# Pulsed Laser Deposition of $FeSe/SrTiO_3$ Heterostructures

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## Introduction

- FeSe has been shown as a high critical temperature superconductor that operates under high vacuum
- Strontium titanite, $SrTiO_3$ (STO), has shown promise in ferroelectric properties in heteroepitaxial systems
- The β phase of FeSe has been shown to be the high temperature superconductor
- STO also has well defined peaks in both XRD and XPS
- Pulsed Laser Deposition was chosen as the growth method for its ease of thin film growth as well as the range of parameters to control deposition
- PLD helps control the energy density of the ions upon deposition which allows for more refined growth of phase-specific materials compared to other methods

## Hypotheses

- Pulsed laser deposition of β-FeSe and STO is a reliable growth method of thin layer superlattices of the materials
- β-FeSe/STO Heterostructures provide a method of atmospheric-protected growth of superconducting FeSe

## Materials and Methods

Target Synthesis

- Fe and Se powder were mixed in a stoichiometric ratio of 1.07:1 and ground in a mortar and pestle
- The target was pressed into a cylindrical disk in a hydraulic press at 6,000 lbs
- The disk was then sintered at 800 degrees Celsius for 8 hours
- The method above was repeated 5 times on the same target to develop a stoichiometric FeSe target
- A single crystal STO target was purchased

Pulsed Laser Deposition

- Samples were grown at a laser fluence of 1.5 J/m^2 with 55mm between the target and the substrate
- β-FeSe layers were grown at 1750 pulses with a substrate temperature of 450 degrees Celsius
- STO layers were grown at 360 pulses with a substrate temperature of 650 degrees Celsius

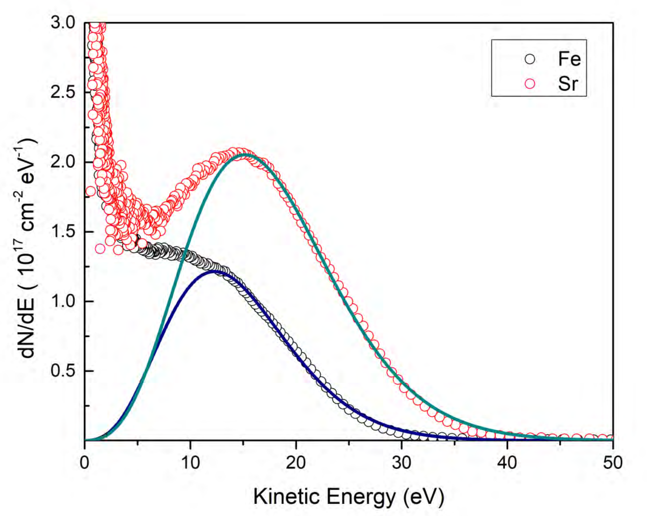
X-Ray Diffraction

- A rocking curve was determined to observer super reflections indicative of superlattice growth
- XRR was also employed to determine the thickness of the superlattices grown

X-Ray Photoelectron Spectroscopy

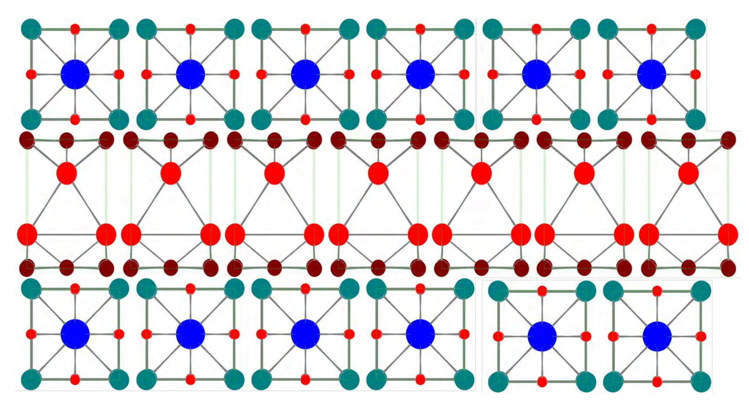
- A monochromatic Aluminum source as well as a conventional Magnesium source were used to determine species binding energy in the superlattice
- The XPS data was sampled at a 75 degree takeoff angle

