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NiO_x Thermal Boundary Conductance

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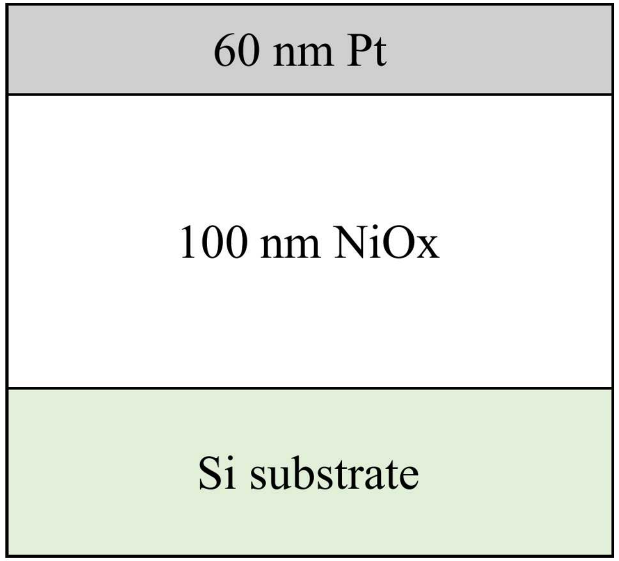
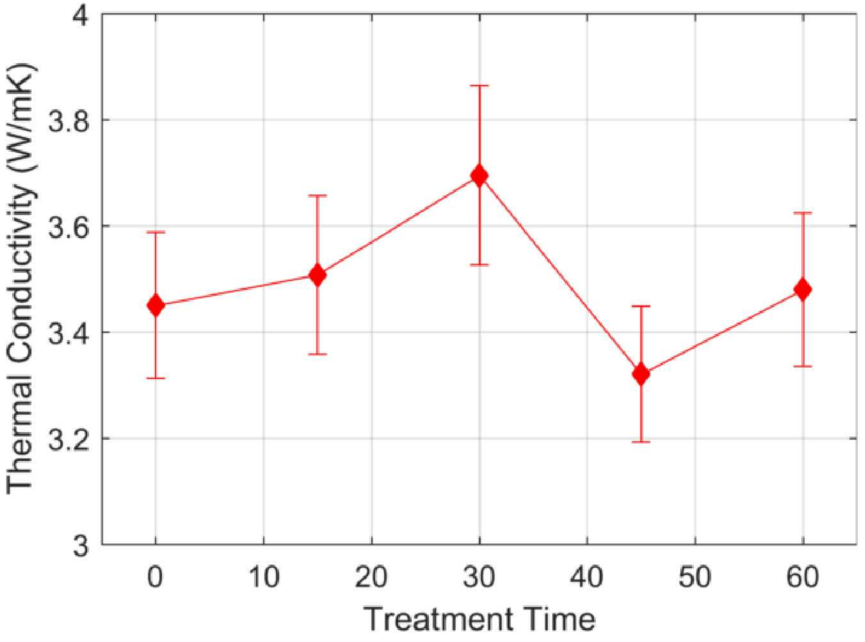
Samples

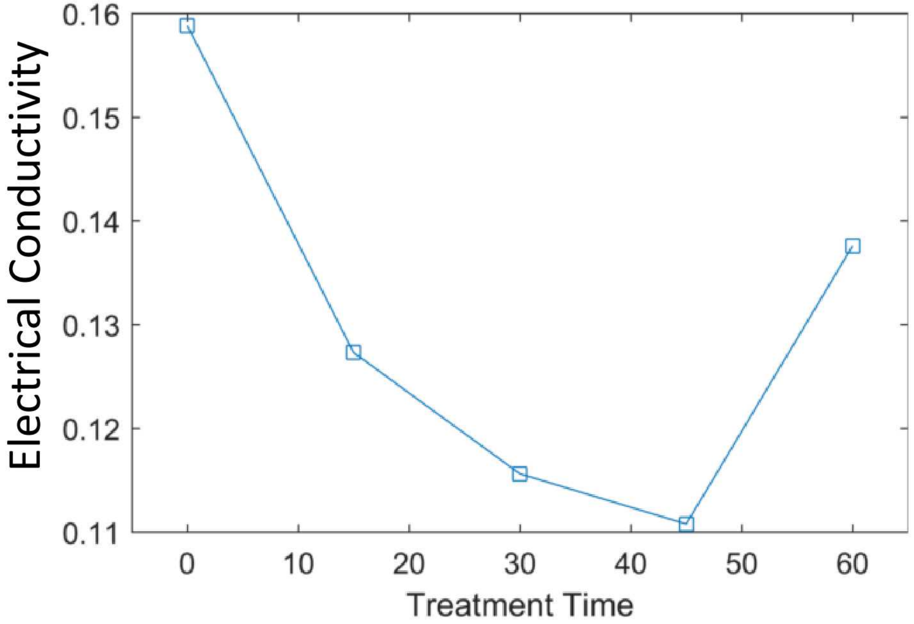
Treatment Time (min)	Electrical Resistivity (Ω.cm)	Expected Electronic Thermal Conductivity (W/mK)
0	6297	$1.2x10^{-6}$
15	7856	$9.3x10^{-7}$
30	8650	$8.5x10^{-7}$
45	9028	$8.1x10^{-7}$
60	7268	$1.0x10^{-6}$



