A Better Method of Electron Doping FeSe Thin Films

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PARADIM
AN NSF MATERIALS INNOVATION PLATFORM

Introduction:

Motivation

- Only one superconductor with room temp T_C (39 million psi)[2]
- The more we know about high T_C superconductors, the better we can design materials with higher T_C
- T_C increases from bulk when grown a monolayer on $SrTiO_3$ (STO)
  - From 8K in bulk to 65K as a monolayer
- STO/FeSe interfacial interaction causes change in T_C[1]

Overarching Research Question

- What about the interfacial interaction causes this change in T_C?
  - Comprised of multiple effects (like electron doping) so we want to isolate and test each one
  - Too big of a question to answer in 10 weeks

My Research Question

- Can we electron dope bulk FeSe with a Cs solid state reaction to produce a film that also gives high quality ARPES data?
  - Other electron doped films incompatible with ARPES or produce poor quality ARPES data

Methods:

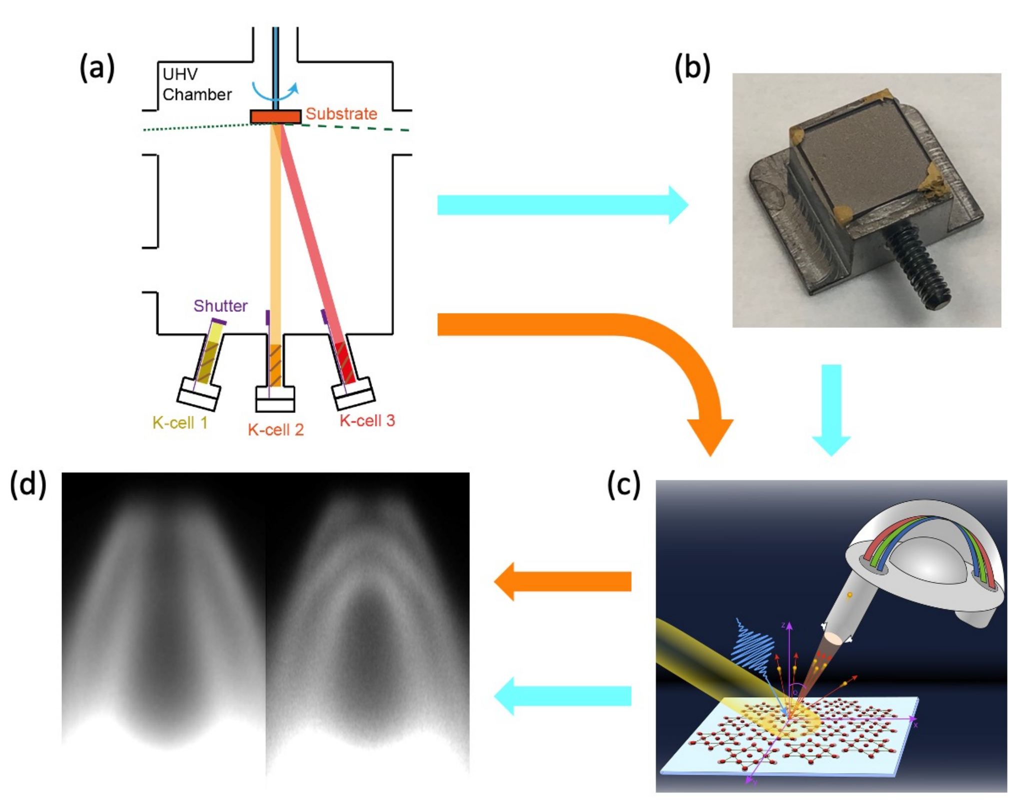

Figure 1. The progression of the growth process for the three films we used in our experiment. Two films followed the light blue path and one film followed the orange path. RHEED images were taken in between steps to monitor the quality of the film and substrate through the growth process. (a) The FeSe films were grown 20 UC thick on STO using MBE. (b) Two films had Cs deposited on their surface while one did not. (c) ARPES data was then taken and analyzed for all three films. (d) The resulting ARPES data was then compared.

