ILLINOIS INSTITUTE OF TECHNOLOGY Argonne NATIONAL LABORATORY

Surface-Engineered Photocathode for Tunable Photoemissive Properties

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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

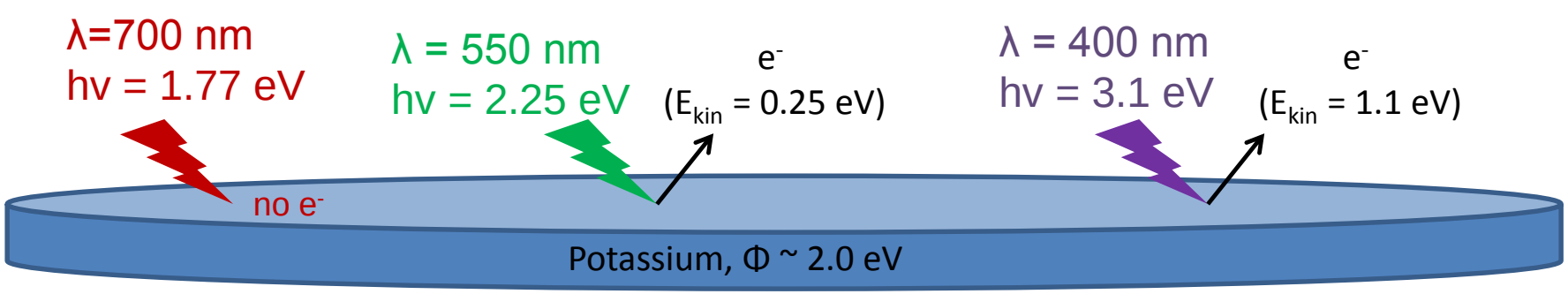
What is a photocathode?

- 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**

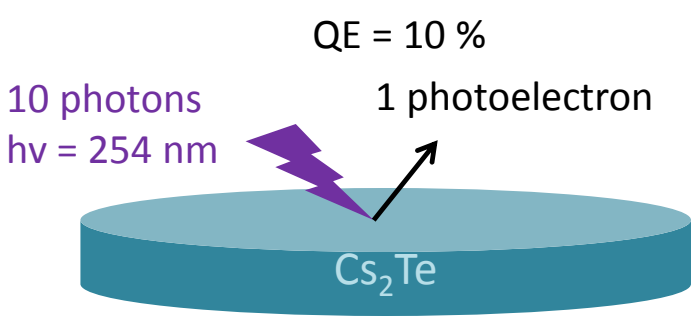
$$E_{kin} = h\nu - \Phi$$

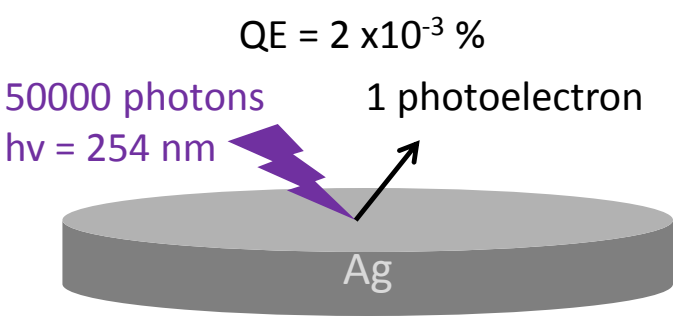


Photoemissive Properties of Photocathodes

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

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





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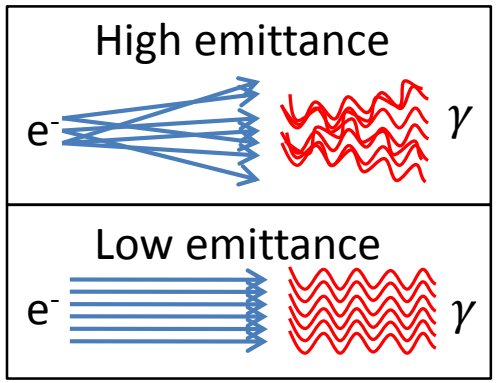
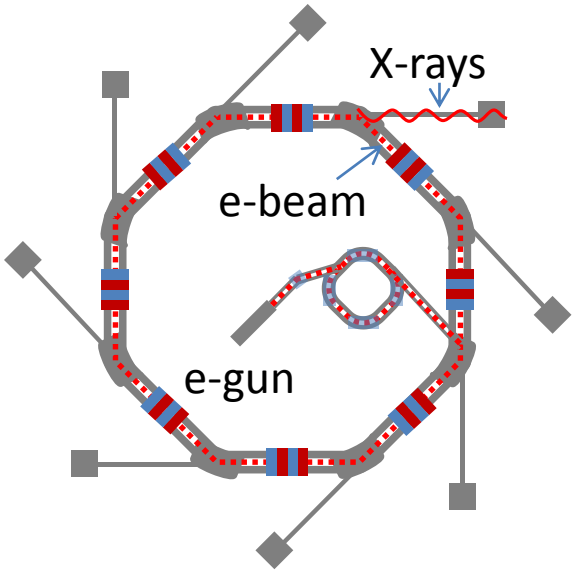




$$\mathcal{E}^2 = \mathcal{E}_{sc}^2 + \mathcal{E}_{int}^2$$

$$\mathcal{E}_{int,||} = \mathcal{E}_{int,x}\mathcal{E}_{int,y}$$

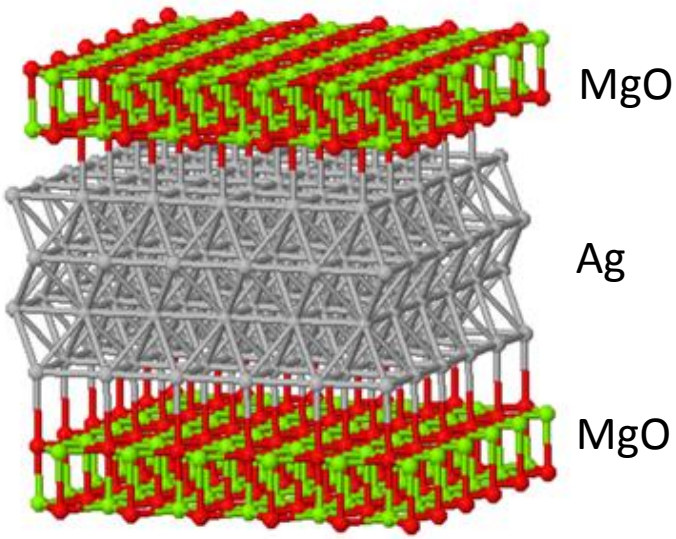
1D intrinsic emittance

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

Figures of Merit of Photocathodes for Photoinjectors

	Low	High
Quantum Efficiency (%)	0.002 (Nb)	15 (Cs_2Te)
Emittance (μm/mm)	0.44 (GaAs)	1.35 (GaN)
Lifetime in UHV (hrs)	$\sim 10^2$ (Na_2KSb)	$\sim 10^4$ (Cu)
Response Time (ps)	<1 (Cu)	>1 (GaN)