## Plasma Ion Density

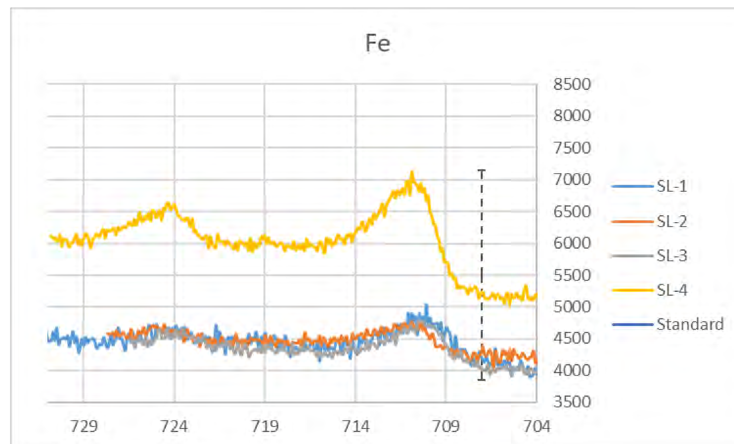



- Plasma Fe and Sr ion energy density
- Fe ions were chosen due to their contribution to the energy density of the FeSe plasma
- Sr ions were similarly chosen for the STO plasma
- The solid lines dictate the ion energy density obtained from Langmuir probe data
- The red and black points dictate the fit of the Fe and Sr ions in their respective plasmas.
- Both plasmas maintain an average ion energy below 35 eV as noted in literature for β-FeSe and STO growth

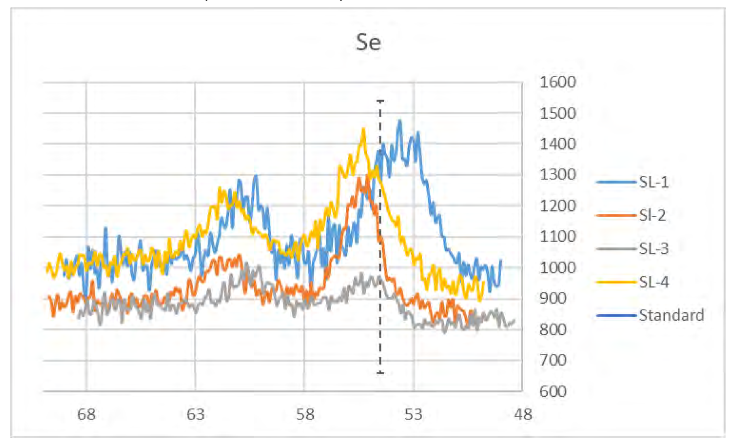
## X-Ray Photoelectron Spectroscopy



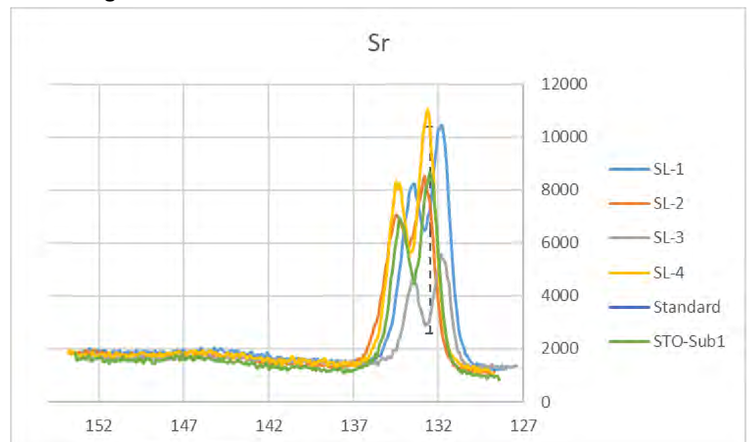
- Diagram of β-FeSe/STO Heterostructure
- β-FeSe layer embedded in two STO layers
- β-FeSe: Maroon-Se, Red-Fe
- STO: Blue-Sr, Green-Ti, Red-O