- 5 samples UV/O3 treated to change resistivity
- Resistivities are several orders of magnitude too large to see change in electronic thermal conductivity
- Any change in thermal properties will be due to a scattering rate change
- **Need resistivities at or above 2e-4 Ω cm**

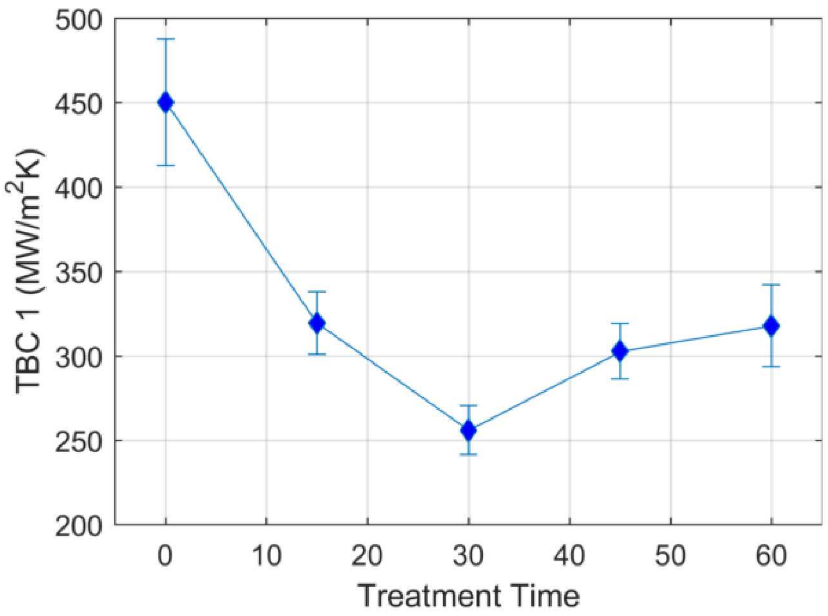
Thermal Conductivity

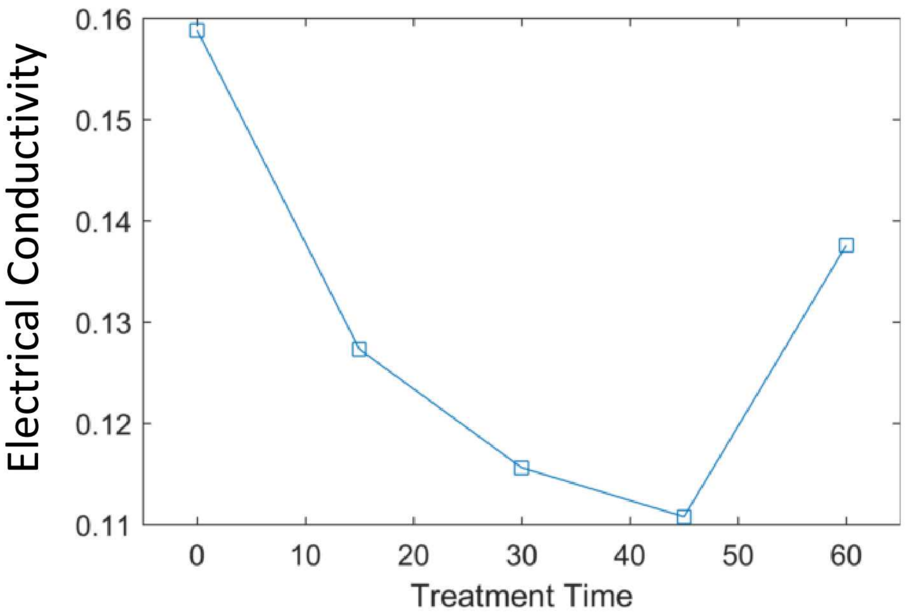




- Thermal conductivities much lower than previous measurements. Size effects?
- No correlation between thermal conductivity and electrical resistivity

Boundary Conductance





- Moderate correlation between boundary conductance and electrical conductivity. Why?
- Electronic component 7 orders of magnitude smaller than lattice component

