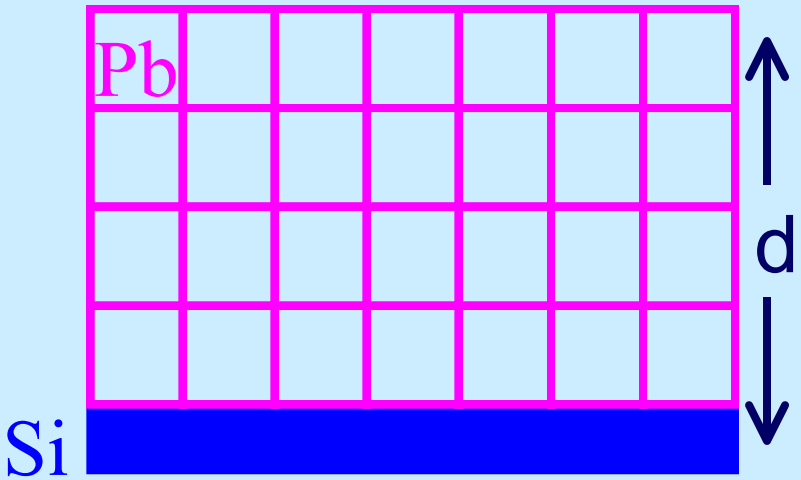
Photoemission Studies of the Electronic Structure and Properties of Thin Lead Films

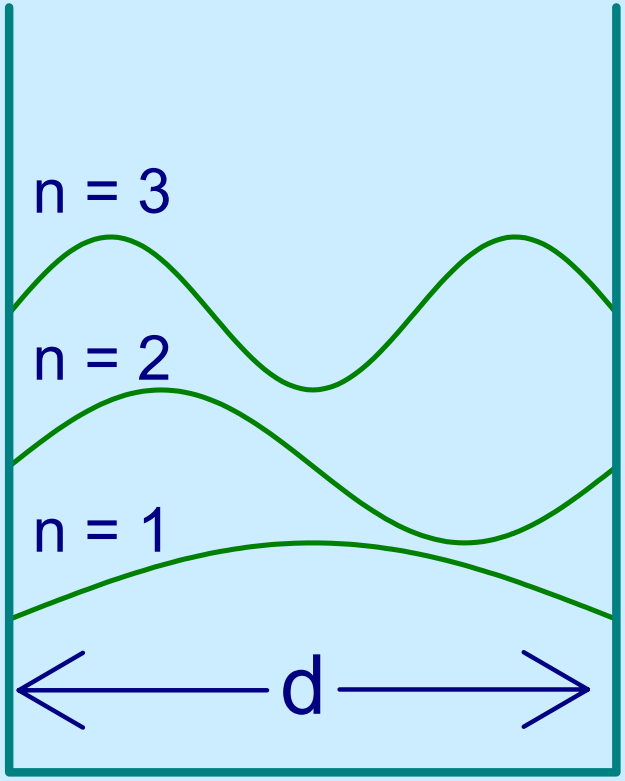
- Introduction
- Growth mode of Pb/Si(111)
- Bilayer Electronic Oscillations
- Dispersion in Pb/Si(111) films
- Thermal Stability of Pb/Si(111) films

Why Study Thin Films?

Physics reasons

- Confined systems
- Materials interaction, coupling
- Growth

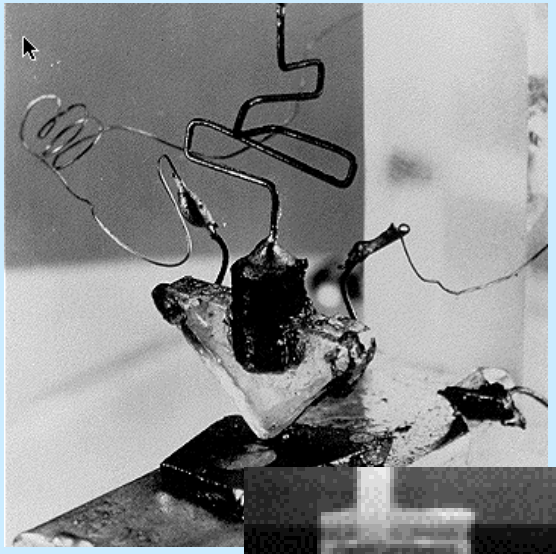




Why Study Thin Films?