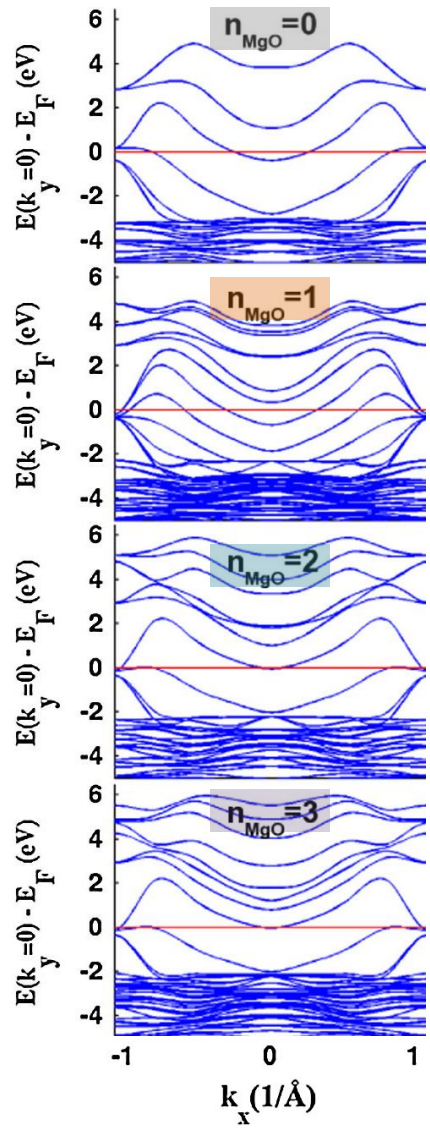
Project Model & Predictions



Multilayer structure:

n ML MgO
4 ML Ag
n ML MgO

n = 1, 2, 3, 4…



Model Predictions:

Work function [eV]

n=0	Φ = 4.25
n=1	Φ = 3.34
n=2	Φ = 3.08
n=3	Φ = 3.11

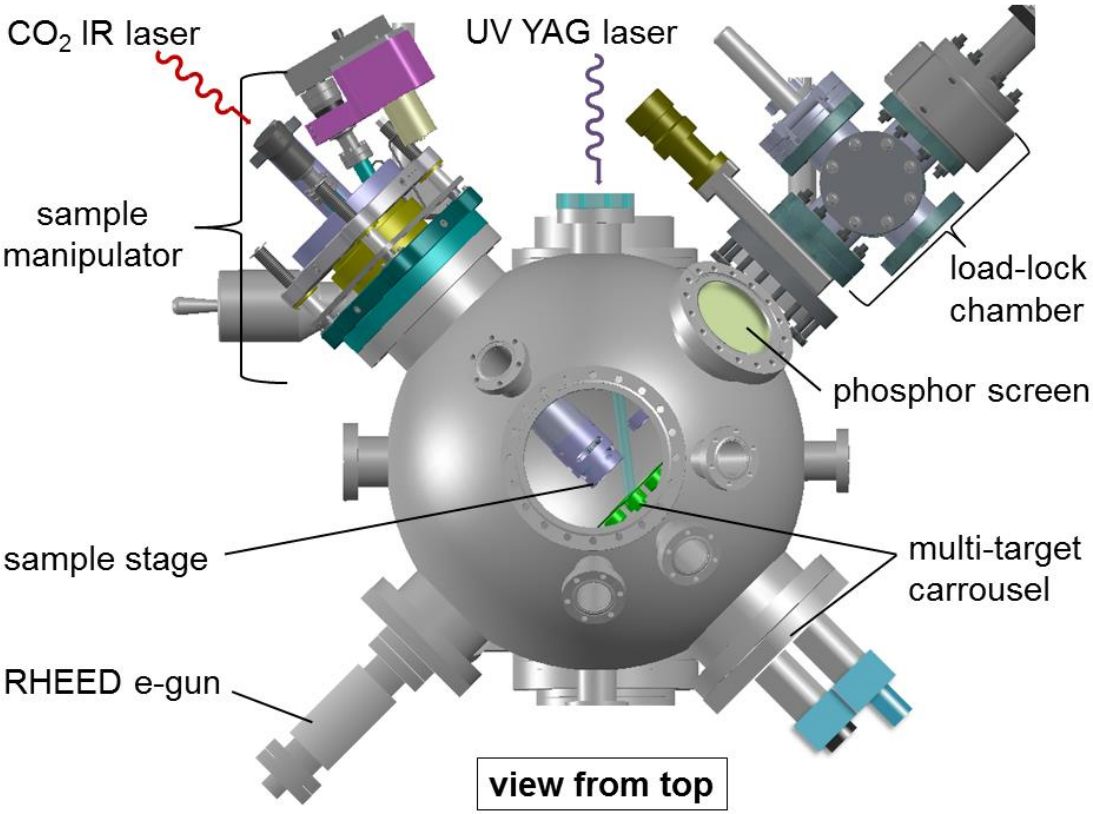
Emittance @ E_F [μm/mm]

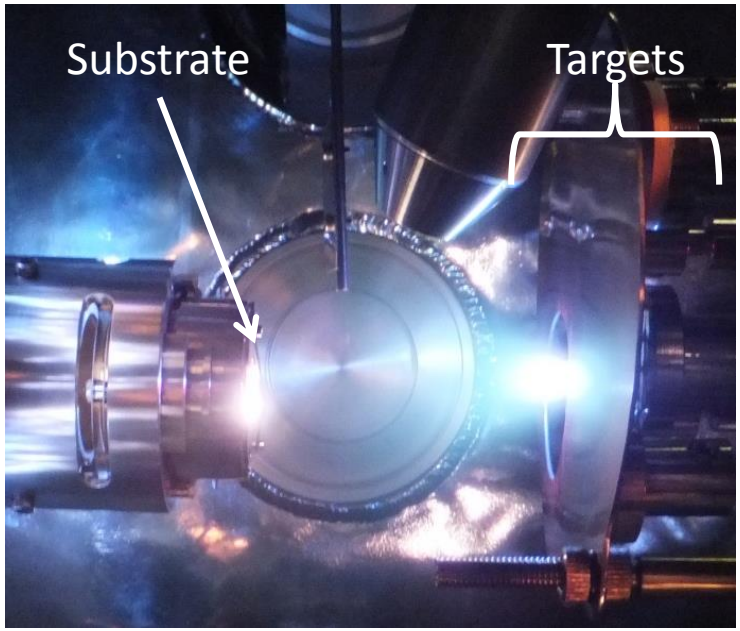
$$\left(\frac{\epsilon_{n,int}}{\sigma_x}\left[\frac{\mu m}{mm}\right] = 3.86\sigma_{k_x}[\text{Å}^{-1}]\right)$$

