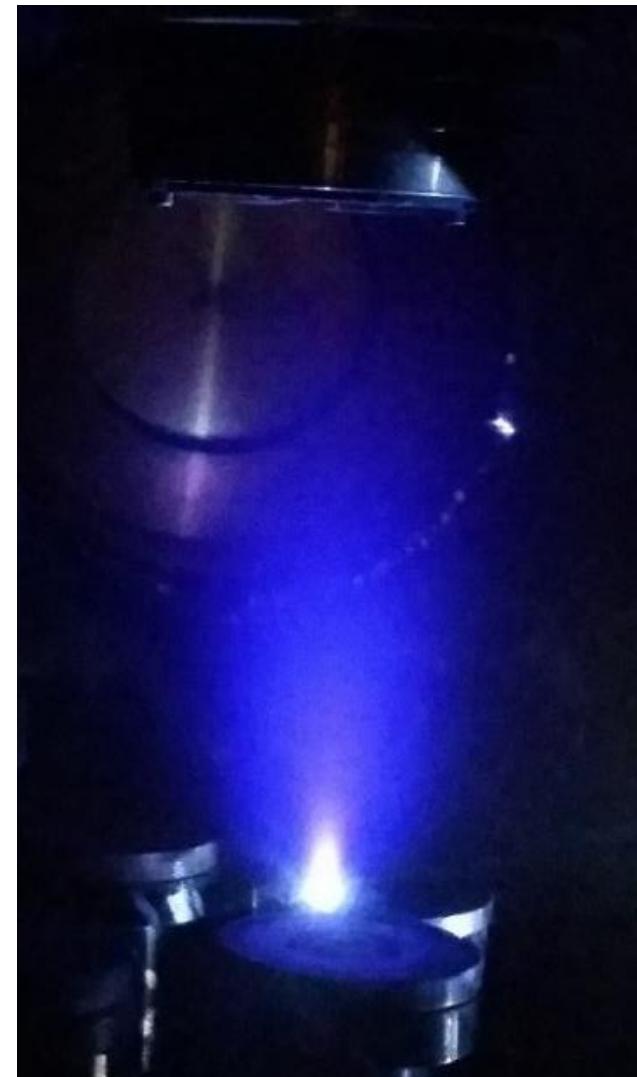
- Motivation & Background
- Theoretical Model

## 2 Synthesis & Structural Characterization

- Roughness vs temp.
- Diffraction
- SEM & STM
- XPS

## 3 Photoemissive Characterization of Multilayers

- Work Function
- QE
- Angular Emission



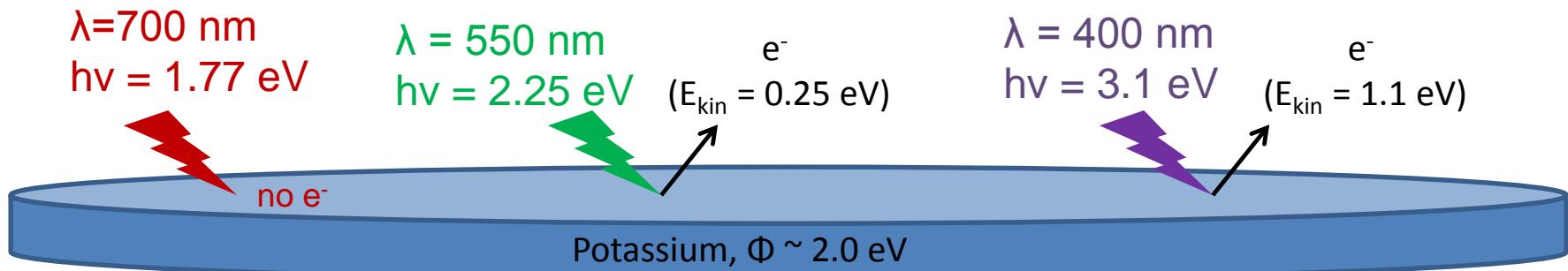
# What is a photocathode?

- Electron source used to exploit the photoelectric effect

## Photocathode Applications

- HEP detectors
- Night vision devices
- Time-resolved spectroscopy
- Ultra-fast electron diffraction
- **Electron sources for photoinjectors**

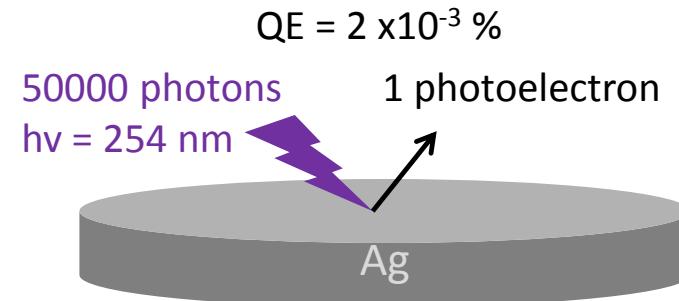
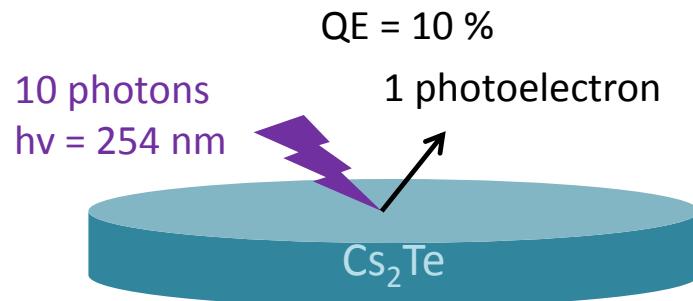
$$E_{kin} = h\nu - \Phi$$



# Photoemissive Properties of Photocathodes

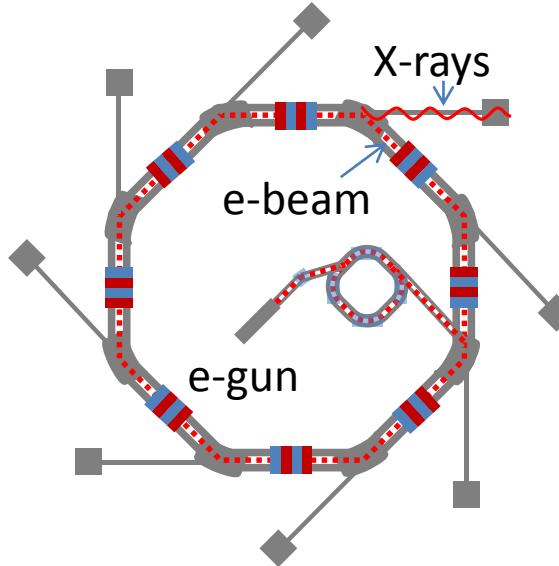
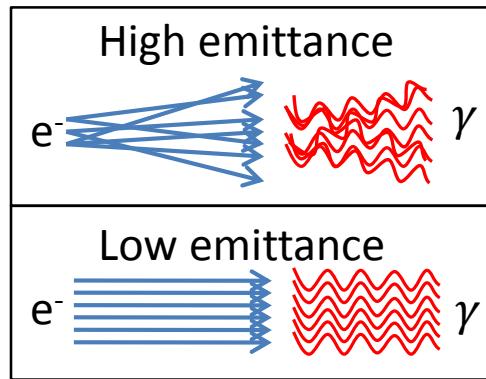
- The ratio of e- emitted per incident photons is called **Quantum Efficiency (QE)**
- Beam size and collimation is called **Emittance ( $\epsilon$ )**