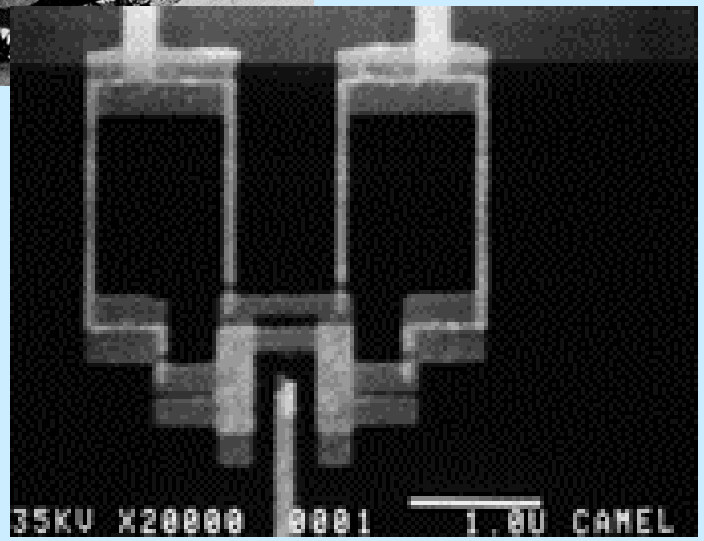
Practical reasons

- What happens as electronics get smaller?
- Thermal stability



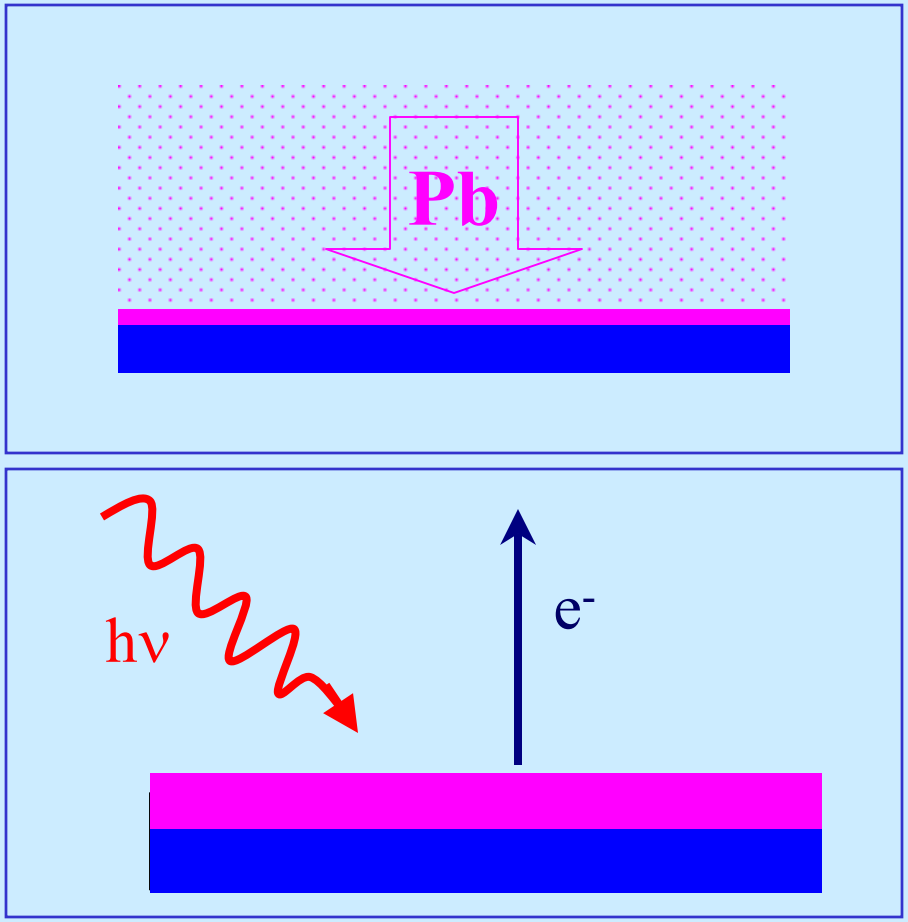
First transistor

Newer transistor

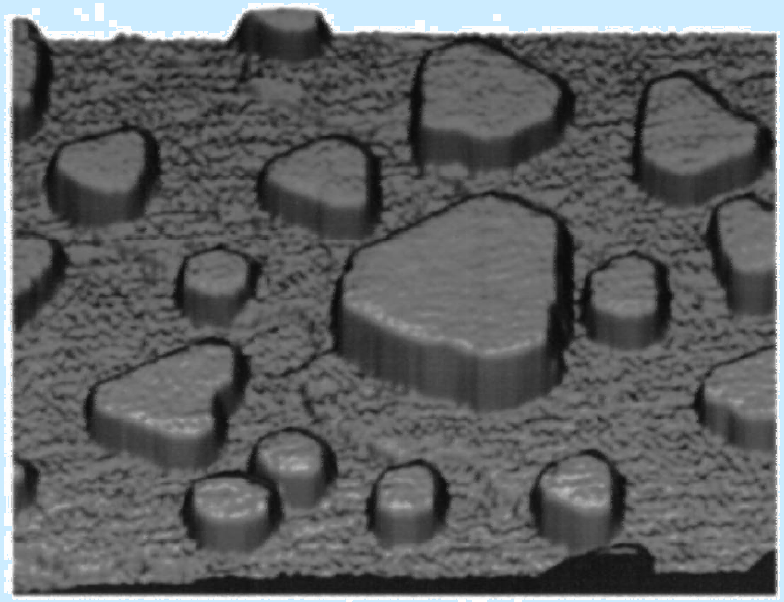


Our Experiment

1. Grow Pb films on 100 K Pb terminated Si with Molecular Beam Epitaxy (MBE).
2. Study sample with photoemission (photons in, electrons out)

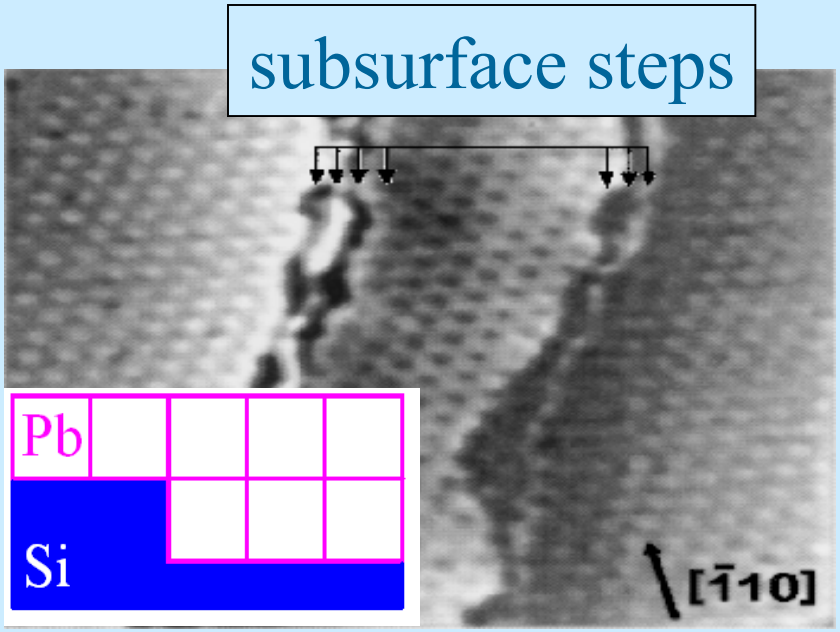


Pb/Si Previous Growth Work - STM



- 200 K growth
- Flat islands
- Preferred heights

Hupalo et al., PRB 2001

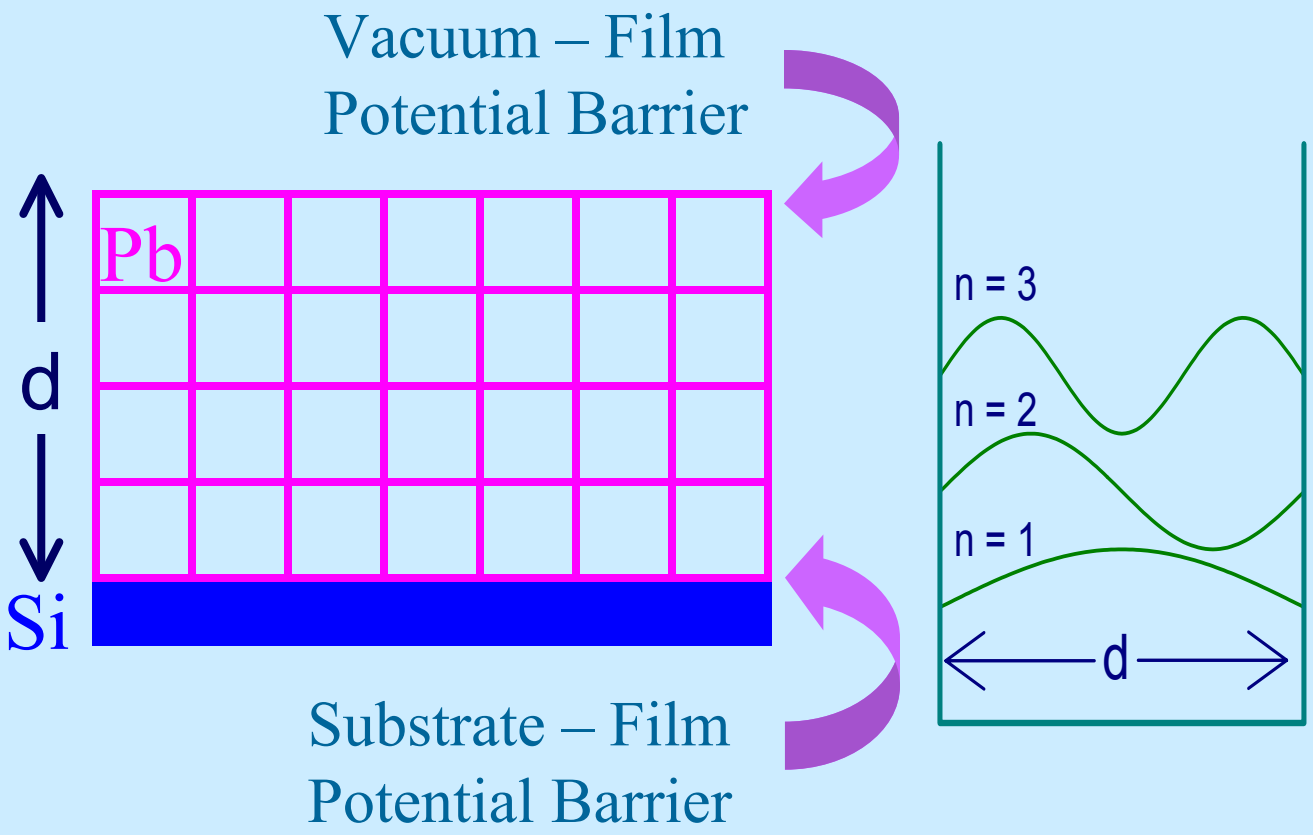


- 77 K growth
- Flat surface islands (uneven substrate)