n=0 ε/σ_x ~ 0.58
n=1 ε/σ_x ~ 1.16
n=2 ε/σ_x ~ 0.06
n=3 ε/σ_x ~ 0.06

K. Nemeth et al. Phys. Rev. Lett. 104, 046801, 2010.

Pulsed Laser Deposition at IIT





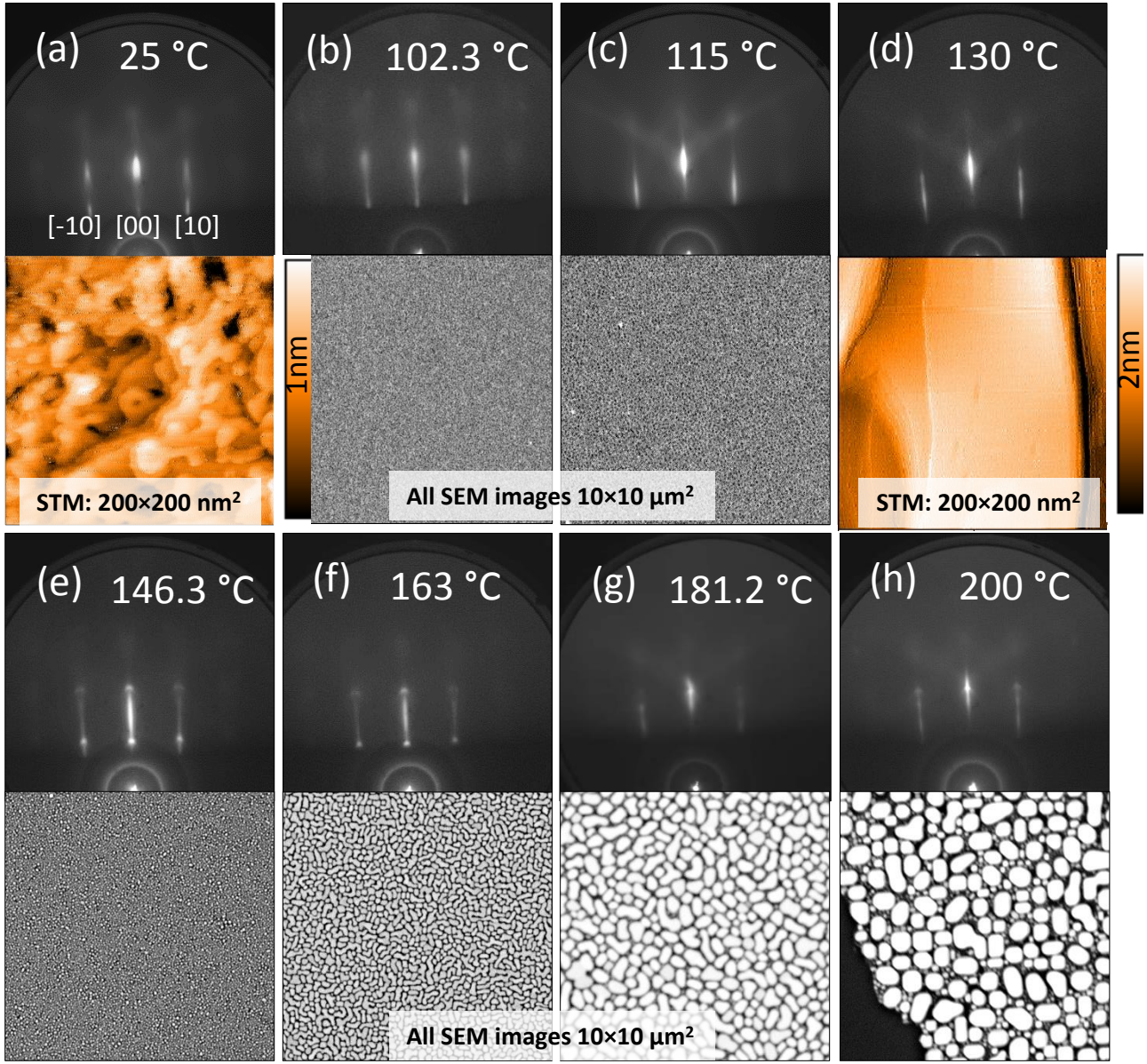
Highly tunable deposition parameters:

- 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)