$$QE = \frac{N_{electrons}}{N_{photons}} \times 100\%$$



# Photoemissive Properties of Photocathodes

- The ratio of e- emitted per incident photons is called **Quantum Efficiency (QE)**
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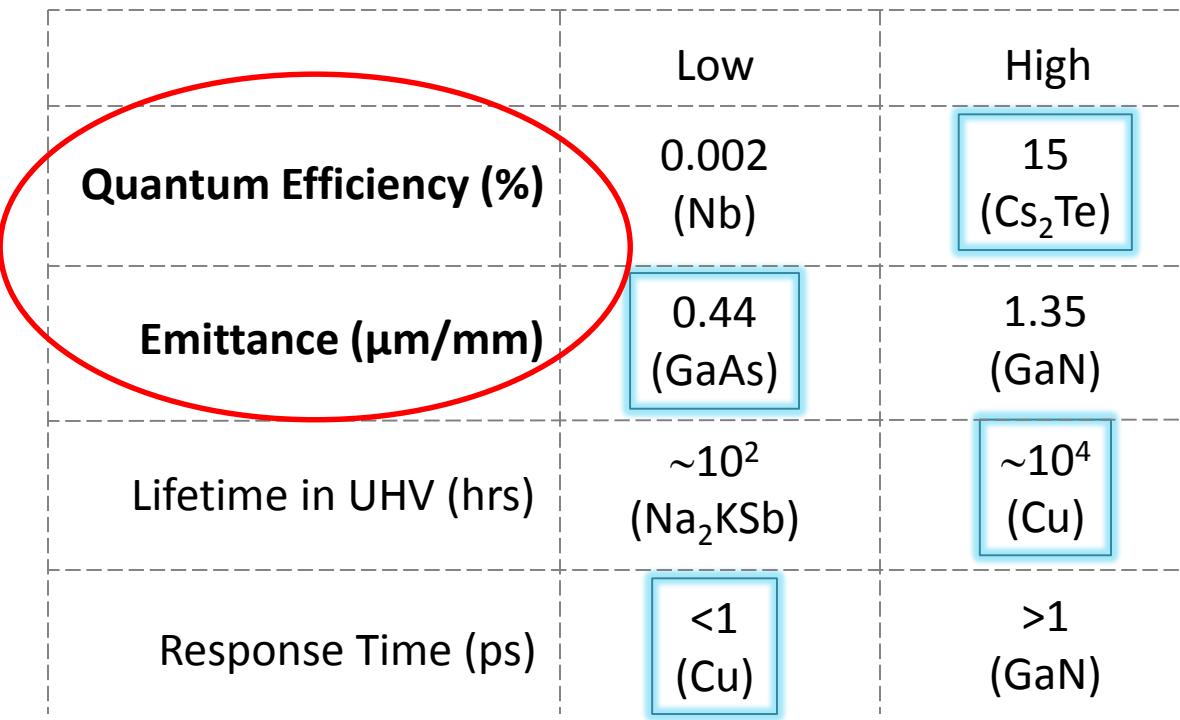
$$\epsilon^2 = \epsilon_{sc}^2 + \epsilon_{int}^2$$

$$\epsilon_{int,||} = \epsilon_{int,x} \epsilon_{int,y}$$

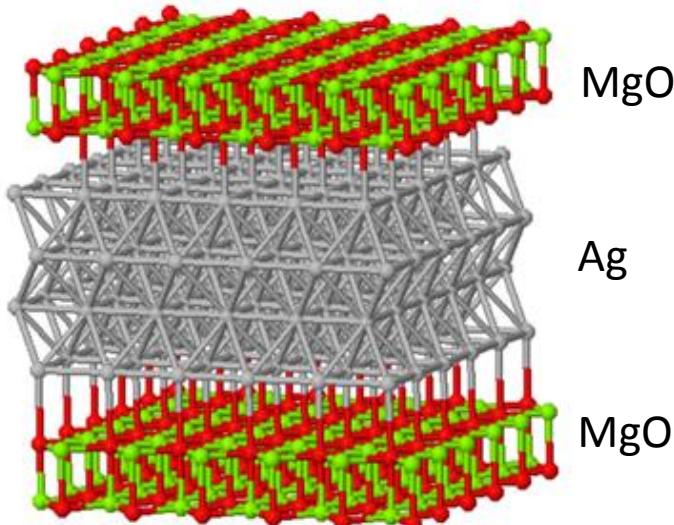
1D intrinsic emittance

$$\epsilon_{int,x} = \frac{1}{mc} \sigma_x \sigma_{p_x} = \frac{\hbar}{mc} \sigma_x \sigma_{k_x}$$

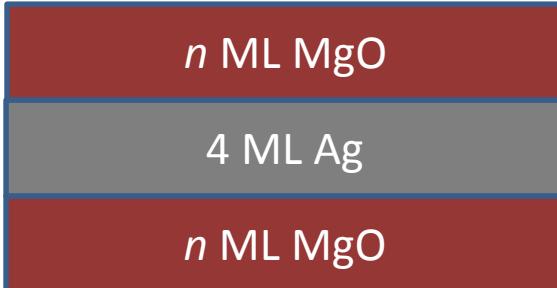
# Figures of Merit of Photocathodes for Photoinjectors



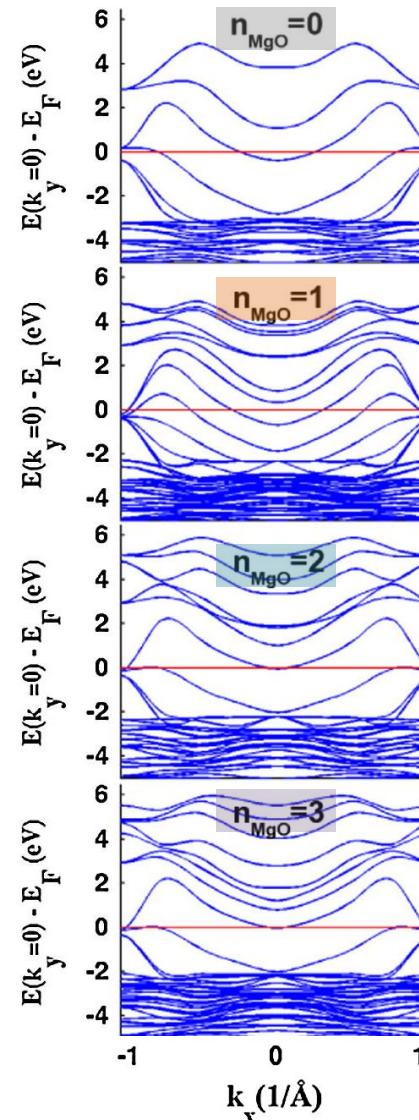
# Project Model & Predictions



Multilayer structure:



$$n = 1, 2, 3, 4\dots$$



## Model Predictions:

### Work function [eV]

$n=0$	$\Phi = 4.25$
$n=1$	$\Phi = 3.34$
$n=2$	$\Phi = 3.08$
$n=3$	$\Phi = 3.11$

### Emittance @ $E_F$ [ $\mu\text{m}/\text{mm}$ ]

$$\left( \frac{\epsilon_{n,int}}{\sigma_x} \left[ \frac{\mu\text{m}}{\text{mm}} \right] = 3.86 \sigma_{k_x} [\text{\AA}^{-1}] \right)$$