Altfeder, Narayanamurti, and Chen, PRL 2002

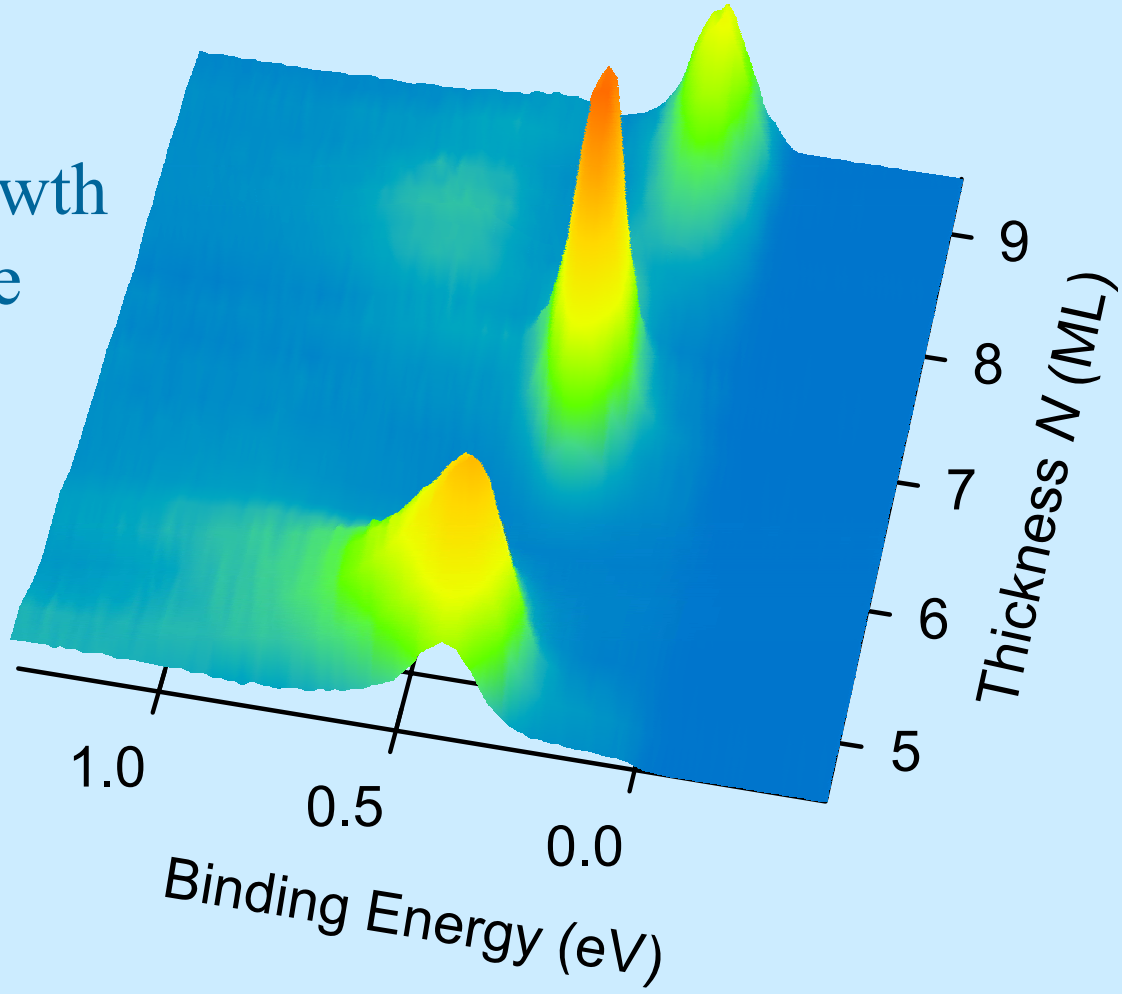
Quantum Well States

- Electron confined in film ⇒ Particle in a box states
- Need close to layer-by-layer growth to see states.



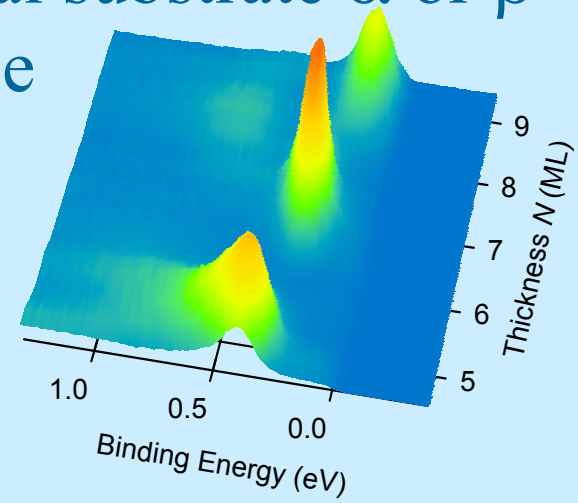
Pb/Si Layer by Layer Growth

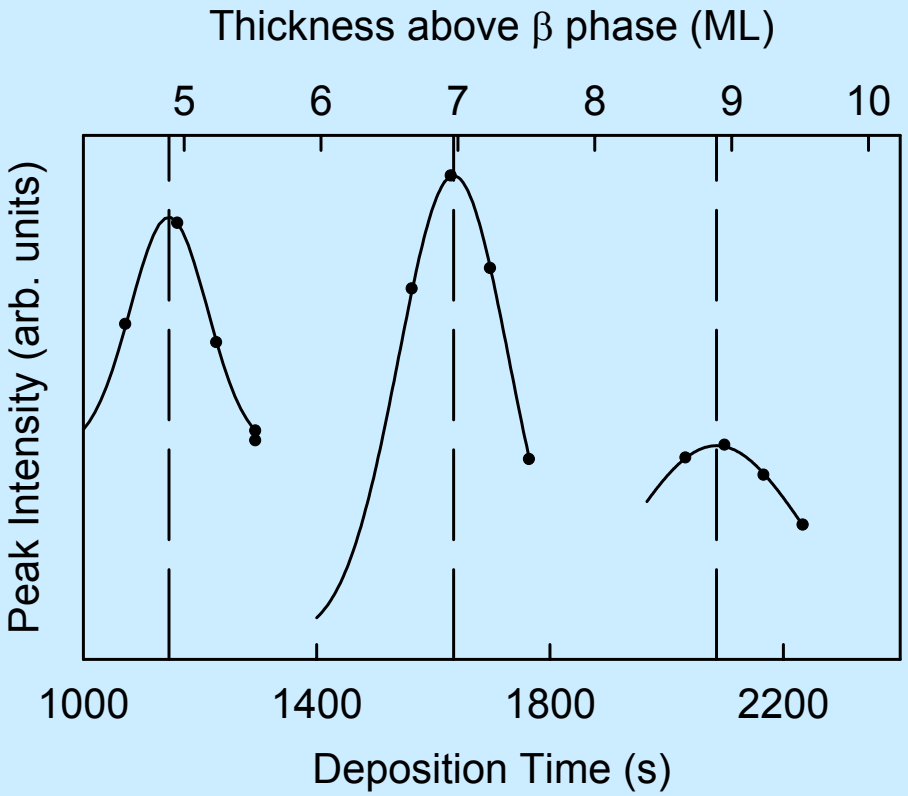
- Layer by layer growth despite large lattice mismatch
- Odd ML→sharp, intense peaks
  Even ML→broad shallow peaks



Film Thickness Determination

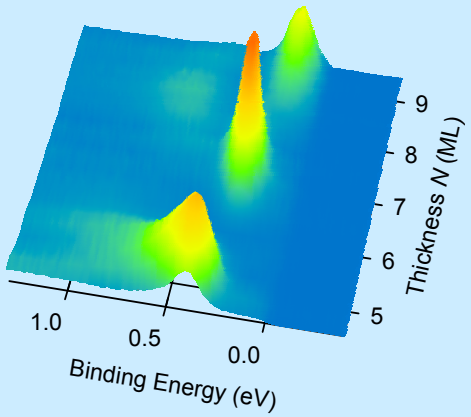
- Deposition time between 1st and 3rd major peak is 4 ML
- Seconds/ML gives total thickness of film
- Initial substrate α or β phase