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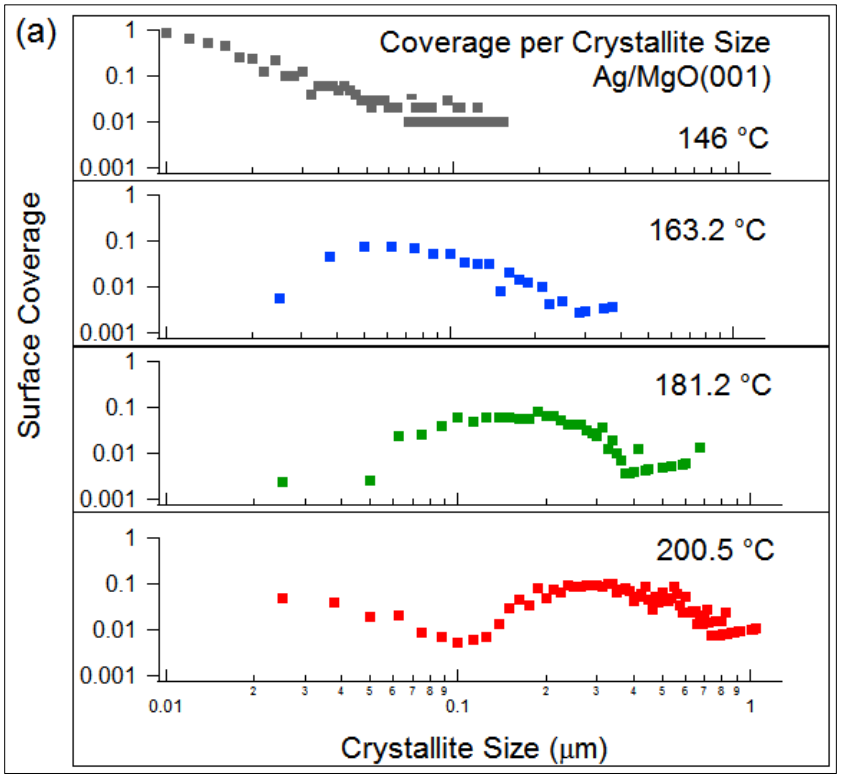
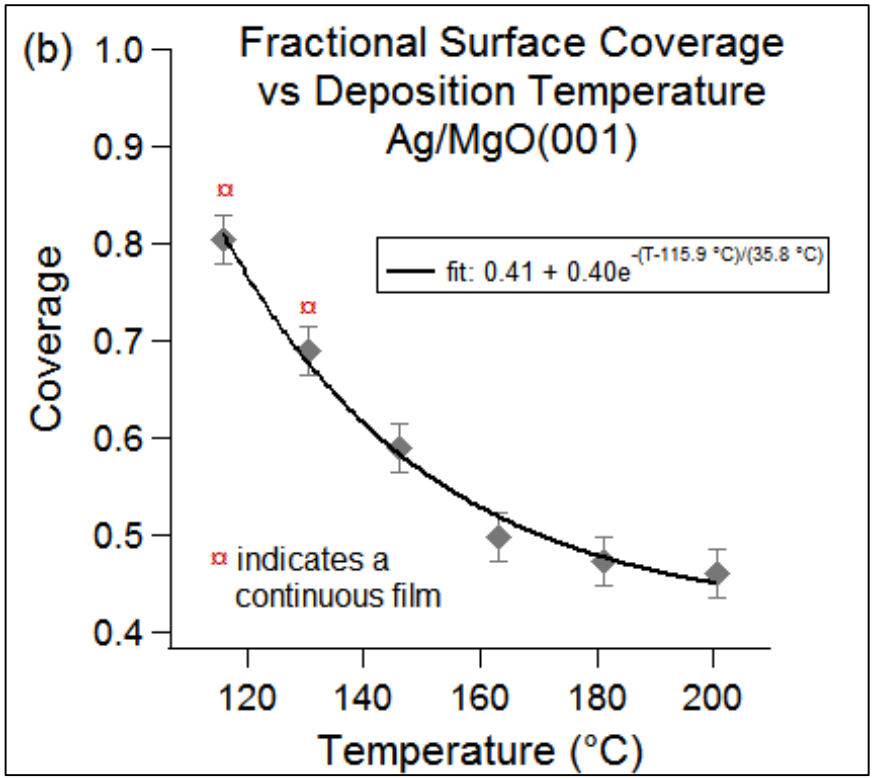
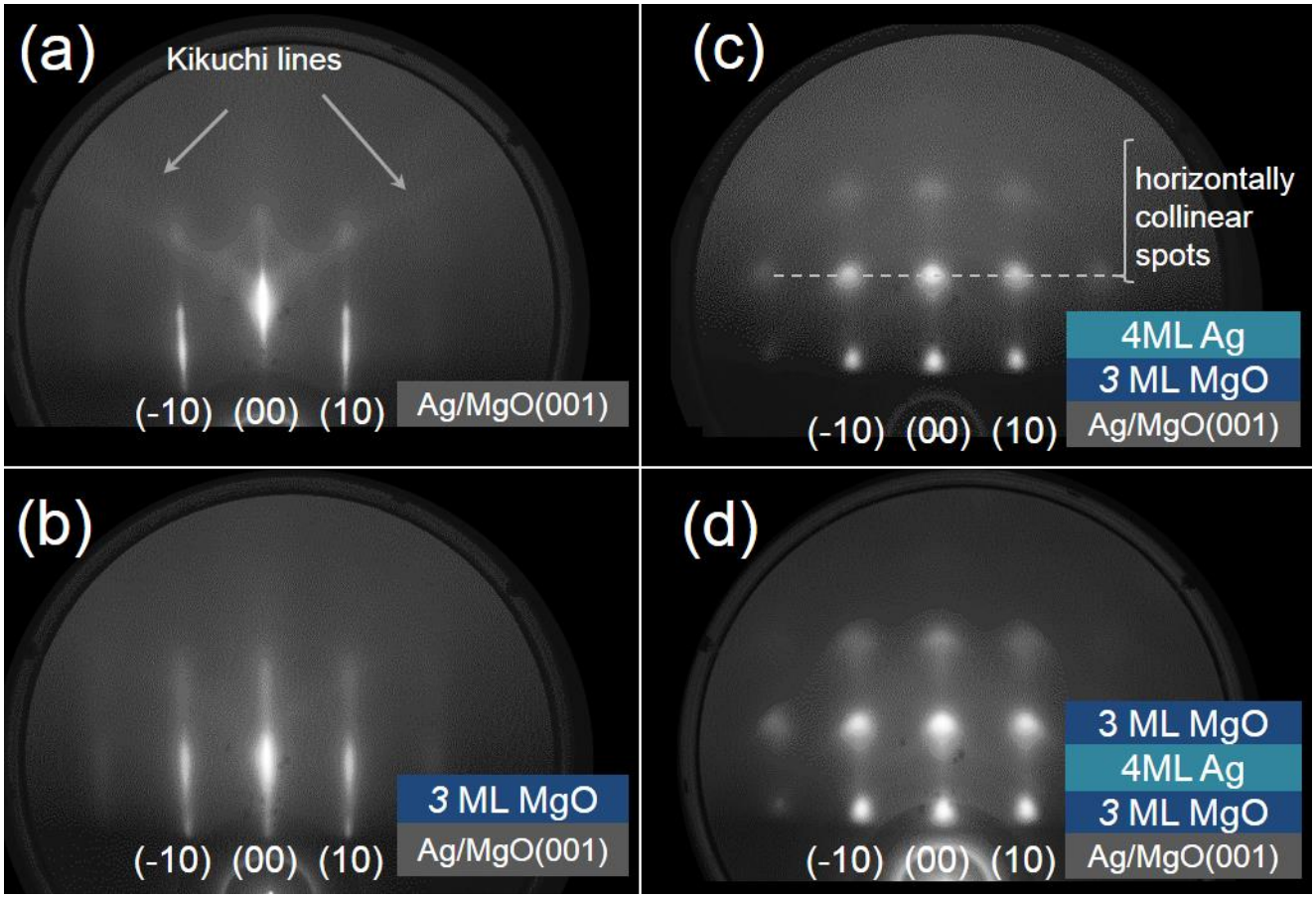




Epitaxial Growth of Ultra-Thin Multilayers
MgO(3 ML)/Ag(4 ML)/MgO(3 ML)