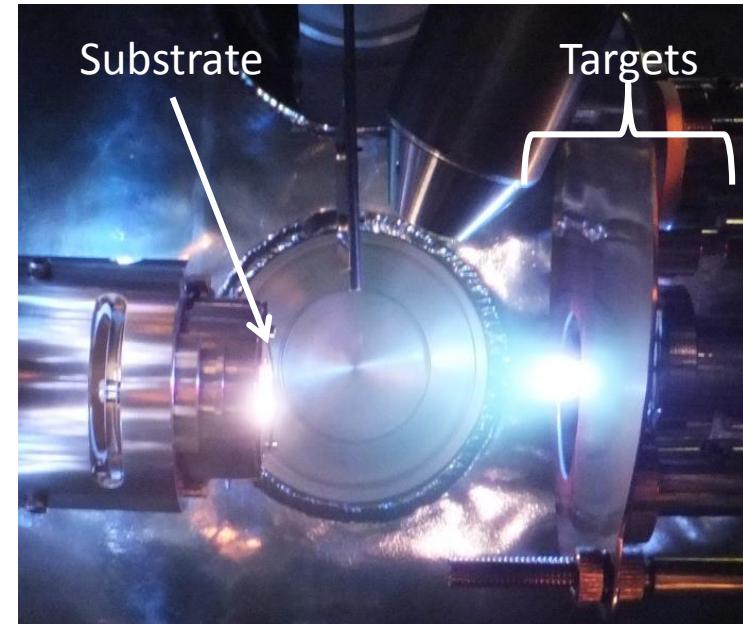
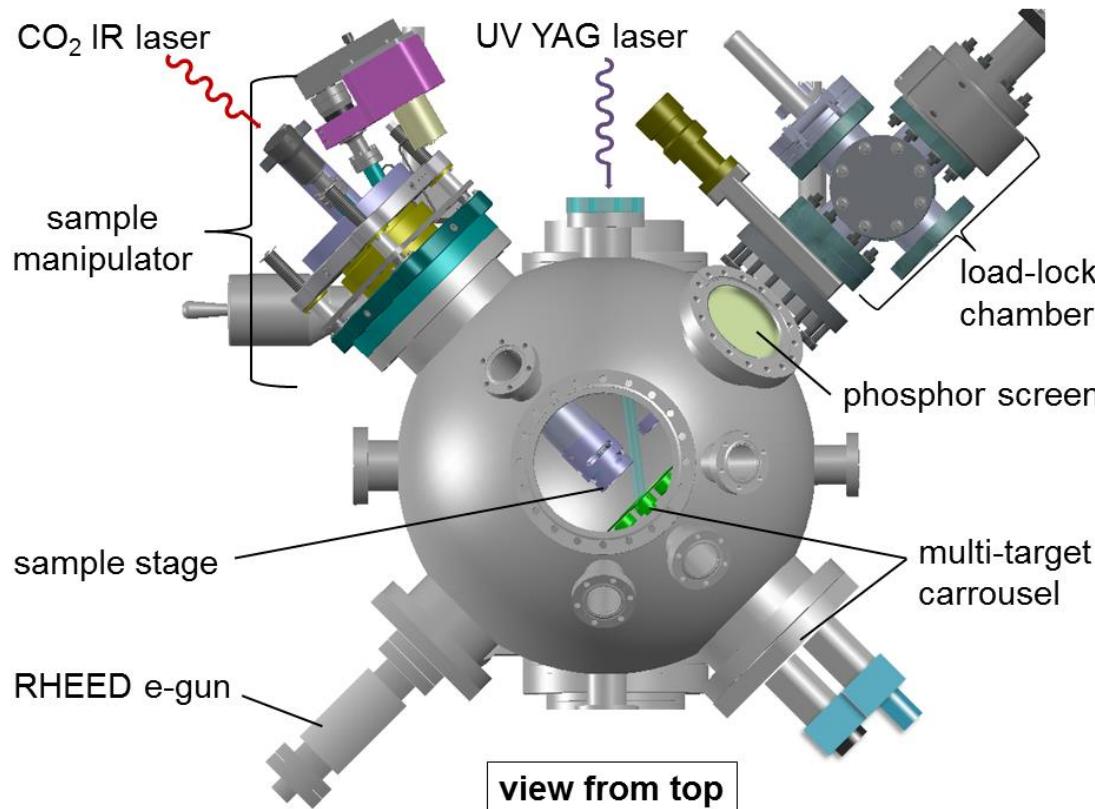
$$n=0 \quad \epsilon/\sigma_x \sim 0.58$$

$$n=1 \quad \epsilon/\sigma_x \sim 1.16$$

$$n=2 \quad \epsilon/\sigma_x \sim 0.06$$

$$n=3 \quad \epsilon/\sigma_x \sim 0.06$$

# Pulsed Laser Deposition at IIT



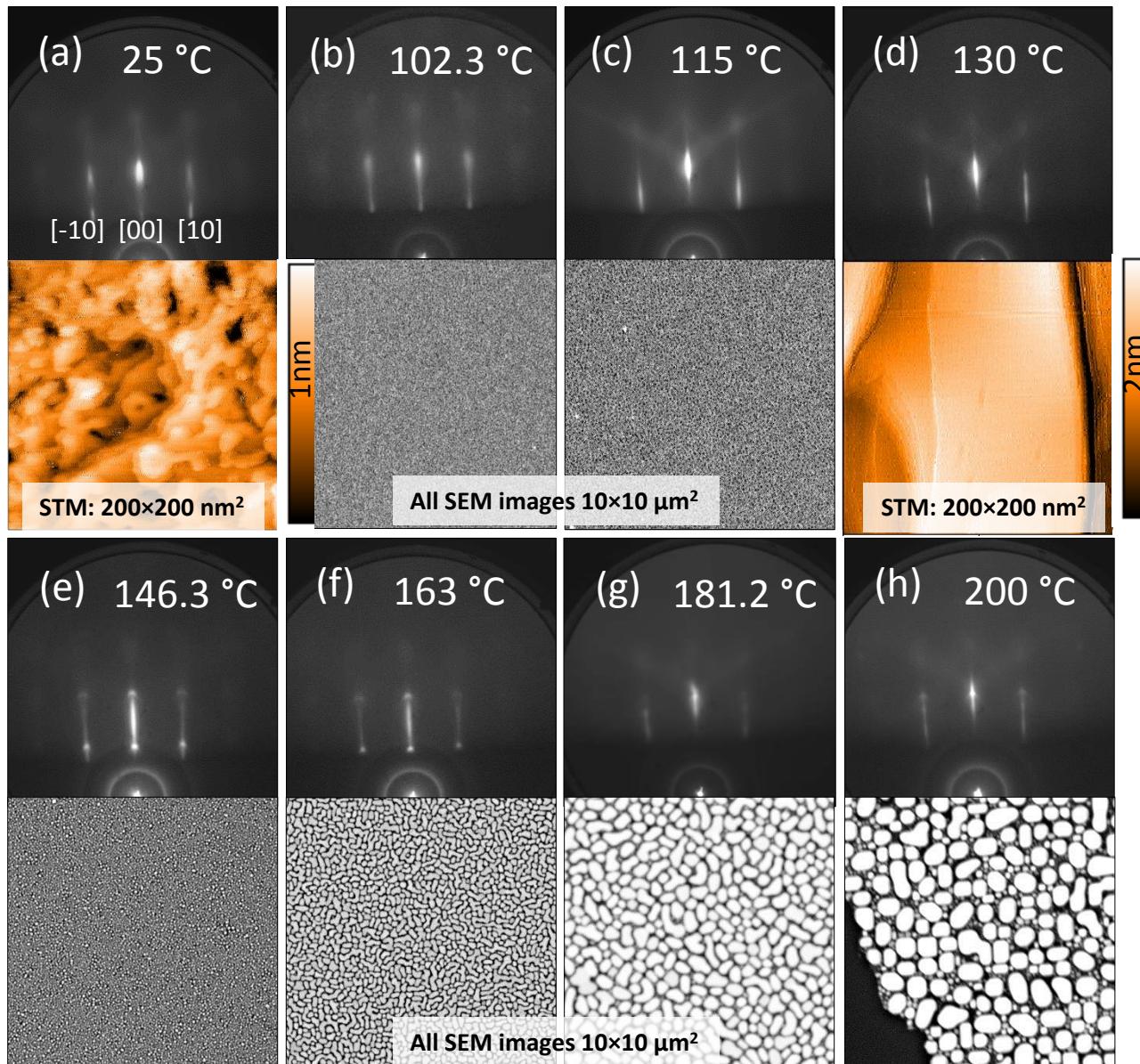
## Highly tunable deposition parameters:

- Target to sample distance
- Chamber pressure
- Fluence (Energy/area)