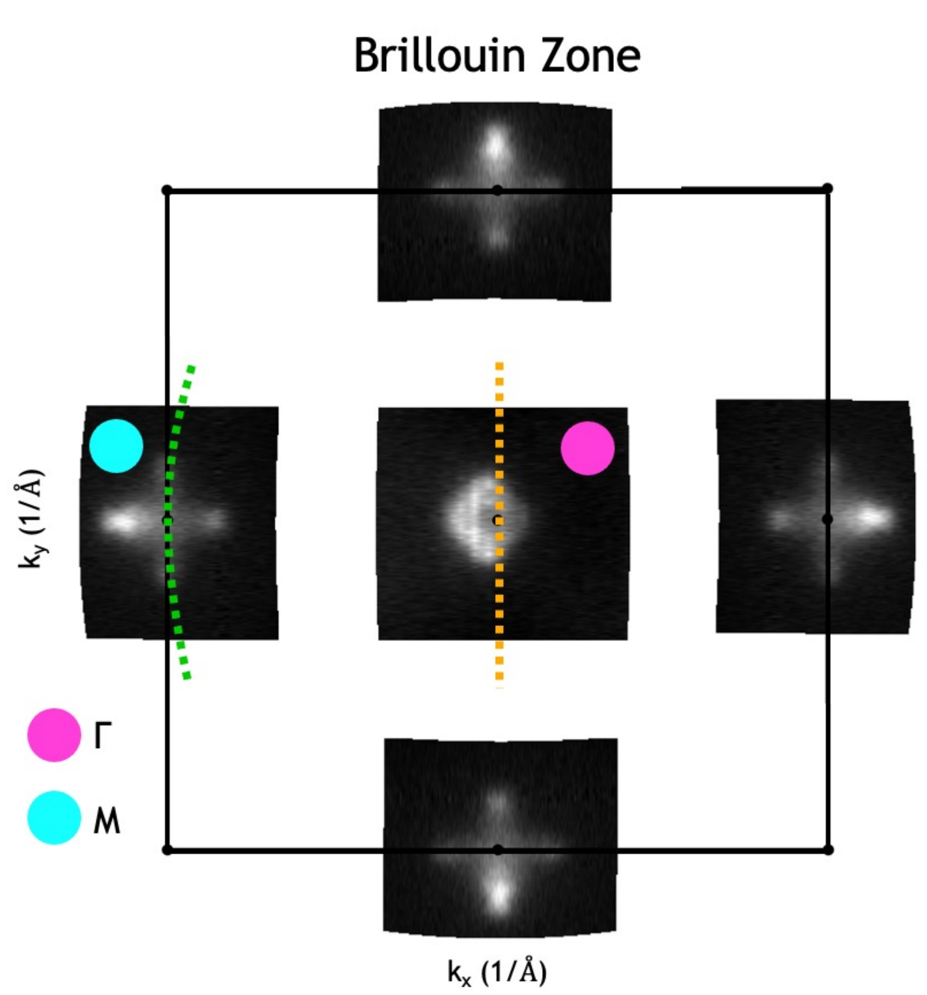

Figure 2. A Fermi Surface Map (FSM) of the undoped film. This is a plot of intensity as a function of electron momentum at the Fermi level. The pink dot marks Γ and the blue dot marks M. The dotted line on each feature marks the location of the cross section through that feature.

Growth

- FeSe films grown on STO using dedicated chalcogenide MBE system (Fig. 1)
- Substrate annealed, then heated to 600 ˚C to degas overnight
- Fe and Se co deposited at 420 ˚C for 13:20
- Cs deposited on two films for five min (solid phase epitaxy)
- Transferred to ARPES system and heated to intercalate Cs

Analysis

- Took ARPES data to capture the 1-Fe UC
  - Two FSMs: Γ and M (Fig. 2)
  - Cross sections through Γ and M (Fig. 2)

Results & Discussion:

Gamma Cross-Section

- Third band, β', in Cs doped samples not in undoped sample [Fig. 3(f)]
  - Caused by superposition of undoped bands onto doped bands

Gamma FSM

- Raw datasets [Fig. 3(a, d)] similar, third band not clearly present
- Third band (light blue) clearer in processed doped data [Fig. 3(c)]
- Outermost band in processed datasets nearly identical [Fig. 3(b, c)]
  - Evidence of superposition