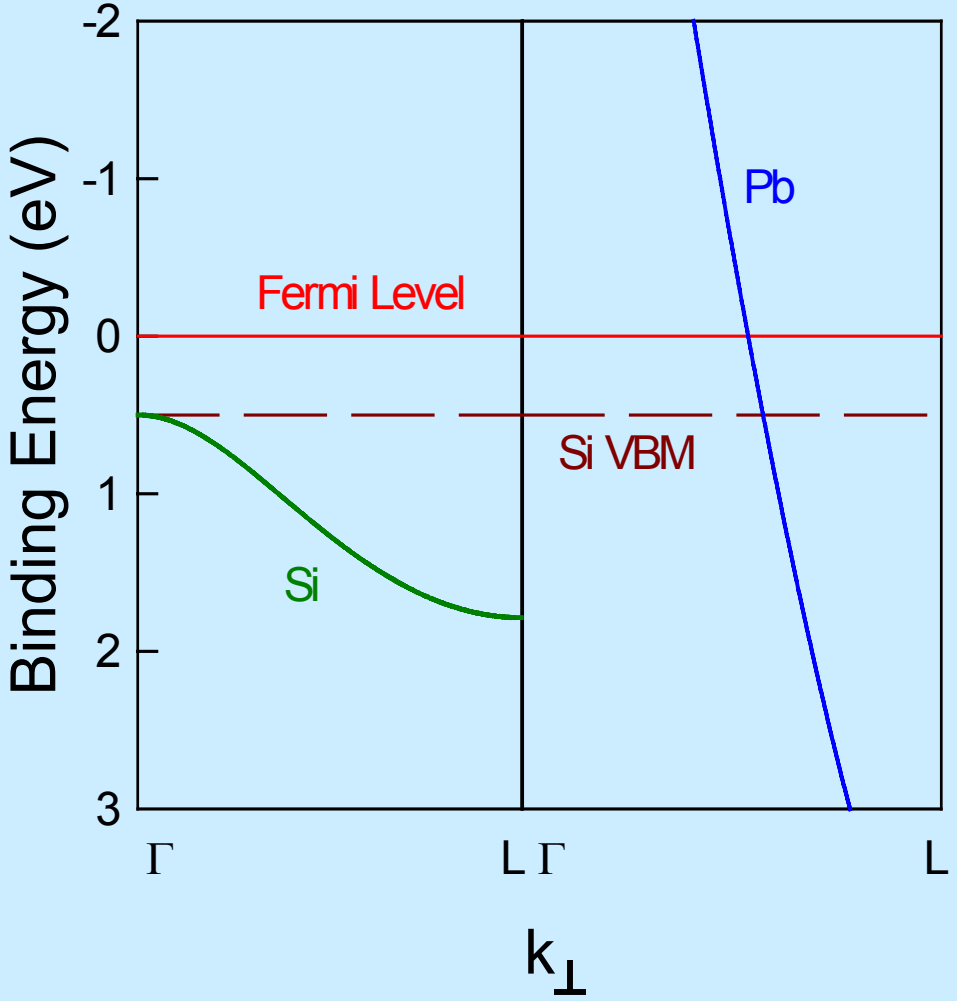




Quantum Well Confinement

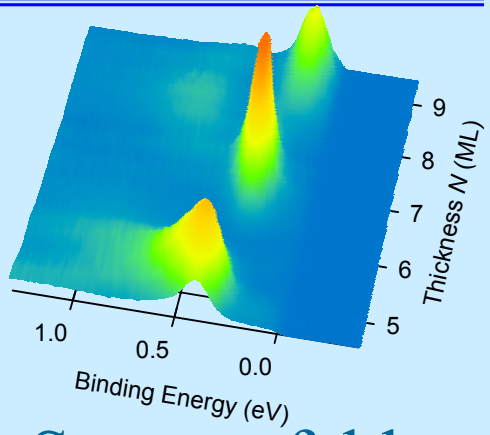
- Sharp peaks - Good confinement between Si VBM and Fermi Level
- Broad peaks - Partial confinement below Si VBM

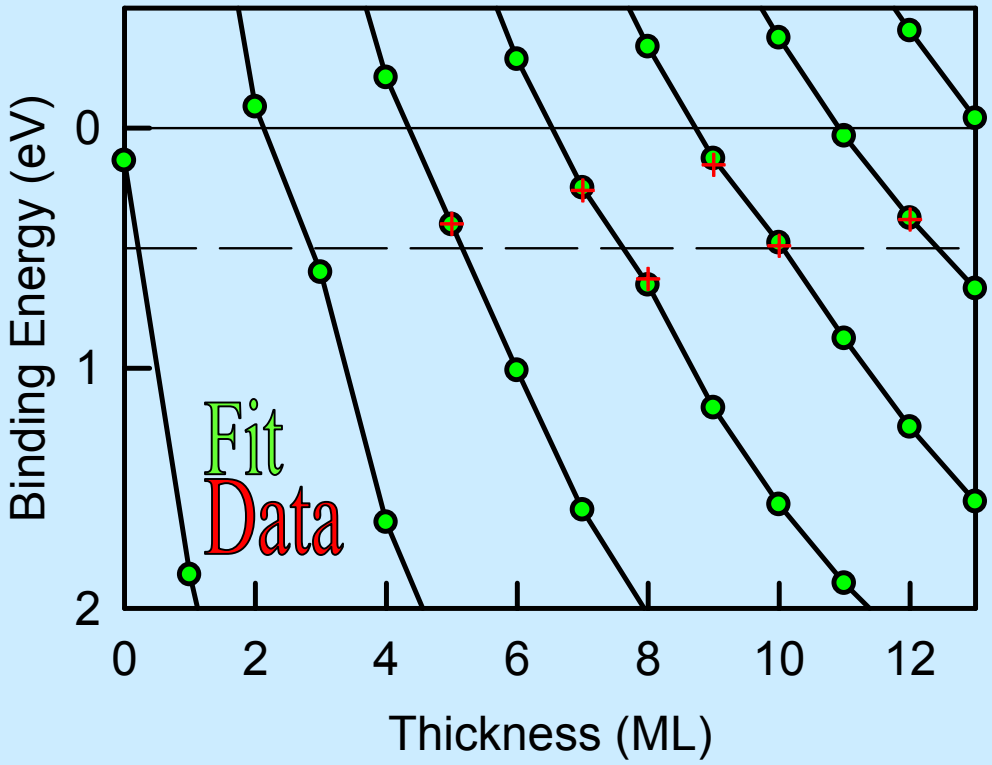




Film Electronic Structure

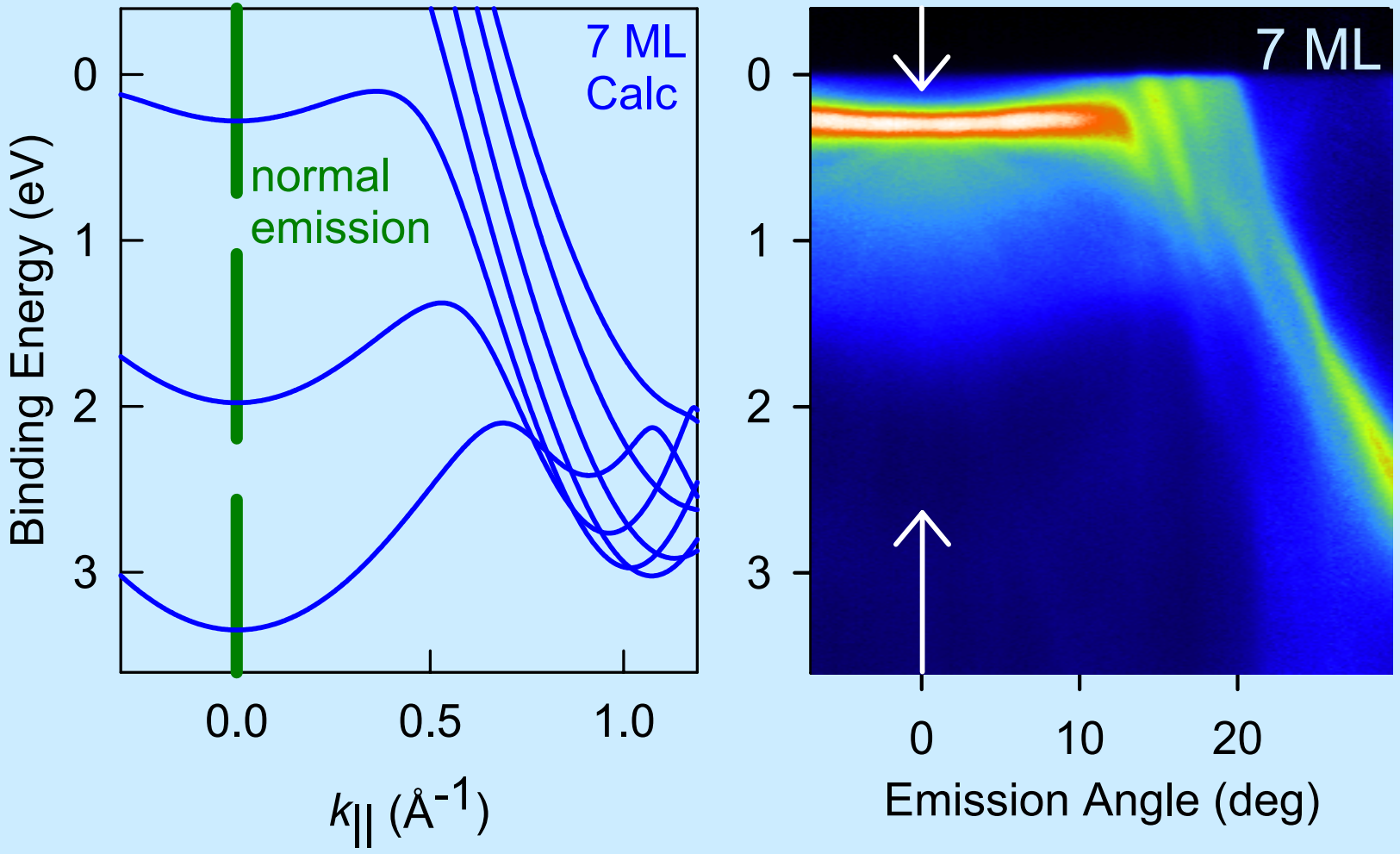
$$\underbrace{2k(E)d}_{\text{phase change in film}} + \underbrace{\phi_V(E)}_{\text{at vacuum}} + \underbrace{\phi_I(E)}_{\text{at interface}} = 2\pi n$$





- Bohr-Sommerfeld model
- Theoretical form for boundary phase shifts
- One parameter fit