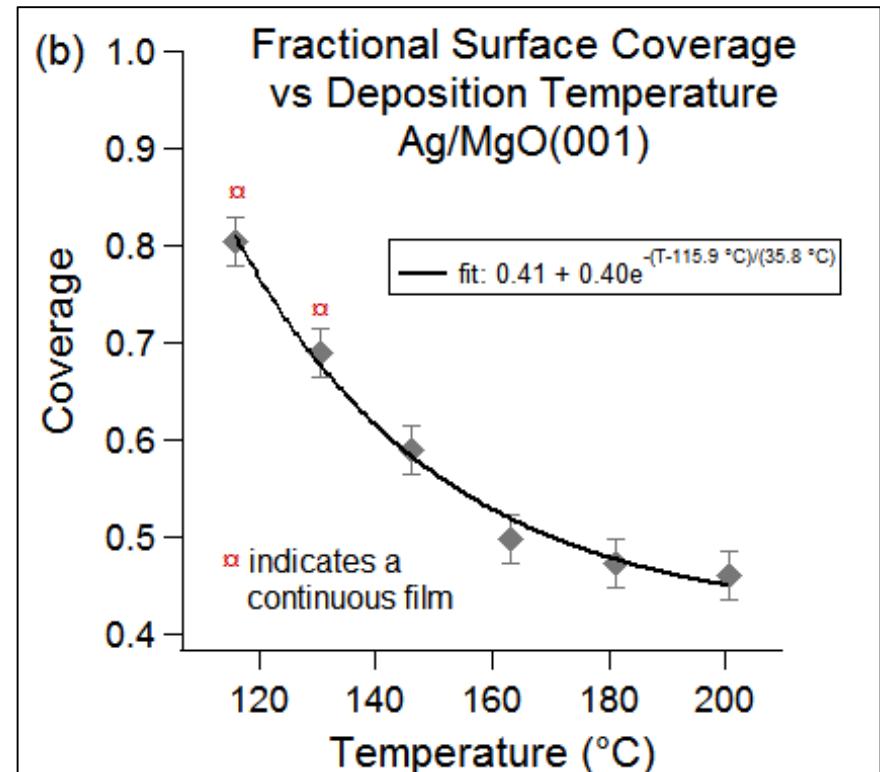
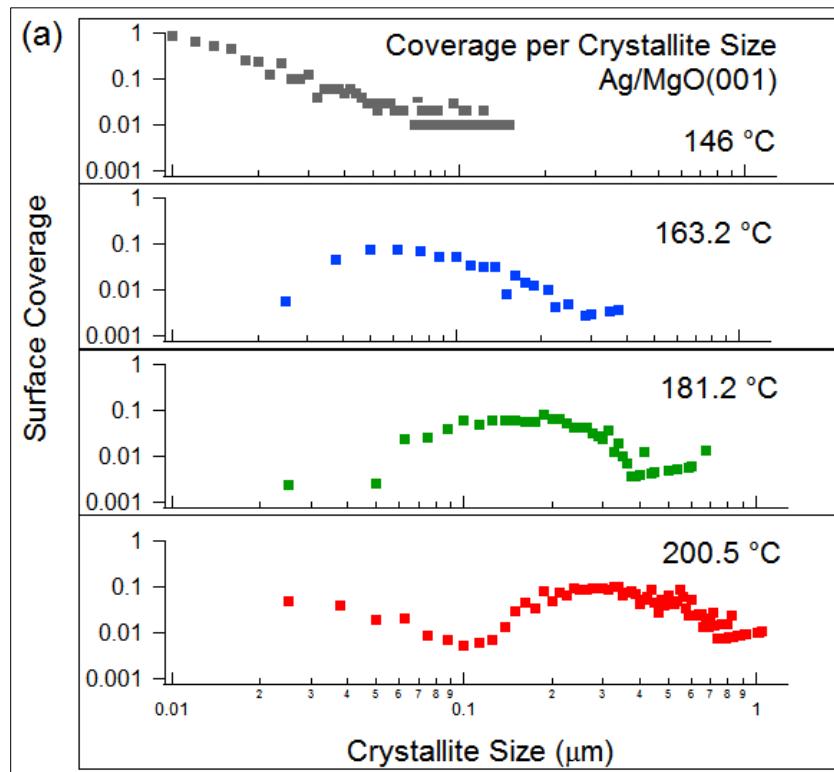
## Resulting in:

- Highly tunable deposition rate:  
<1 Å/sec to a few nm/sec
- Chemical and physical structure precision  
(stoichiometry transfer, homoepitaxy)