M Cross-Section

- Doped datasets not the same at M [Fig. 4(b, c)]
  - Doped Sample A has undoped and lower doped phases [Fig. 4(b)]
  - Doped Sample B has additional higher doped phase [Fig. 4(c)]
    - Higher doped phase causes additional pink band [Fig. 4(b, c)]
    - Pink band closely mirrors dispersion of monolayer film [Fig. 4(d)]

Electron Doping Quantification

- Higher doped phase of sample B has about equal doping to monolayer [Fig. 5(c, d)]

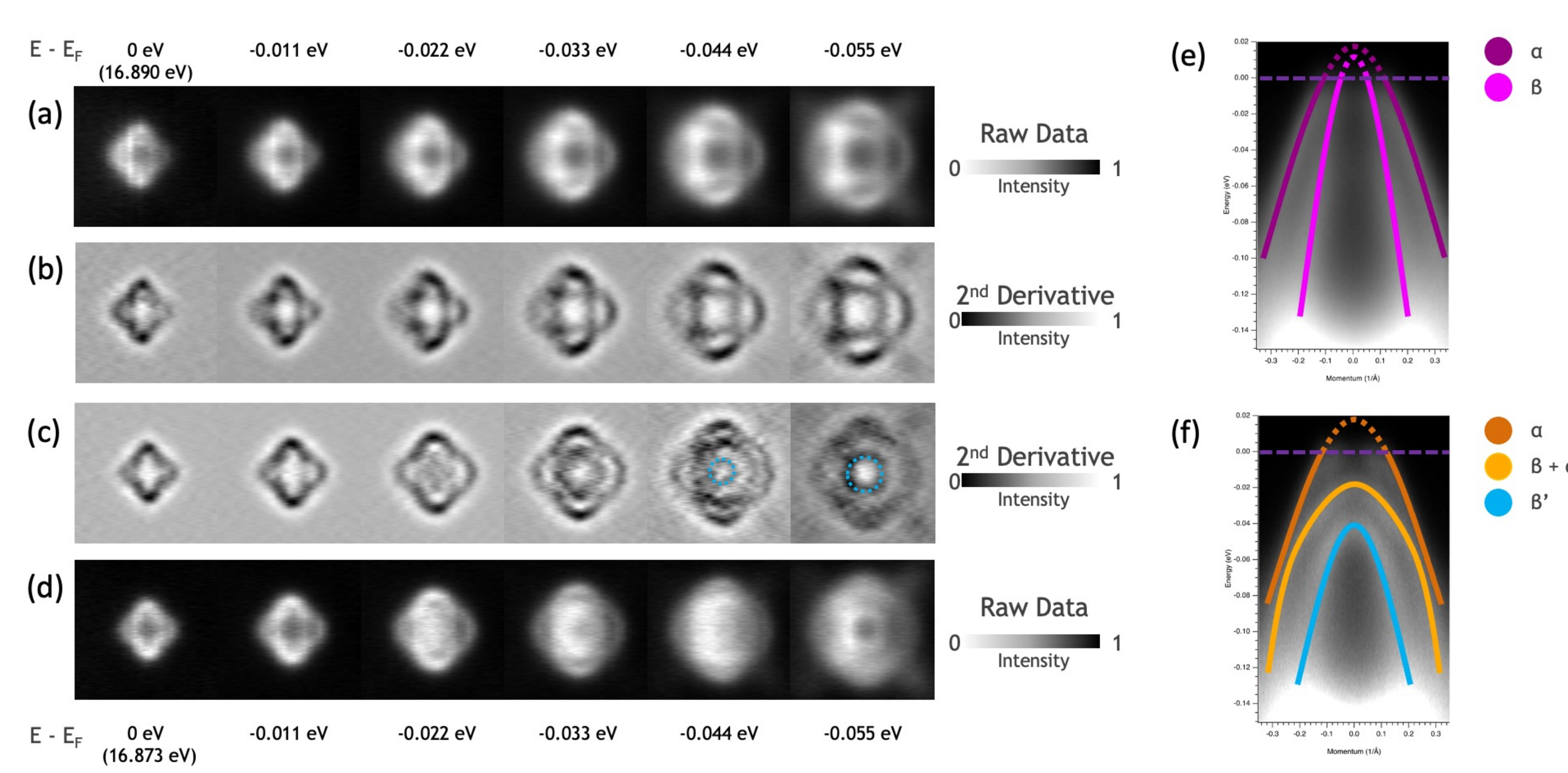

Figure 3. Breakdown of the feature at Γ. (a)–(d) are series of iso energy cuts at Γ which start at the Fermi level and decrease in energy. (a) Raw data progression of Γ in the undoped sample. (b) Processed raw data to accentuate the bands in the undoped sample. (c) Processed raw data for Cs Doped Sample A. The blue circle maps the dispersion of β'. (d) Raw data progression for Cs Doped Sample A. (e) Cross-section of Γ for the undoped sample. The colored lines map the band dispersion. (f) Cross-section of Γ for Cs Doped Sample A. α' and β' are the shifted versions of α and β due to electron doping.