Off Normal Spectroscopy

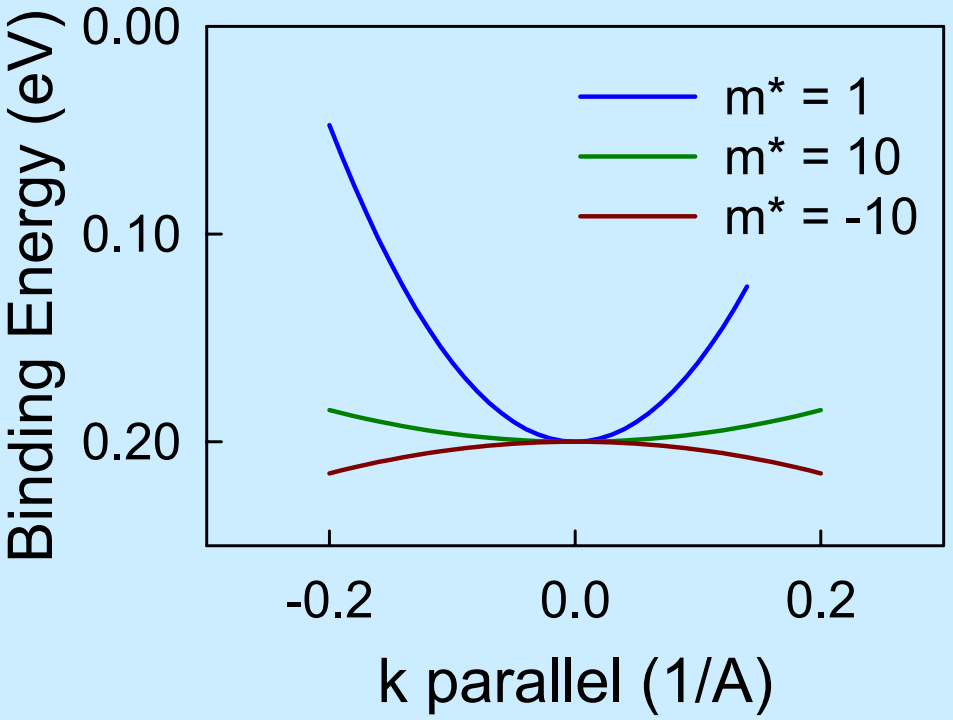


Effective Mass Refresher

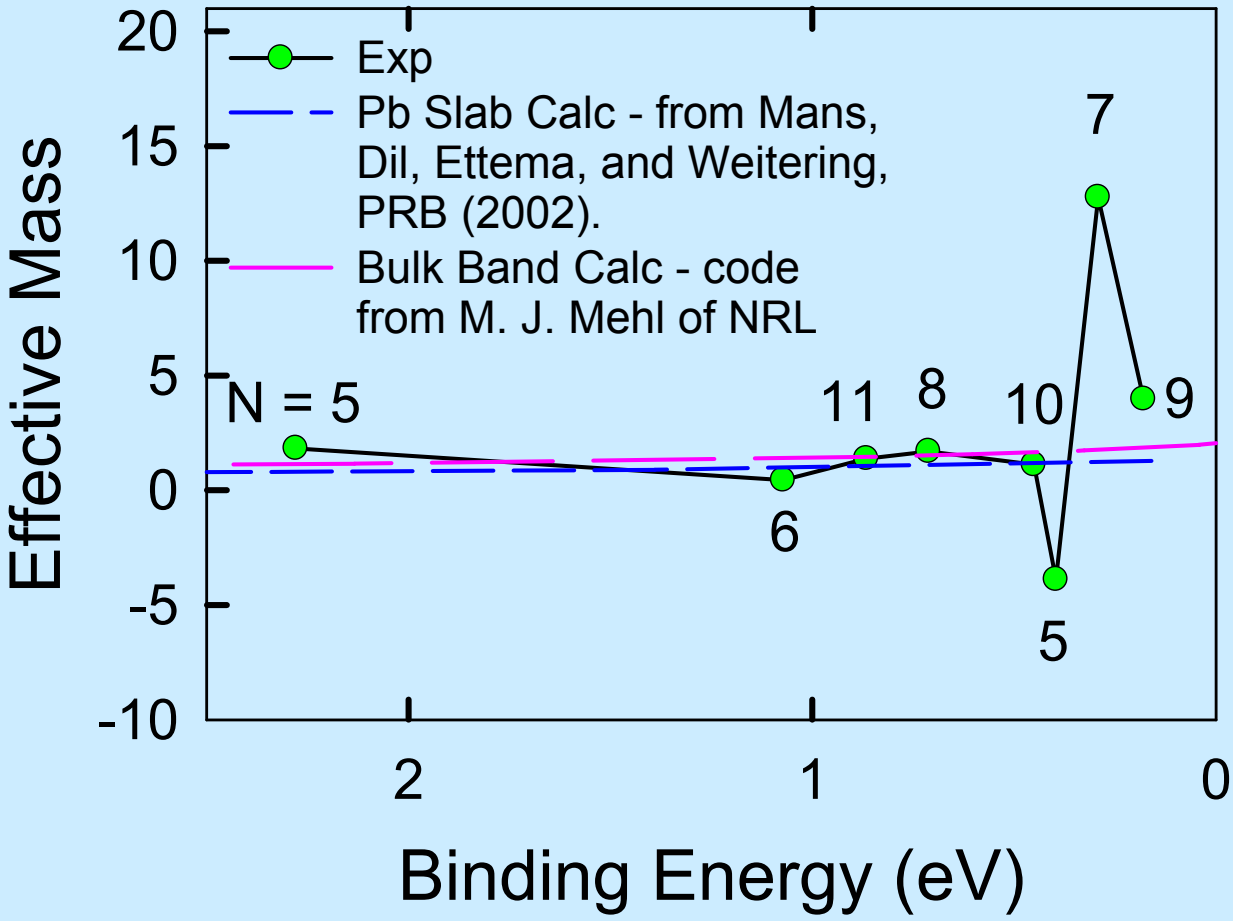
- Curvature of energy band

$$E \sim \frac{\hbar^2 k_{||}^2}{2m_e} \frac{1}{m^*}$$

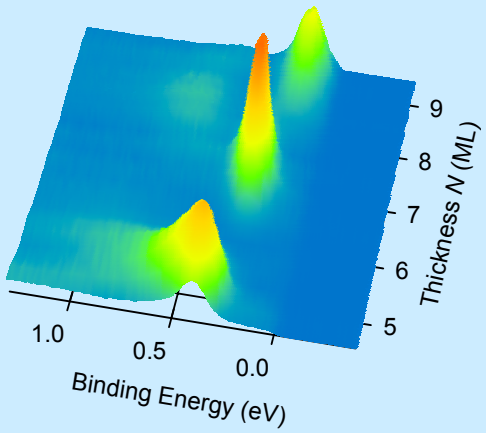
- Curved band ⇒ low m*
- Flat band ⇒ high m*