Summary

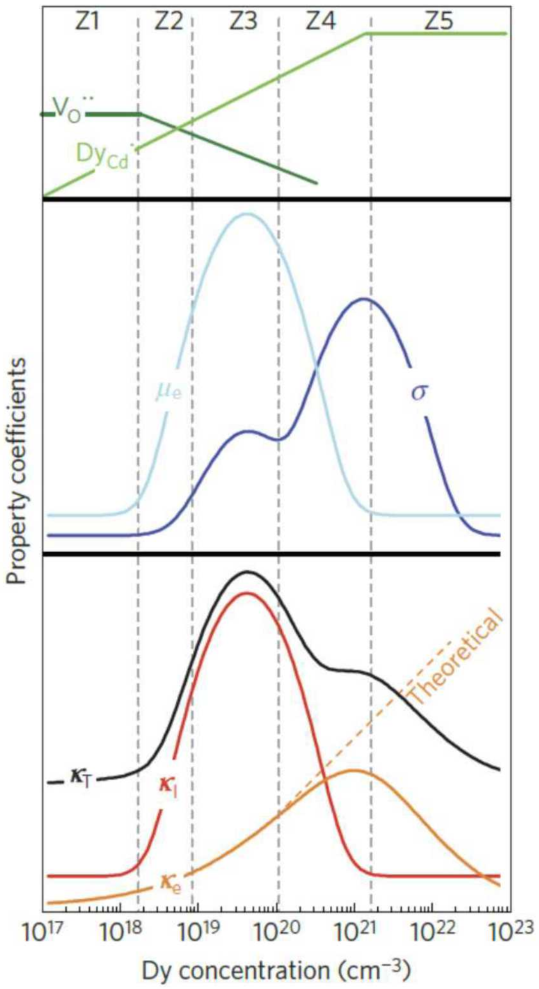
- Resistivities too large to change electrical component of thermal conductivity.
- Thermal conductivity much lower than previous measurements. Size effects?
- Correlation between boundary conductance and resistivity, but WHY?

Questions

- Are the resistivity measurements from sister samples or a new sample set?