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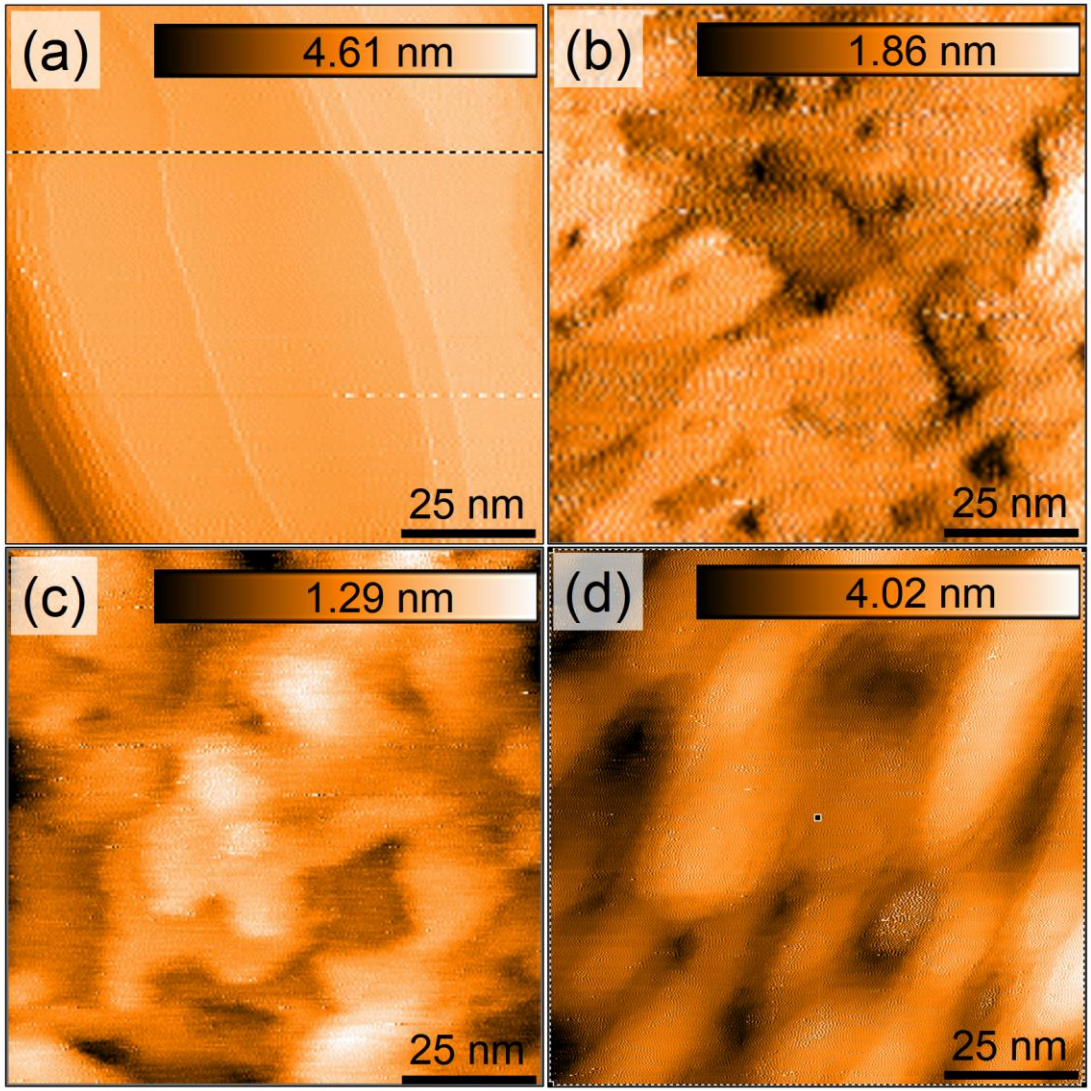
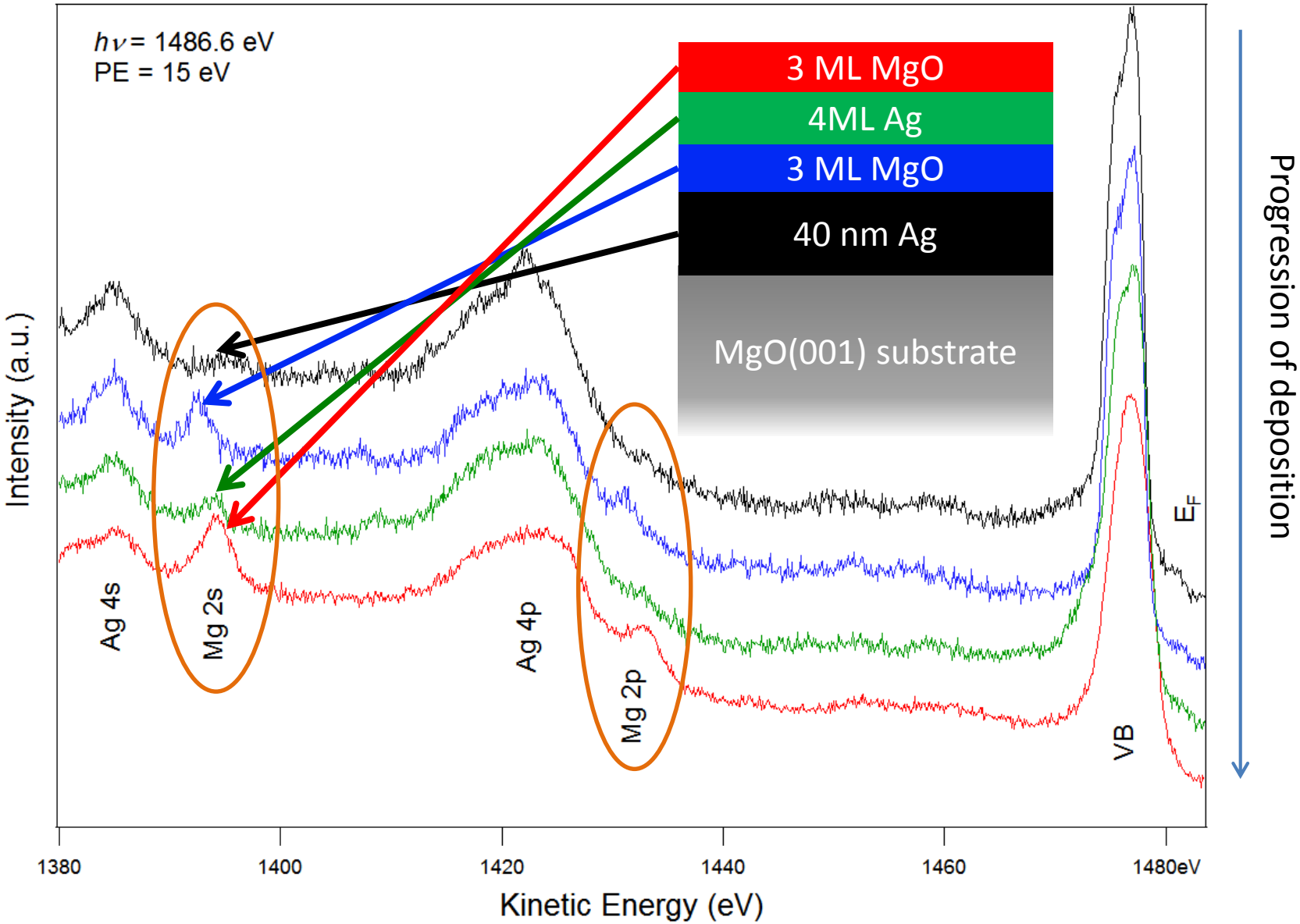
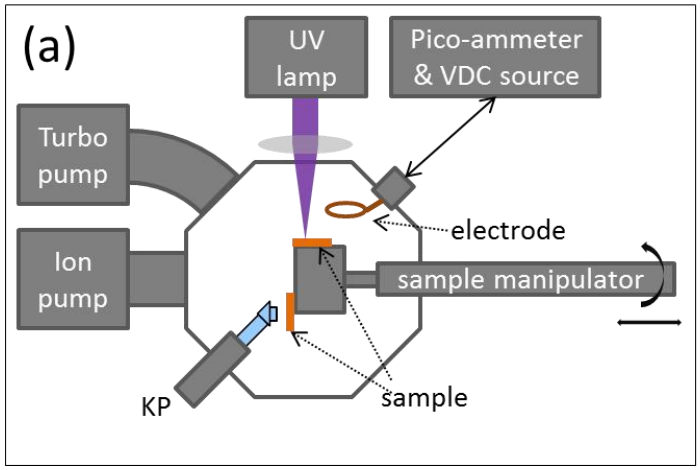
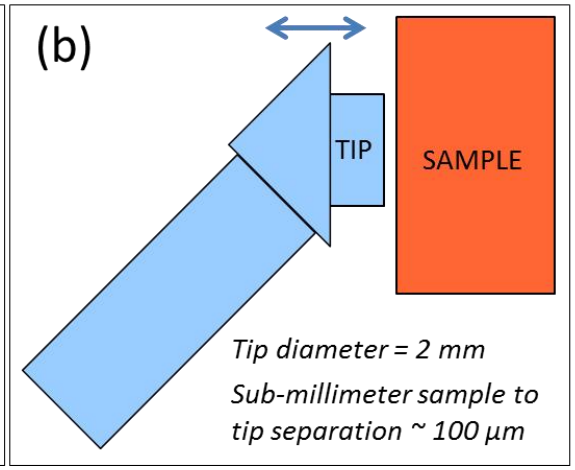