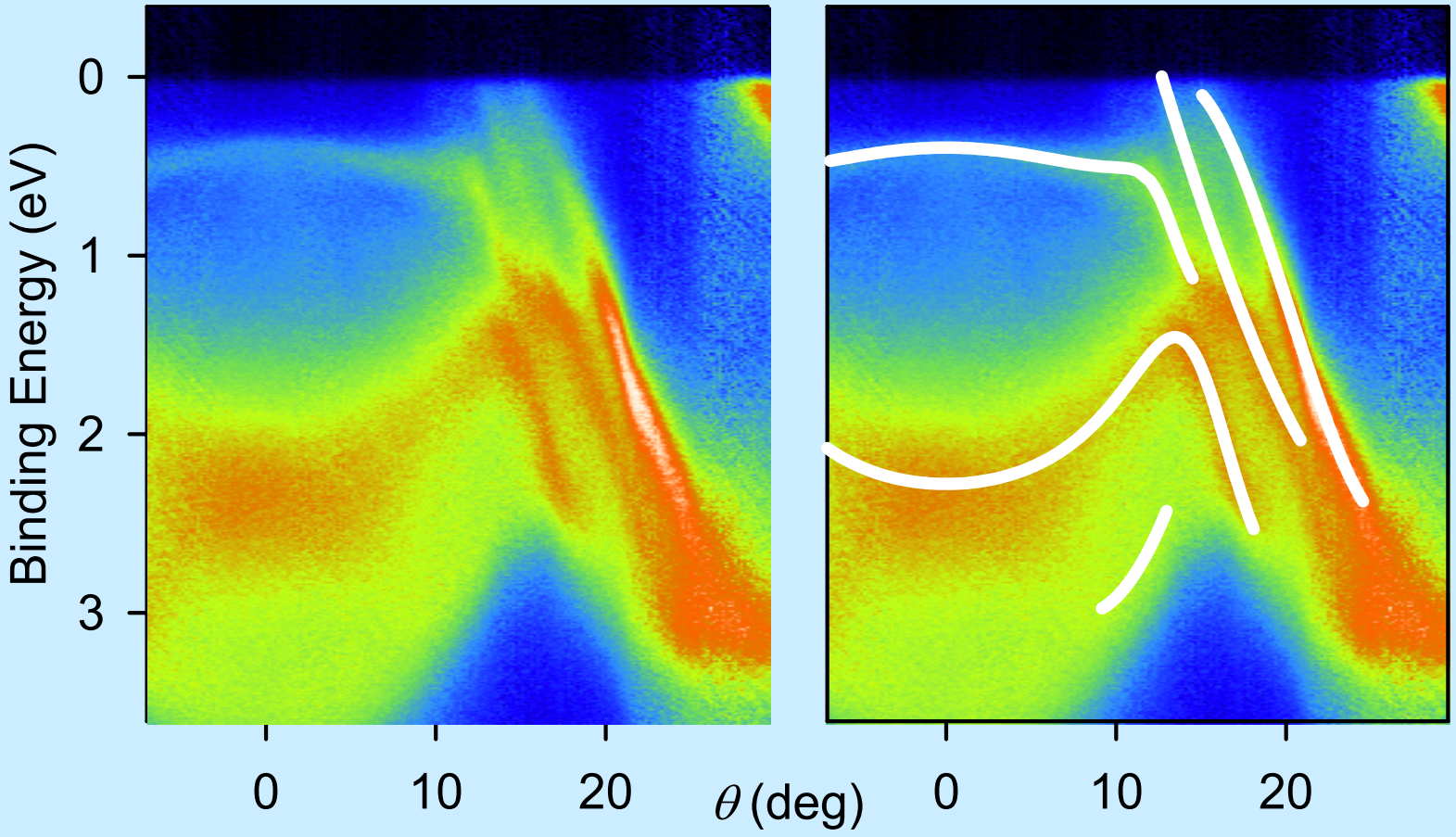
Effective Mass Measurements



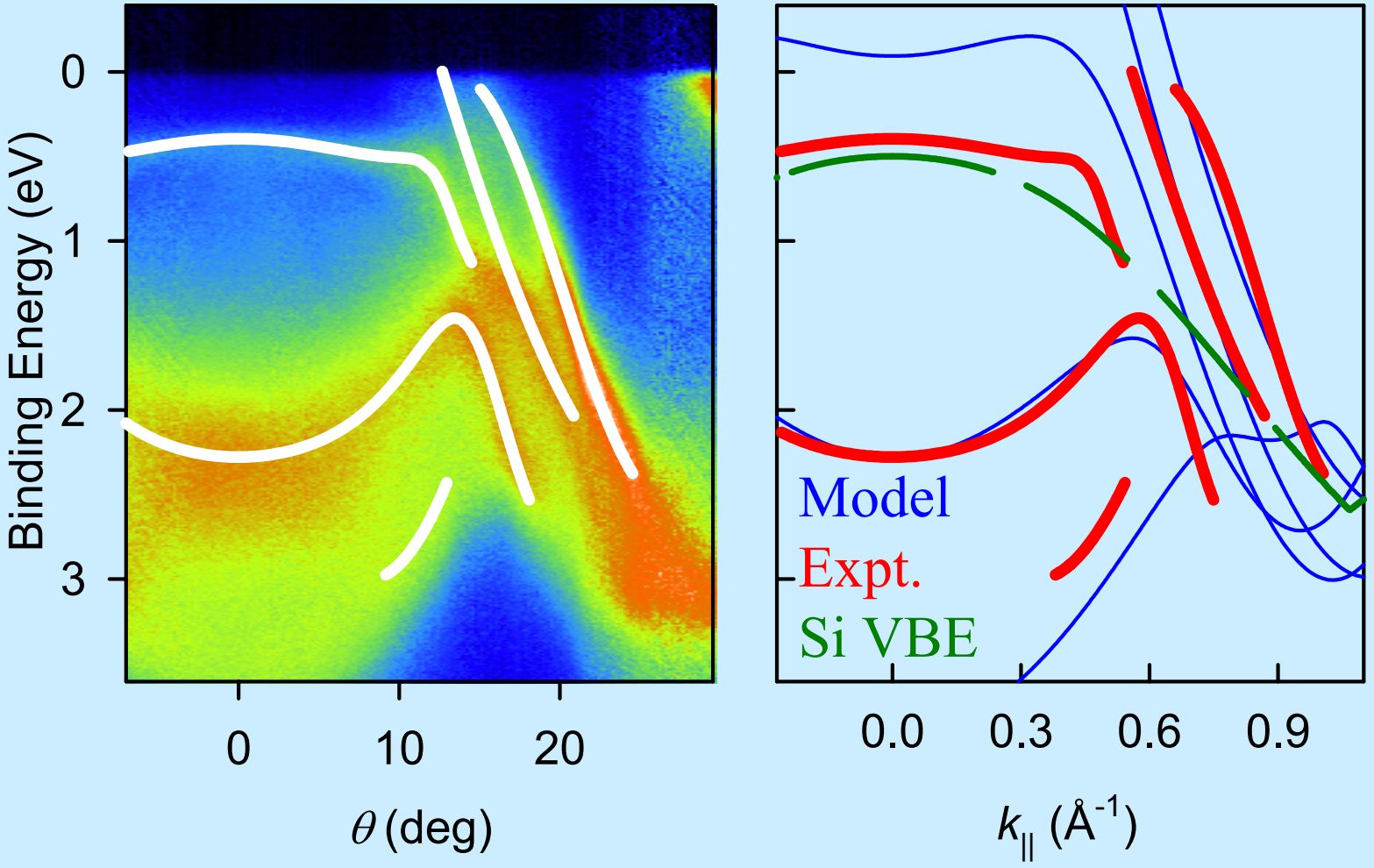
- Theory good at high BE
- Aberrant effective mass near Si VBM