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

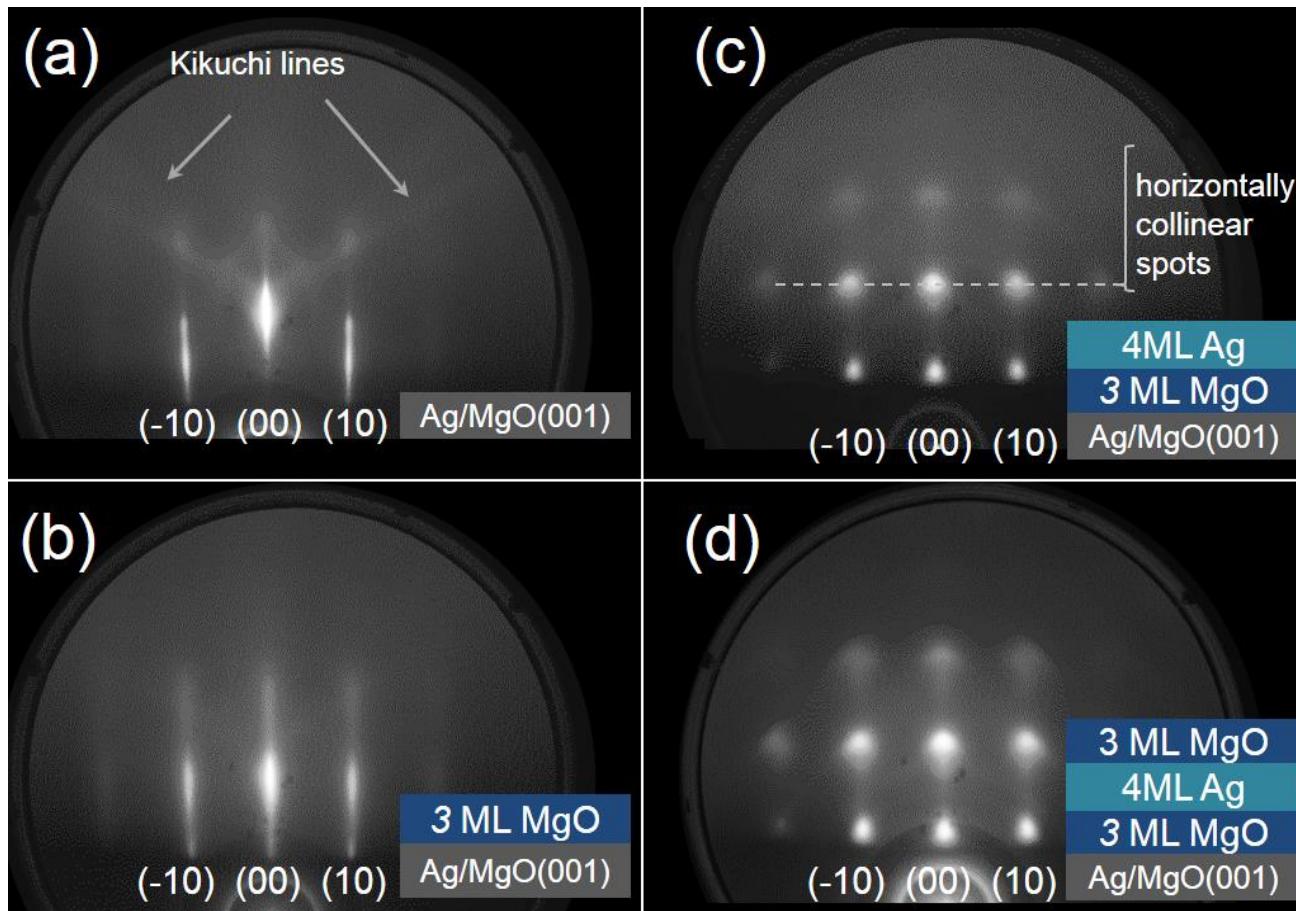


# Ag film growth at various temperatures: Ag/MgO(001)



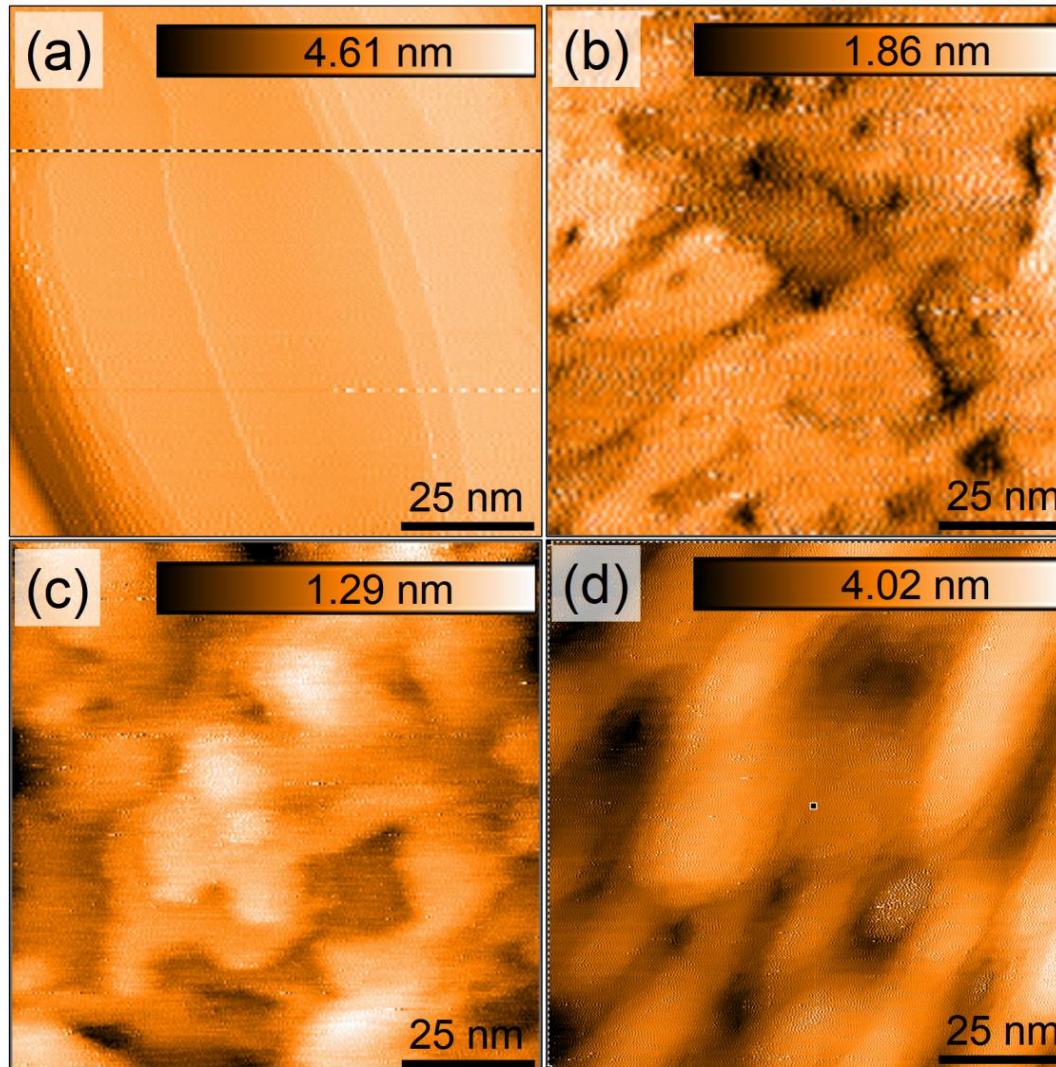
# Epitaxial Growth of Ultra-Thin Multilayers