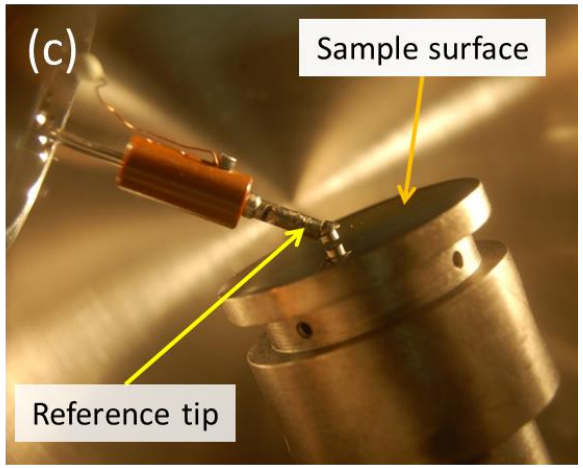
XPS shows stages of multilayer growth

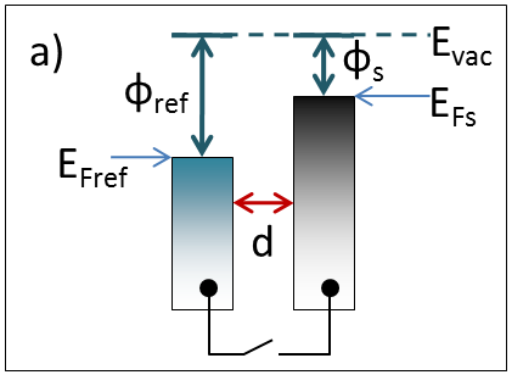


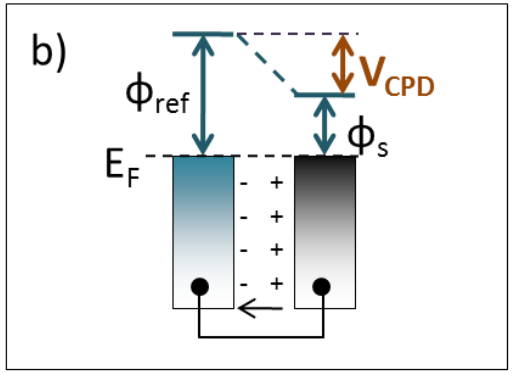
Tandem KP/Photocurrent-detector

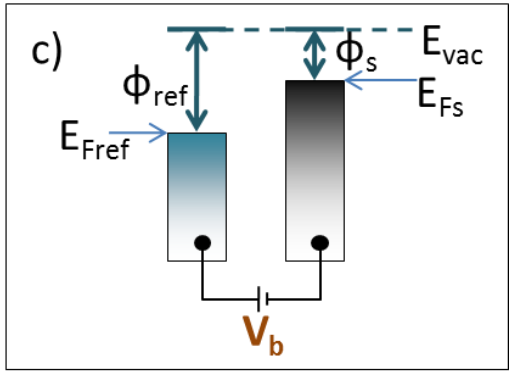










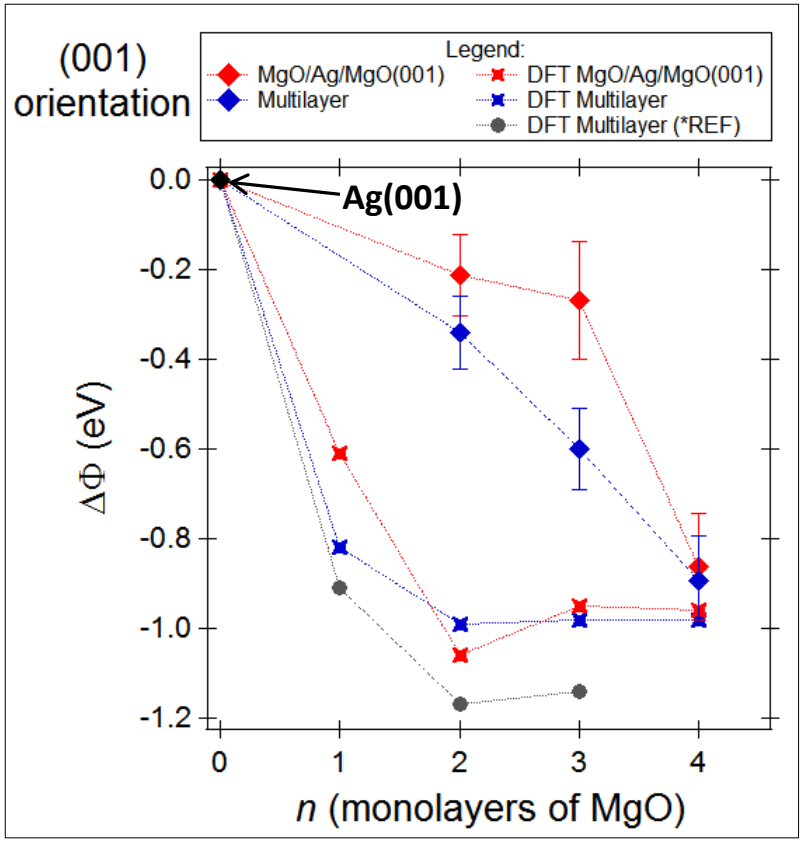


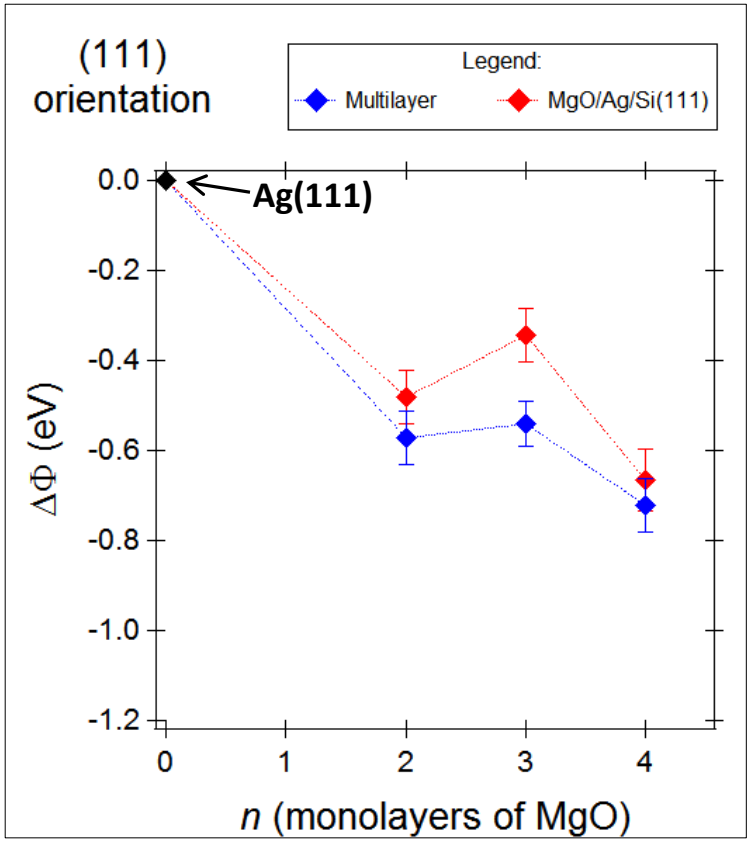
$$i(t) = \frac{dQ}{dt} = \Delta V \frac{dC}{dt}$$