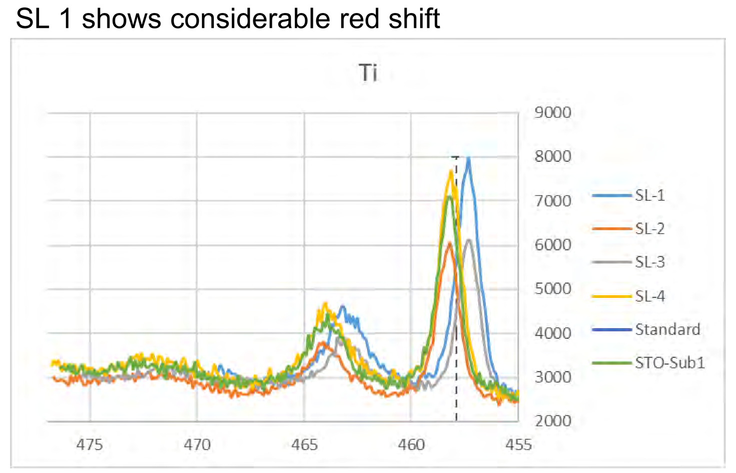

- XPS Analysis of Fe 2p peak
- SL 1-4 show considerable blue shift consistent with Fe-O bonding



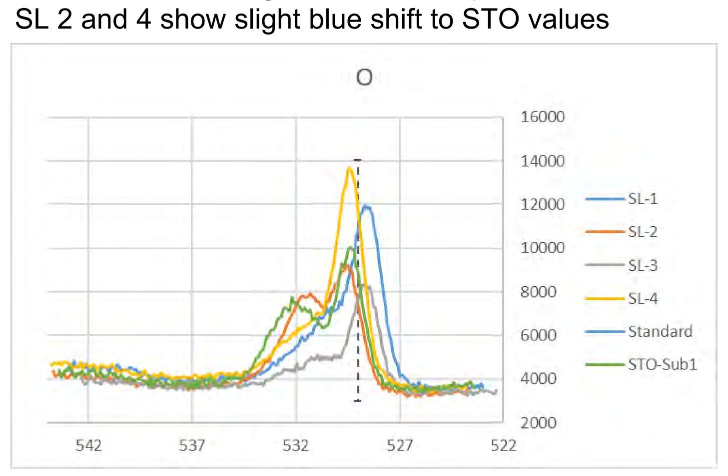

- XPS Analysis of Se 3d peak
- SL 2 and 4 show considerable blue shift
- SL 1 shows considerable red shift




- XPS Analysis of Sr 3d peak
- SL 1 and 3 show slight red shift compared to STO values
- SL 2 and 4 show slight blue shift to STO values