## MgO(3 ML)/Ag(4 ML)/MgO(3 ML)

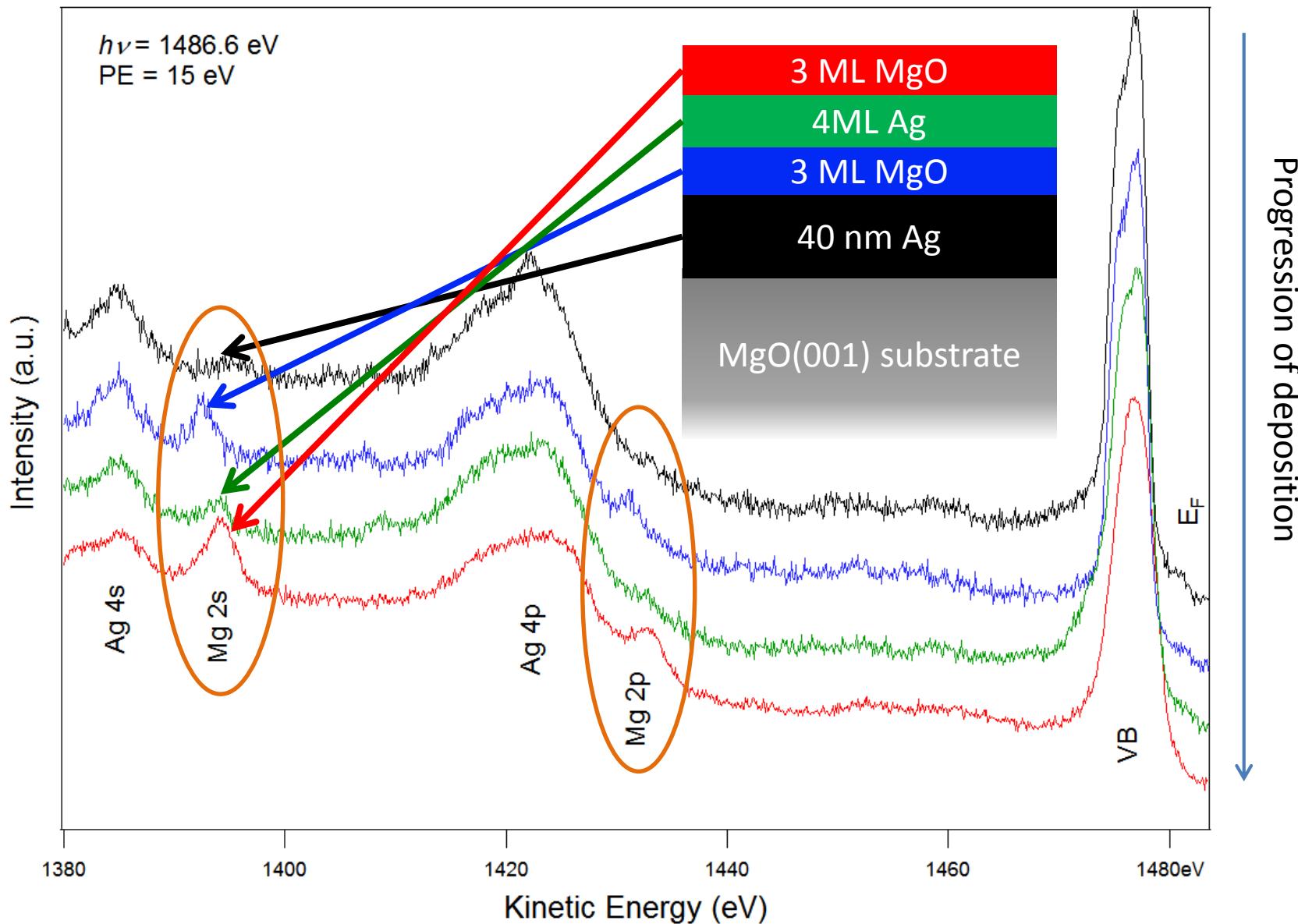


# Epitaxial Growth of Ultra-Thin Multilayers

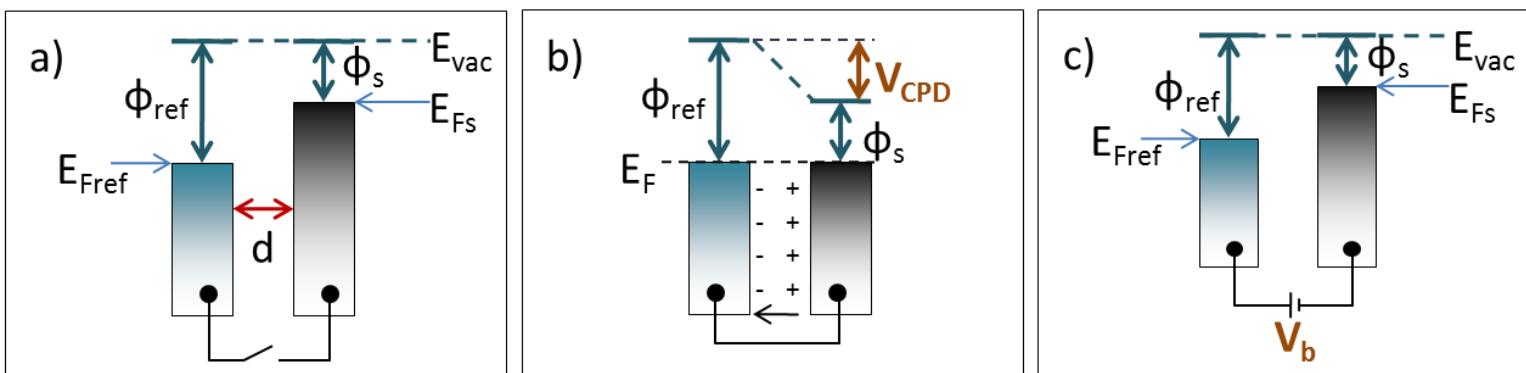
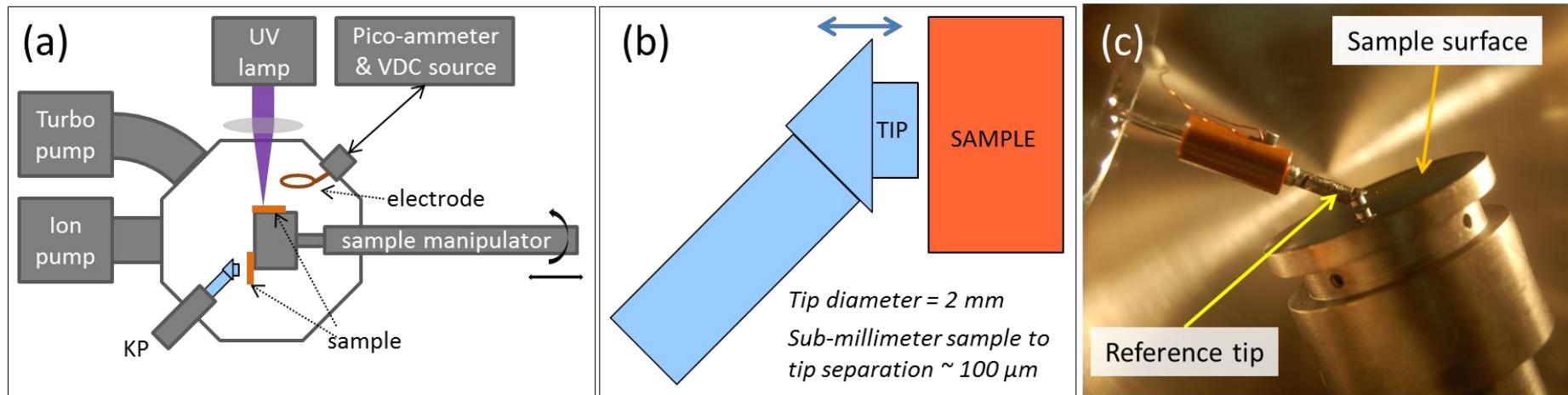
MgO(3 ML)/Ag(4 ML)/MgO(3 ML)



# XPS shows stages of multilayer growth



# Tandem KP/Photocurrent-detector

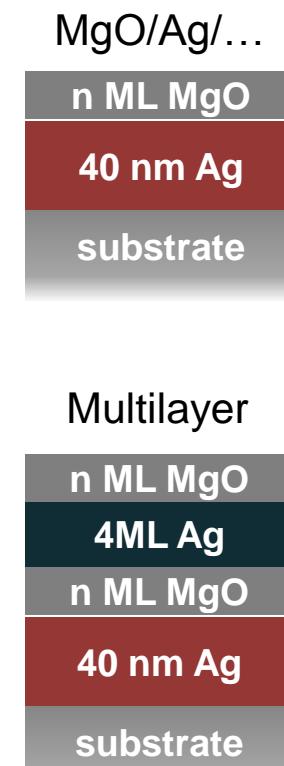
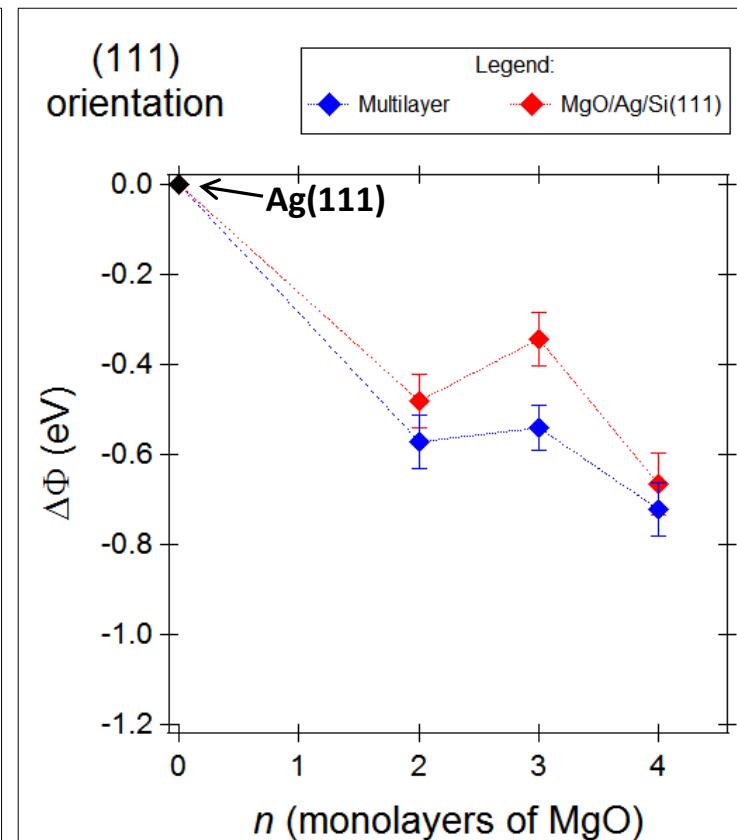
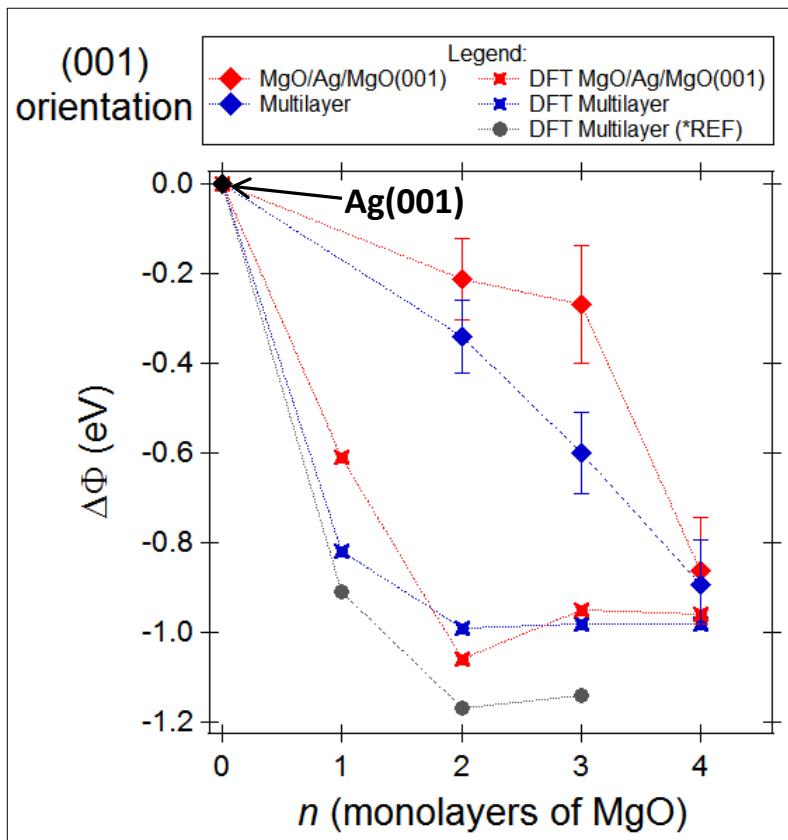