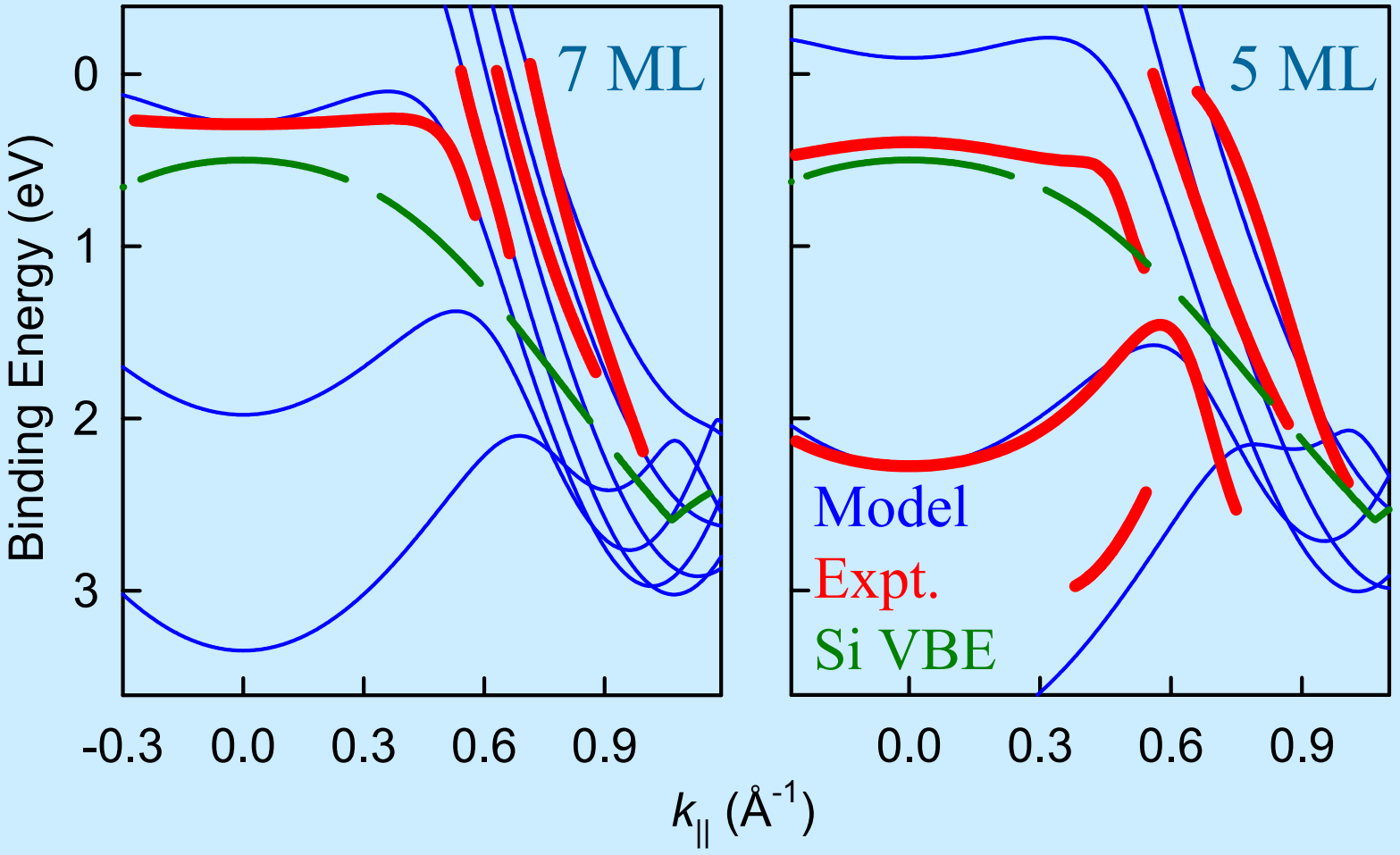
Dispersion Measurement – 5ML



Dispersion Measurement – 5ML

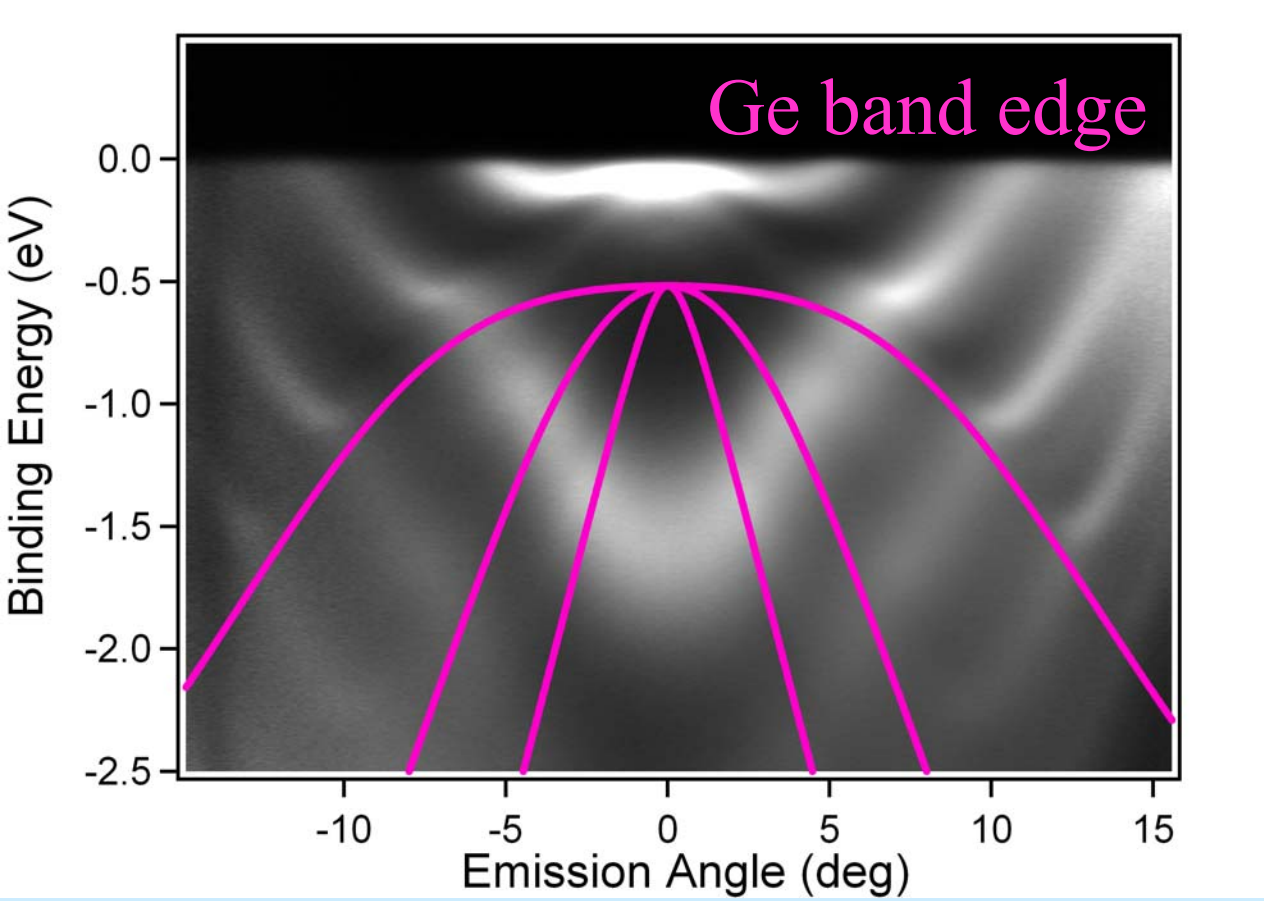


Si Band Edge Effect - Anticrossing

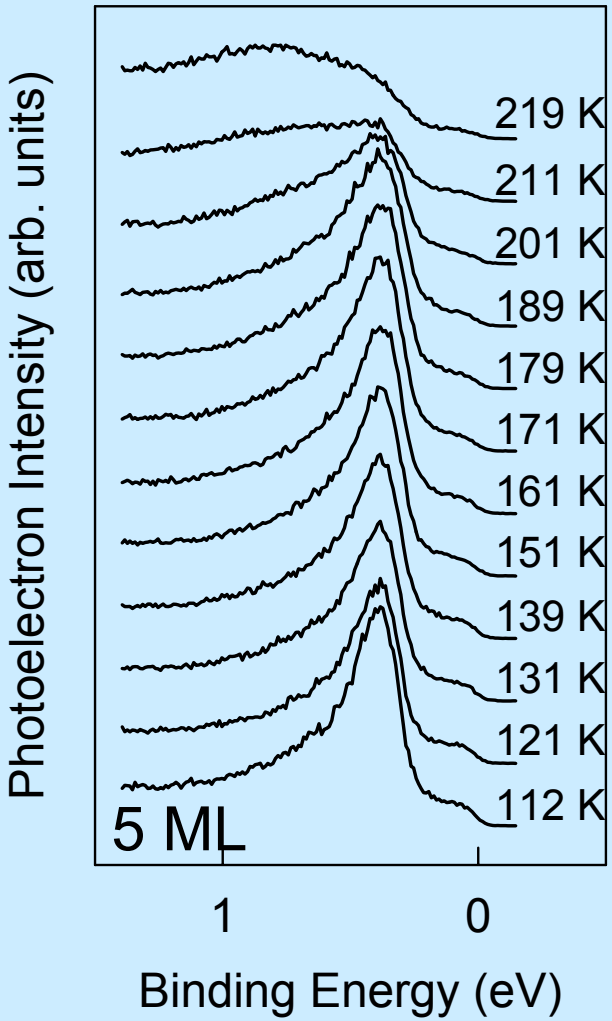


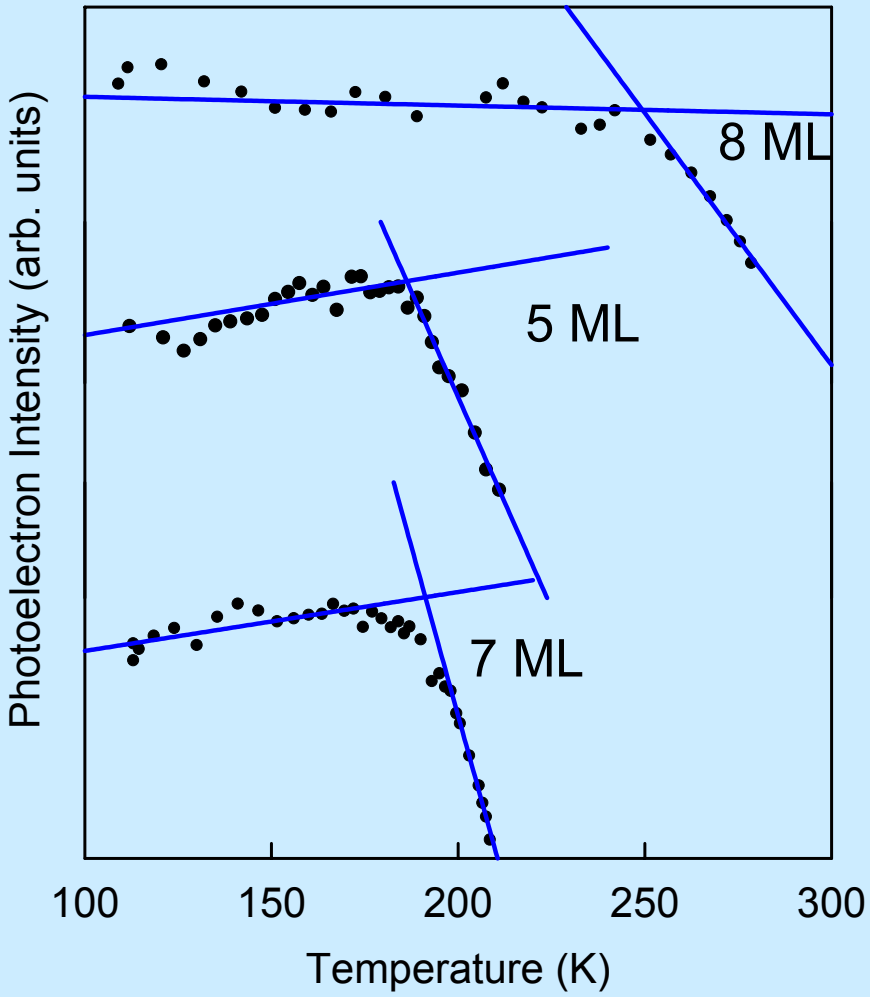
New Anticrossing Observations

8 ML Ag/Ge(111) S.-J. Tang et al. PRL 96, 216804

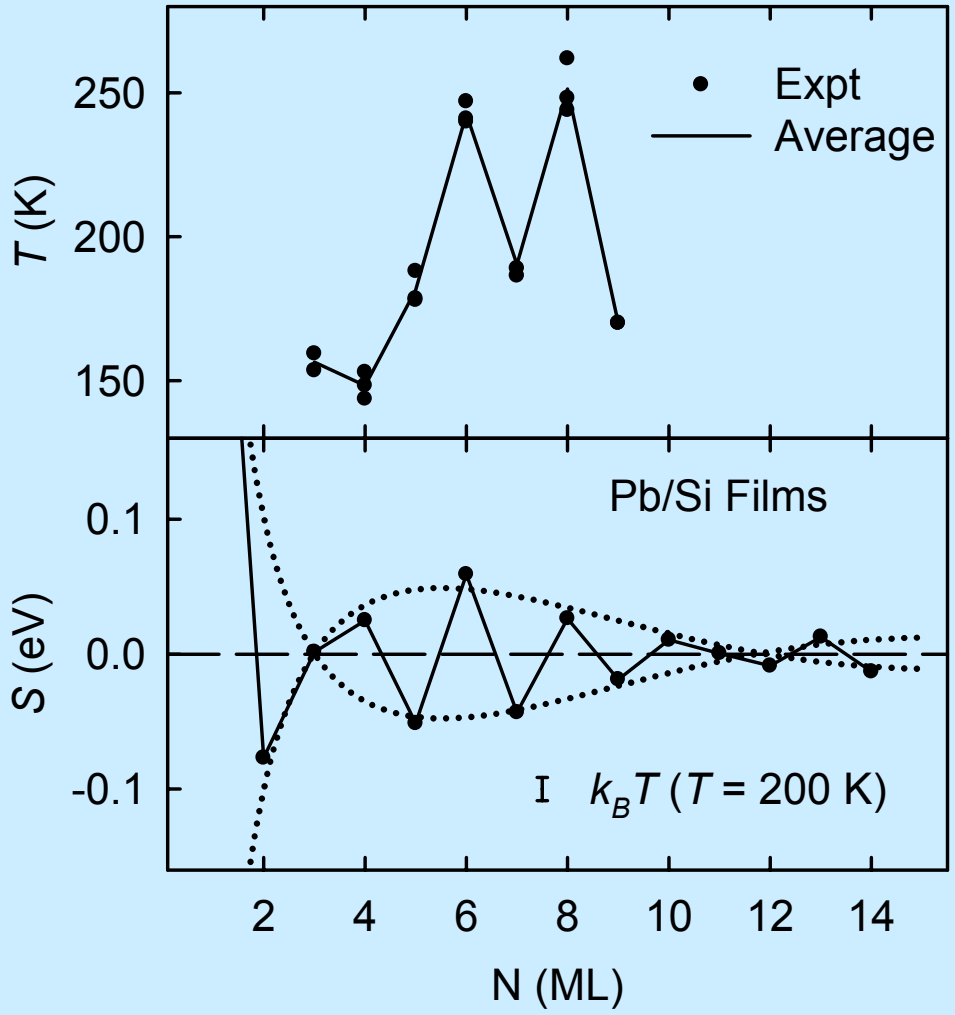


Measuring Thermal Stability





Thermal Stability



- 5-9 ML has bilayer oscillation as predicted
- Low ML unusually unstable