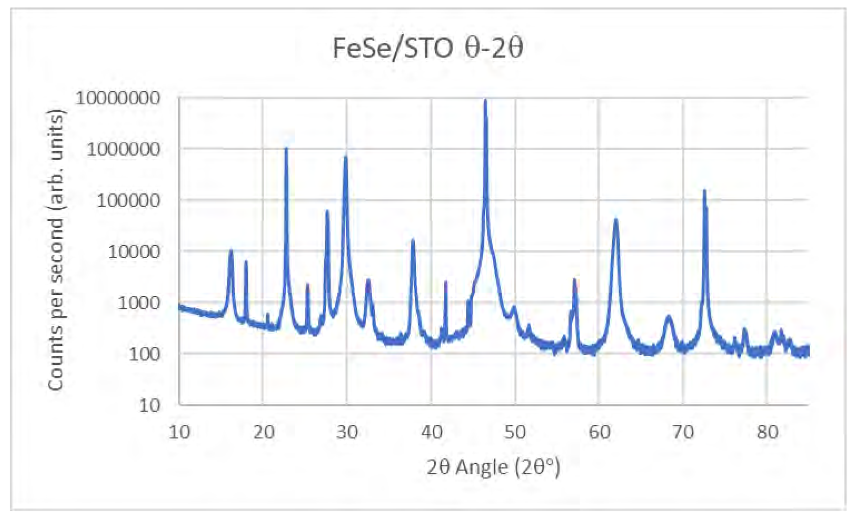


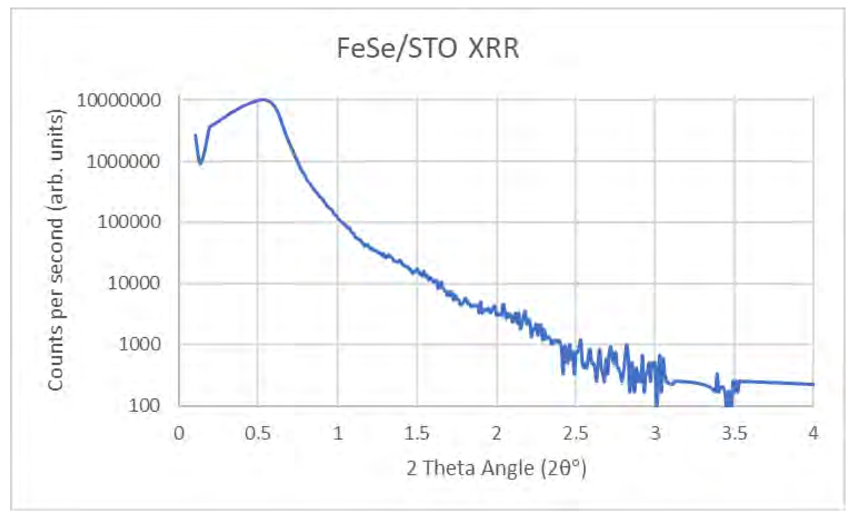

- XPS Analysis of Ti 2p3/2 peak
- SL 1 and 3 show red shift compared to STO values
- SL 2 and 4 show blue shift to STO values




- XPS Analysis of O 1s peak
- SL 1 and 3 show red shift compared to STO values
- SL 2 and 4 show blue shift to STO values

## X-Ray Diffraction




- β-FeSe/STO superlattice grown on a STO substrate
- The counts per second are graphed on a logarithmic axis due to the large signal of the STO
- The β phase of FeSe can be seen indicated in the peaks offset from the substrate peaks
- Some Fe contamination can also be found among smaller peaks representing less Se bonding

- XRR of β-FeSe/STO shows a complex structure for analysis due to the presence of the superlattice growth
- The superlattice growth results in two variations in peaks in which the larger peaks, dictated by STO, are filled with smaller peaks which are indicative of the β-FeSe
- Due to the abnormal structure and limit to the resolution, a thickness measurement was not performed

## Discussion

- A β-FeSe superlattice was grown with slight deficiency in the Se bonding of the FeSe layers as well as slight Fe-O bonding
- STO is shown to have wide variations in binding energy in the 1 eV range due to the formation of excess $TiO_2$ layers
- Fe blue shifts in XPS can be attributed to Fe-O bonding between the β-FeSe and the STO monolayers
- Se blue and red shifts are consistent with nonstoichiometric β-FeSe growth in the monolayers
- Ti and O XPS peaks indicate identical $TiO_2$ growth to the STO substrate on the 6 and 22-layer superlattices with the 11-layer superlattices containing red shifted peaks
- Sr presents identical and red shifted values comparable to the Ti and O peaks with the addition that the peak width is variable between the STO substrate and the grown monolayers
- XRD shows the deposition of both β-FeSe and STO monolayers in a 1:5.5 ratio superlattice
- XRR is consistent with superlattice growth in the oscillations of the peaks

## Future Direction

- Further study of the β-FeSe and STO Heterostructures is needed for the structured growth of superconducting β-FeSe with minimal contamination
- Analysis of the critical temperature of the superconducting layer is needed within the superlattice
- Further growth is needed for the refinement of the PLD conditions during superlattice growth

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