$$i(t) = \frac{dQ}{dt} = \Delta V \frac{dC}{dt}$$

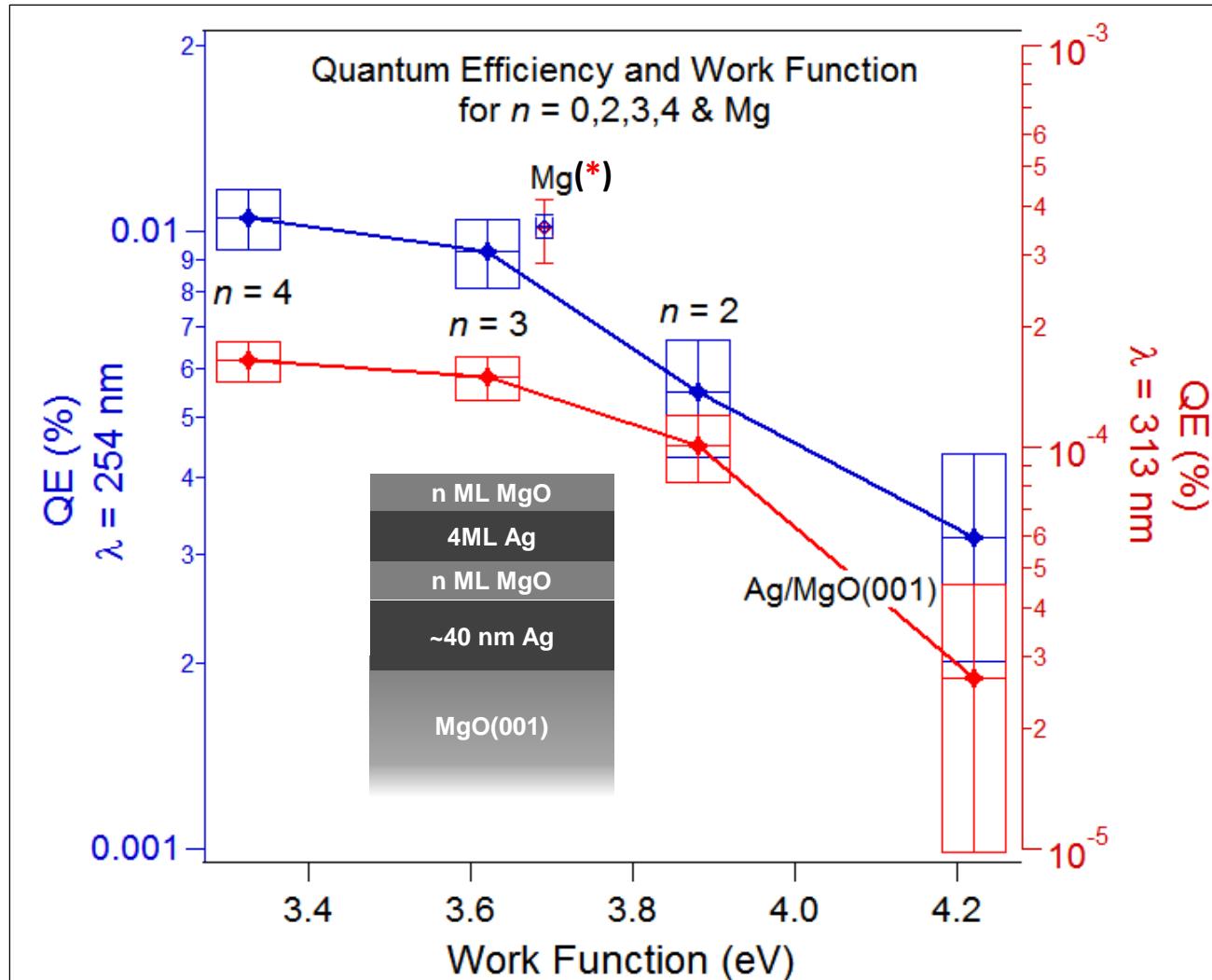
$$\Delta V = V_b + V_{CPD}$$

$$i_{pp}(V_b) = (V_b + V_{CPD}) \left( \frac{dC}{dt} \right)_{pp}$$

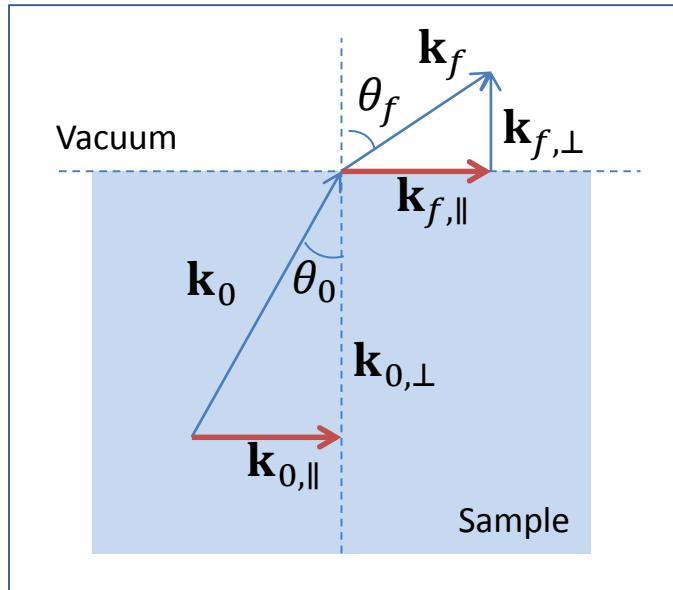
# Work Function of measurements: MgO/Ag and Multilayer surfaces