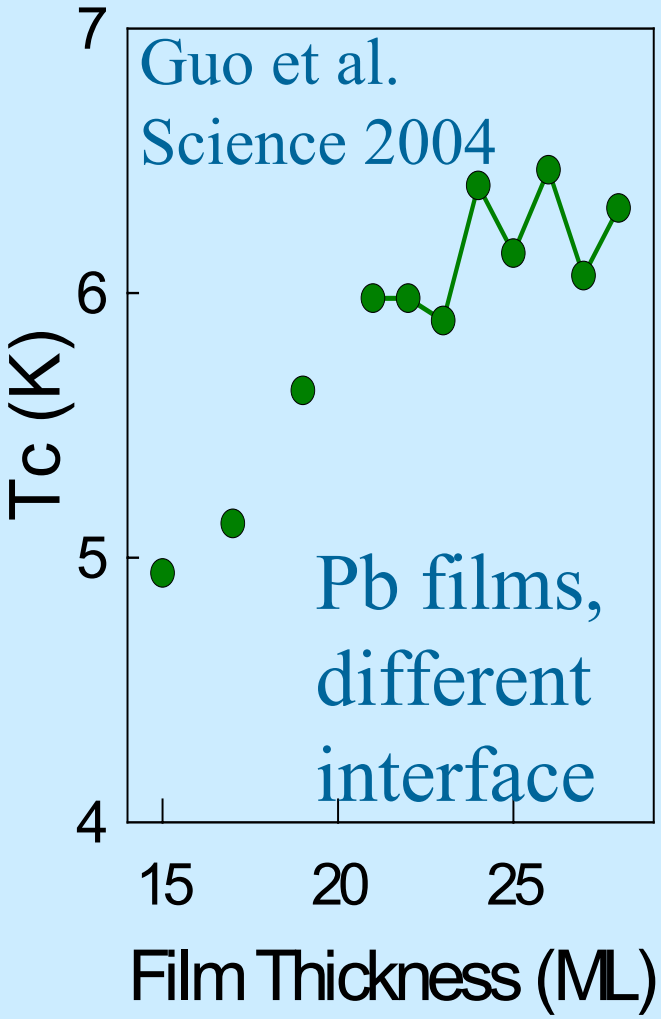
Calculation

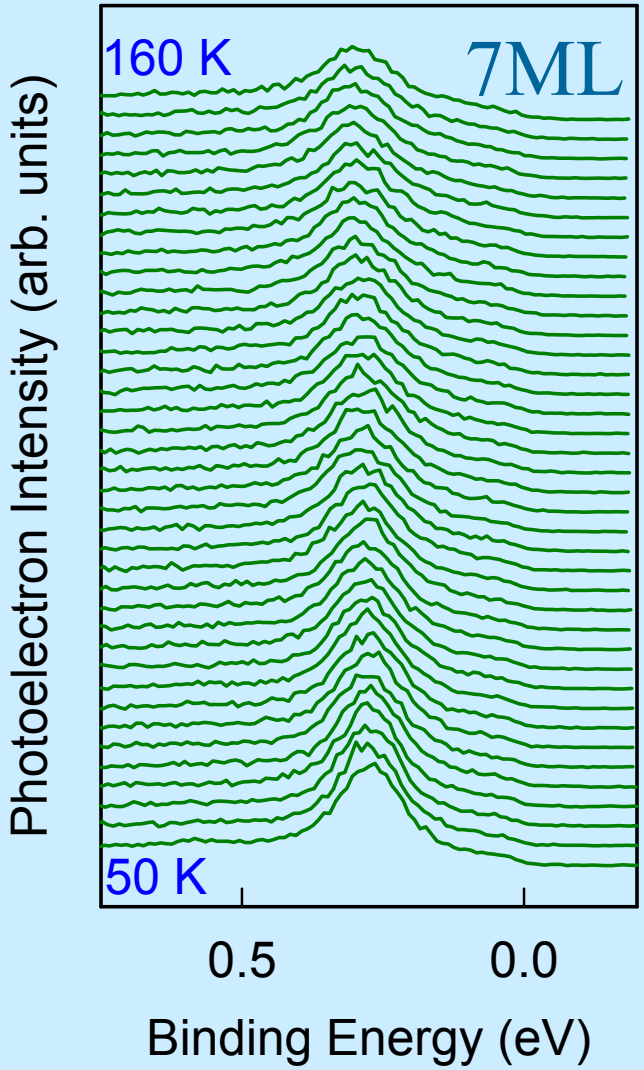
- S = 2nd derivative of Surface Energy

$$S = \frac{E(N+1) + E(N-1)}{2} - E(N)$$

- Si lattice is compressed to match Pb lattice

Next: Electron-Phonon Coupling





- Electron-Phonon coupling from peak width change with temp
- Peak position moves - lattice expansion?

Summary

- Atomically uniform films
- Bilayer electronic oscillations
- Quantum well sub-band dispersion
- Thermal stability of films shows even-odd oscillations