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

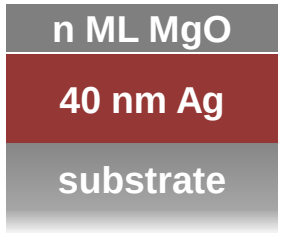
$$i_{pp}(V_b) = (V_b + V_{CPD})\left(\frac{dC}{dt}\right)_{pp}$$

Work Function of measurements: MgO/Ag and Multilayer surfaces





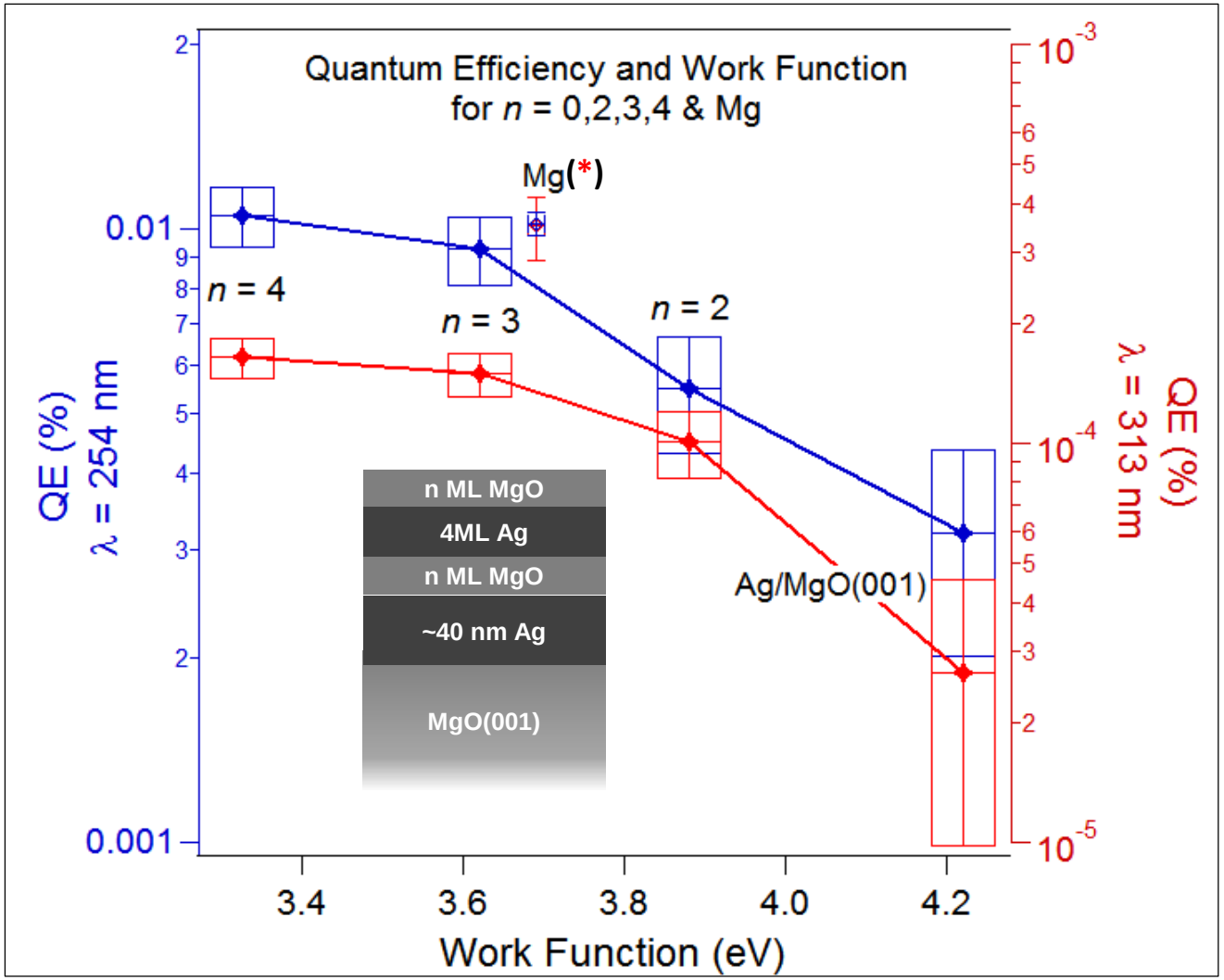
MgO/Ag/…



Multilayer

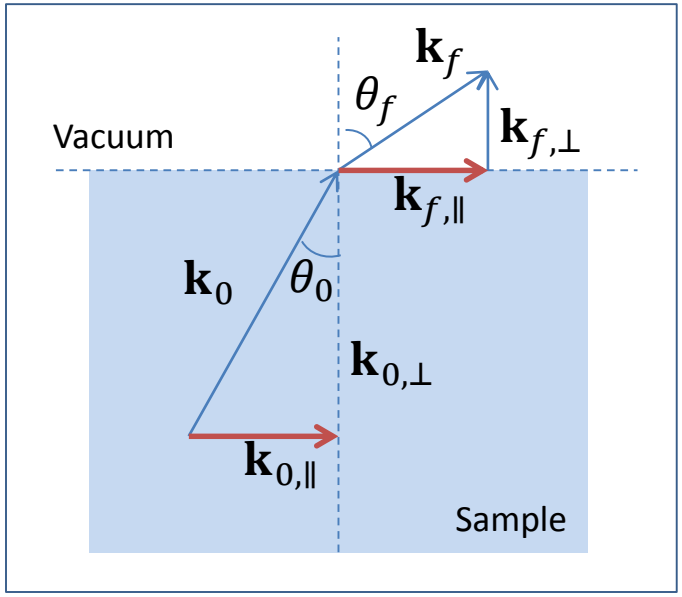
(*) K. Nemeth et al. Phys. Rev. Lett. 104, 046801, 2010.