# QE vs WF of Multilayers $n = 2\text{-}4$ ML

(\*) QE(Mg @ 266 nm)  $\in (0.01\%, 0.06\%)$

# Electron refraction: conservation of surface-parallel $k$

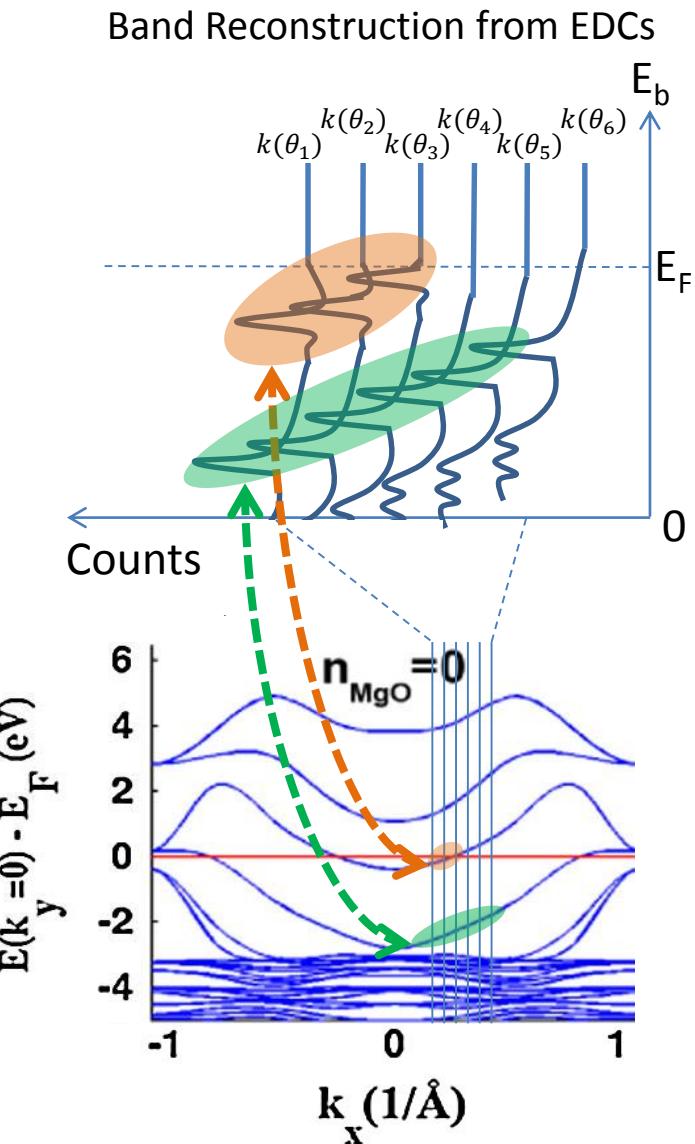


$$k_{f,||} = k_{0,||}$$

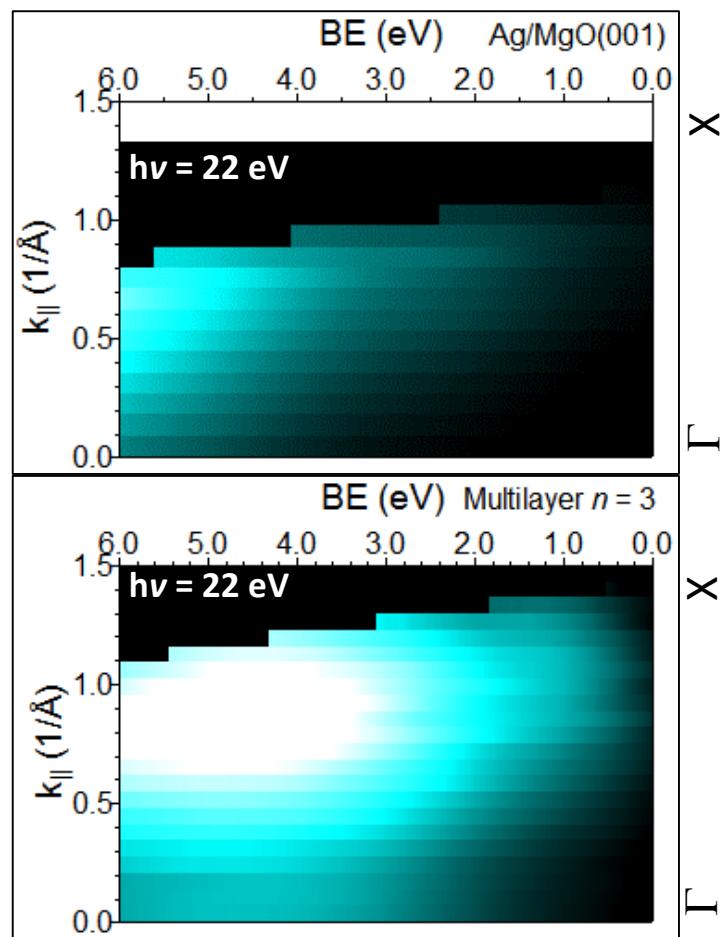
$$k_{||} = \frac{1}{\hbar} \sqrt{2m_e^* E_K} \sin \theta_f$$

Low momentum spread  $\rightarrow$  low angular spread  $\rightarrow$  low intrinsic emittance

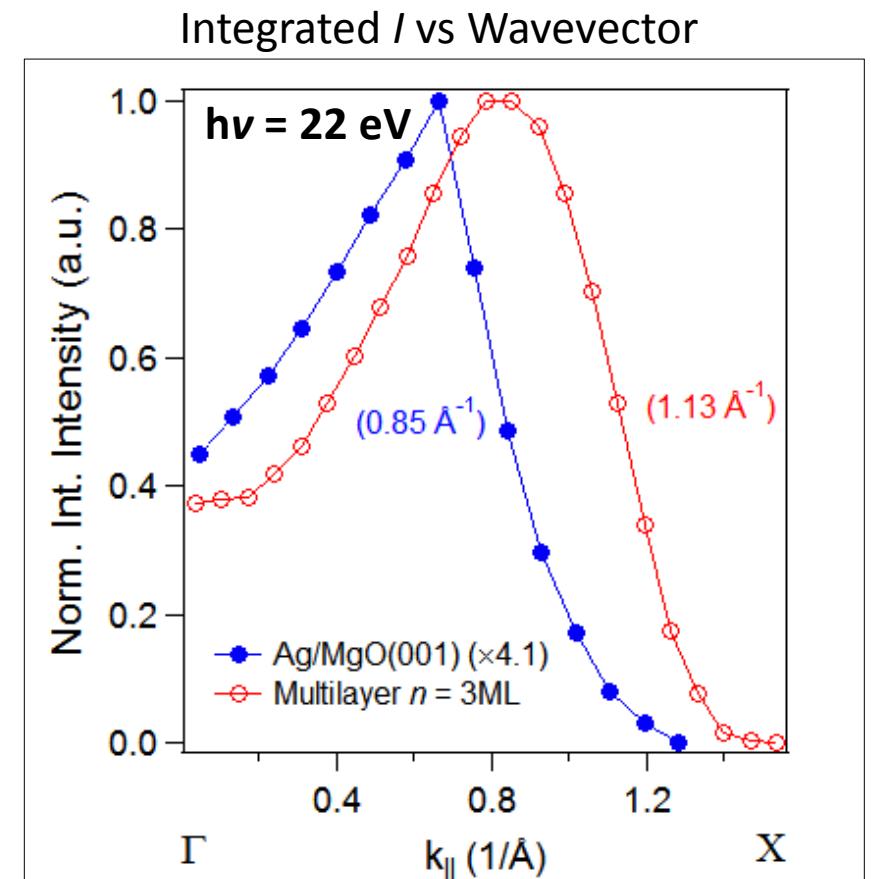
$$\varepsilon_{int,i} = \frac{\hbar}{mc} \sigma_{||} \sigma_{k_{||}}$$



# Emittance: Ag/MgO(001) vs Multilayer (001) $n = 3$ ML



$$\frac{\epsilon_{n,int}}{\sigma_x} \left[ \frac{\mu\text{m}}{\text{mm}} \right] = \frac{\hbar}{mc} \sigma_{k_x} = 3.86 \sigma_{k_x} [\text{\AA}^{-1}]$$



$\text{Ag/MgO}(001) \rightarrow 3.28 \mu\text{m/mm}$

$\text{ML } (n = 3) \rightarrow 4.36 \mu\text{m/mm}$

3 ML MgO
4ML Ag
3 ML MgO
40 nm Ag
MgO(001) substrate

# Summary

- Epitaxial deposition of metallic substrate surfaces: highly controllable roughness with temperature
- Synthesized **epitaxial stoichiometric multilayer** structures.
- **Work Function vs multilayer thickness** (decreased with thickness).
- Measured **Quantum Efficiency** vs **multilayer thickness** (increased with thickness).
- Limited measurements of **Angular Emission** show narrowing of momentum dispersion for ML.



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