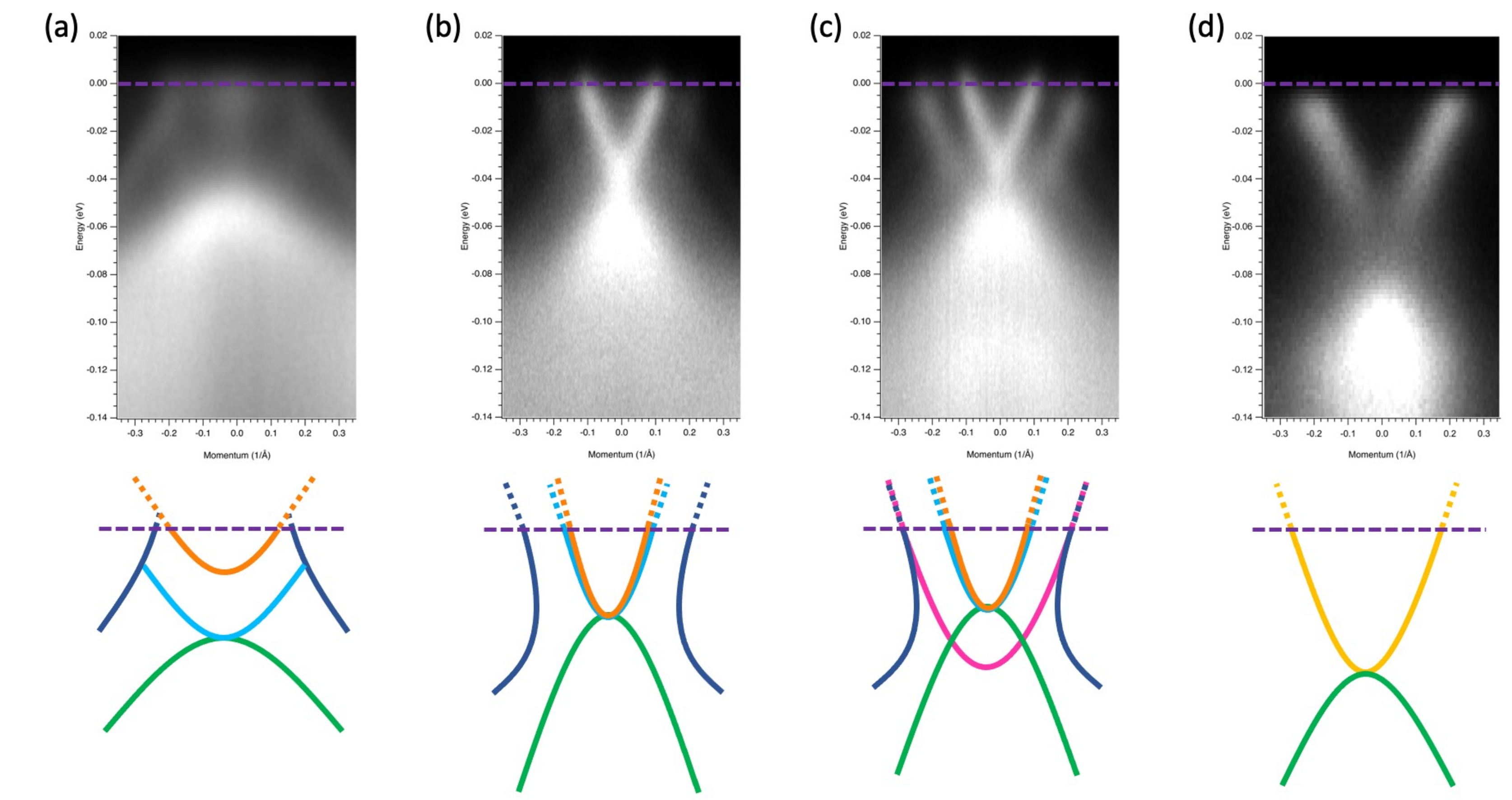

Figure 4. The cross-section slice through M for 4 different samples. The colored bands below each slice map the band dispersion in the data. The purple dotted line represents the Fermi level of each sample. (a) Undoped. (b) Cs Doped Sample A. (c) Cs Doped Sample B. (d) Monolayer FeSe

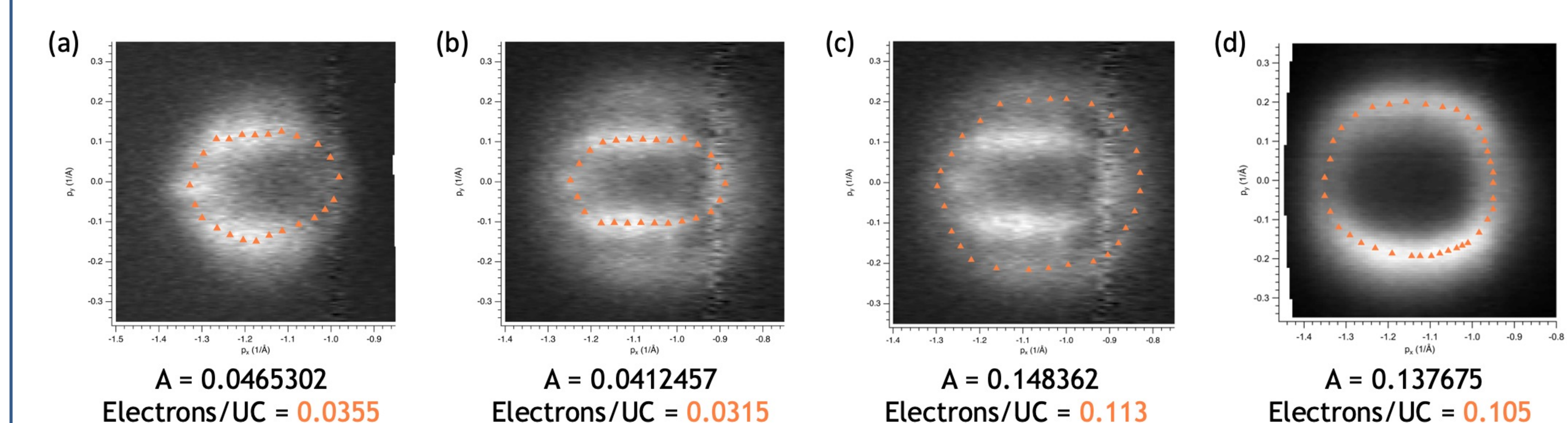

Figure 5. Outline of the bands at M in each sample's ARPES data at the Fermi level. The size of the bands corresponds to the doping level of the sample. (a) Cs Doped Sample A. (b) Lower doped band structure in Cs Doped Sample B. (c) Higher doped band structure in Cs Doped Sample B. (d) Monolayer FeSe.

Conclusions & Next Steps:

Conclusions:

- We successfully electron doped multilayer FeSe with Cs
  - This film produced very high quality ARPES data
  - However, this data was a mixture of phases with discrete doping levels

Next Steps:

- Determine if we can better control doping to create a uniform film
  - Ideally this film would be doped to about 0.1 additional electrons per unit cell, the same as the monolayer
- Test temperature dependence of the higher doped band structure

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References:

(1) Huang, D.; Hoffman, J. E. Monolayer FeSe on $SrTiO_3$. *Annu. Rev. Condens. Matter Phys.* **2017**, *8* (1), 311–336.

(2) Room Temperature Superconductor? Rochester Lab Sets New Record toward Long-Sought Goal. *NewsCenter*, 2021.