QE vs WF of Multilayers *n* = 2-4 ML



(*) QE(Mg @ 266 nm) ∈ (0.01 %, 0.06 %)

Electron refraction: conservation of surface-parallel *k*



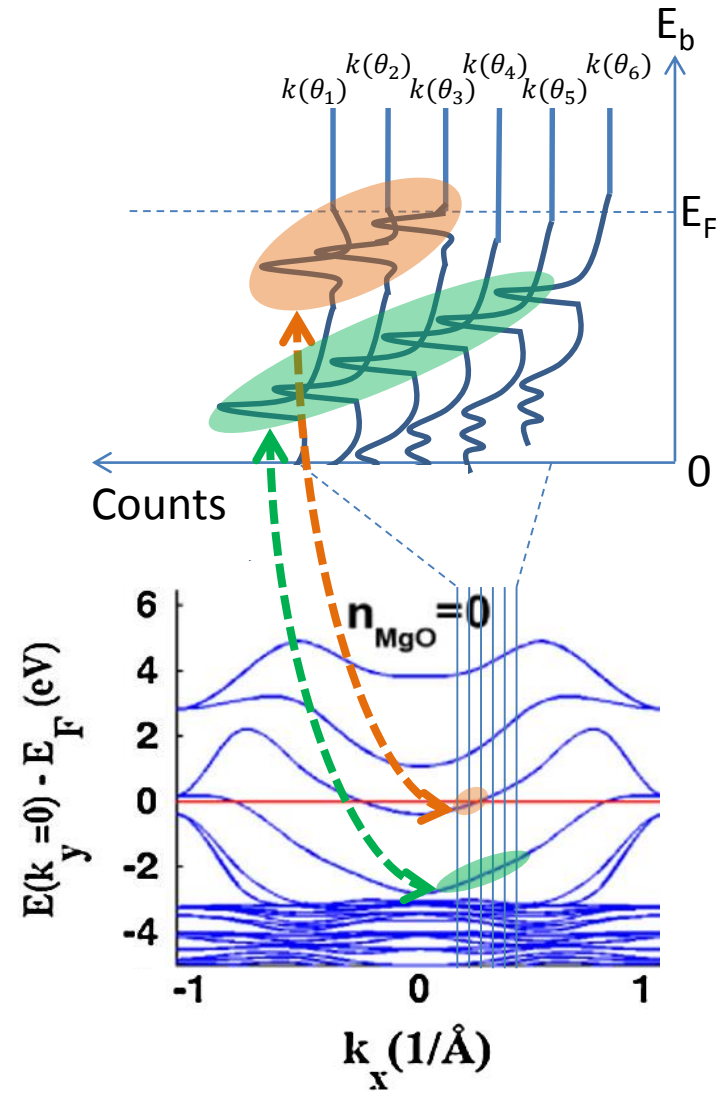
$$k_{f,\parallel} = k_{0,\parallel}$$

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

Low momentum spread → low angular spread → low intrinsic emittance

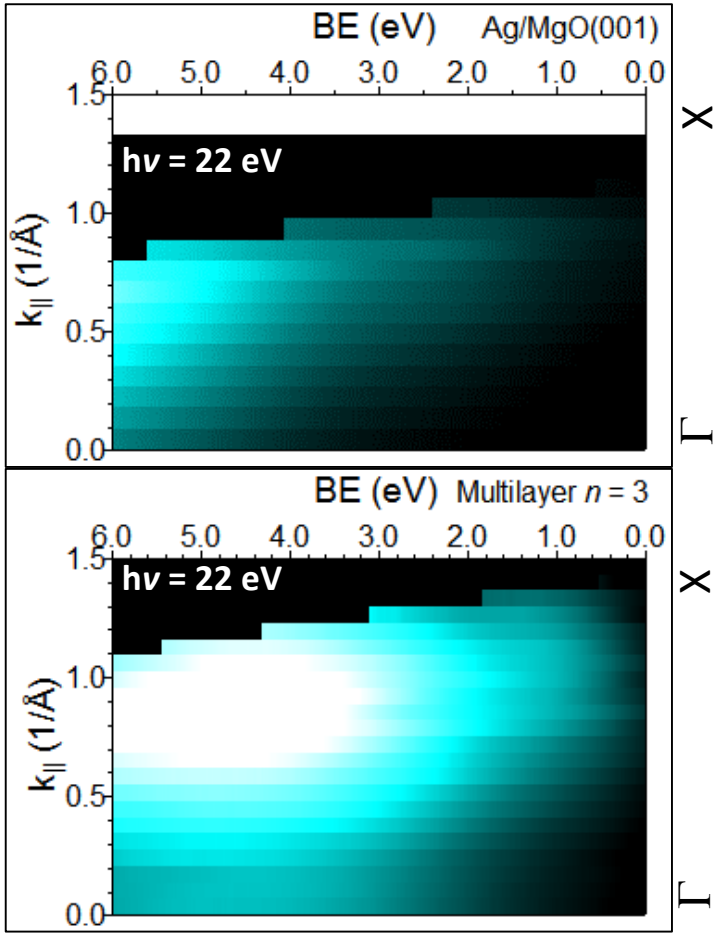
$$\varepsilon_{int,i} = \frac{\hbar}{mc}\sigma_\parallel \sigma_{k_\parallel}$$

Band Reconstruction from EDCs

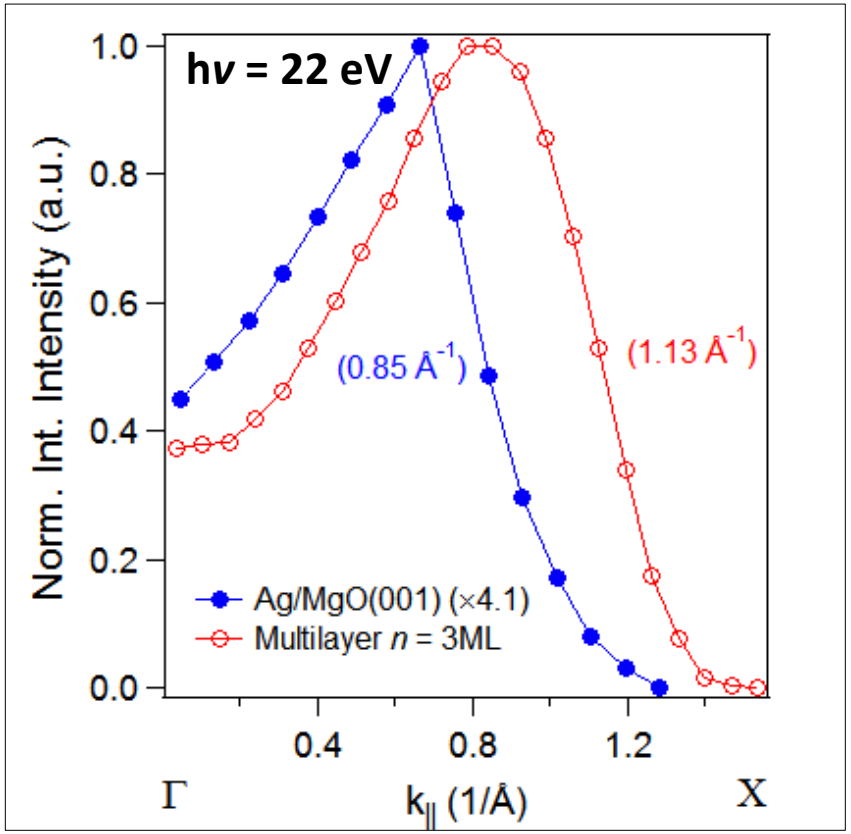


K. Nemeth et al. Phys. Rev. Lett. 104, 046801, 2010.

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



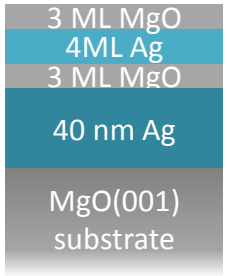
Integrated *I* vs Wavevector



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

Ag/MgO(001) → 3.28 µm/mm

ML (n = 3) → 4.36 µm/mm



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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