- Can we grow an untreated size series? 50, 100, 500, 1000 nm

Dopant effects in CdO

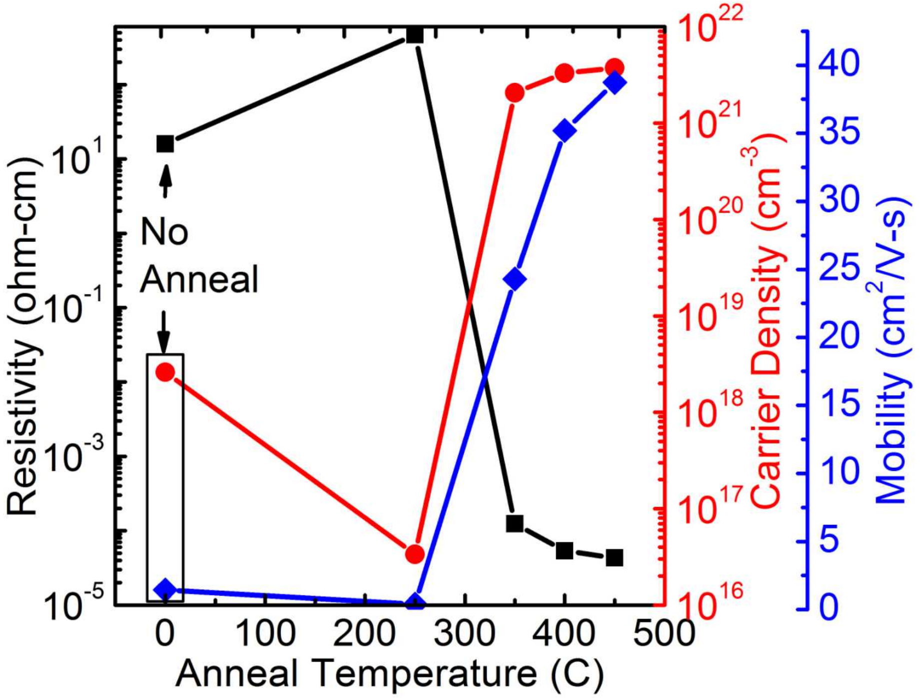


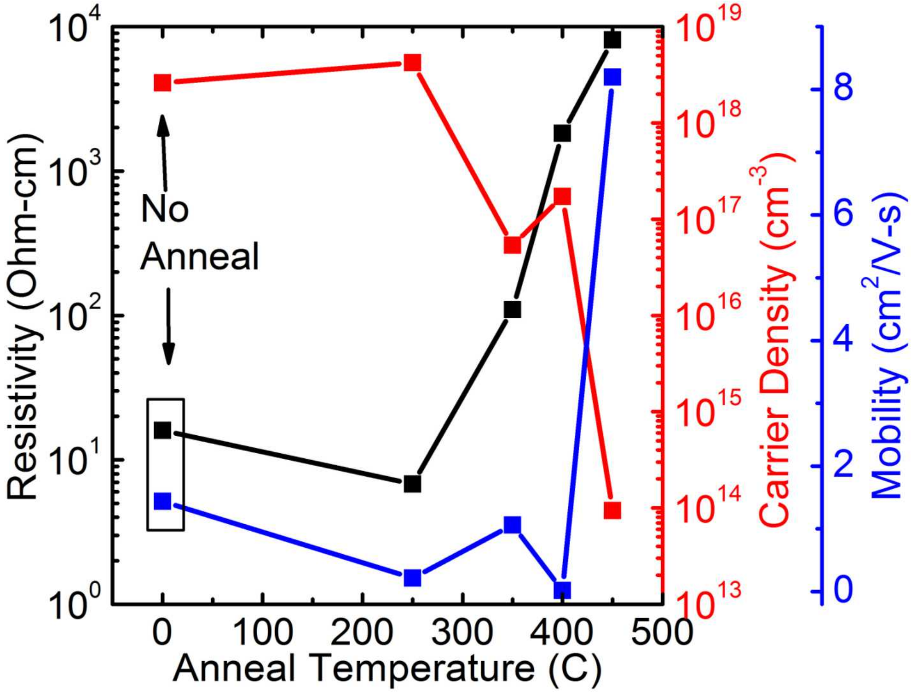
- As dopant level increases oxygen vacancies decrease
- Oxygen vacancies induce a larger strain in the lattice than Dy dopant inclusions
- As strain decrease electron mobility rises due to high quality lattice
- Simultaneously the lattice thermal conductivity rises
- When dopants reach a certain level they act as scattering site for both electrons and phonons leading to a reduction in mobility and lattice conductivity
- Eventually the number of electrons from dopants reaches a level where electronic transport contributes to thermal and electrical conductivity
- Finally, dopants precipitate out of the lattice leading to very large scattering sites and a reduction in both thermal and electrical conductivity

Sachet, E.; Shelton, C. T.; Harris, J. S.; Gaddy, B. E.; Irving, D. L.; Curtarolo, S.; Donovan, B. F.; Hopkins, P. E.; Sharma, P. A.; Sharma, A. L.; Ihlefeld, J.; Franzen, S. & Maria, J.-P. Dysprosium-doped cadmium oxide as a gateway material for mid-infrared plasmonics *Nature Materials,* **2015**, *14*, 414–420

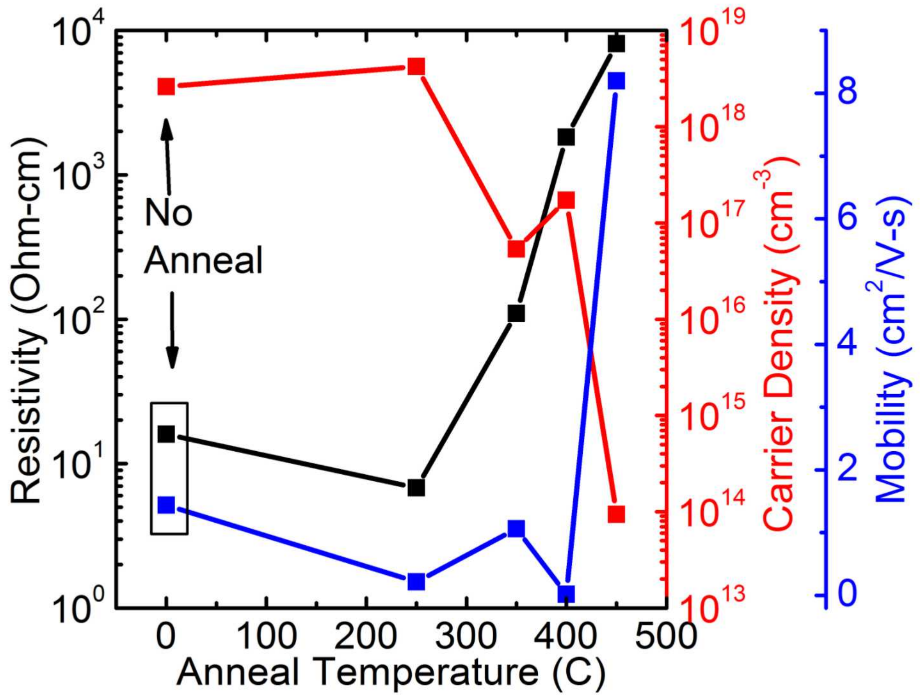
Annealing NiOx

- Forming gas changes the stoichiometry of NiOx by “sucking” of oxygen
- N2 is an inert gas and so changes are only due to lattice rearrangement



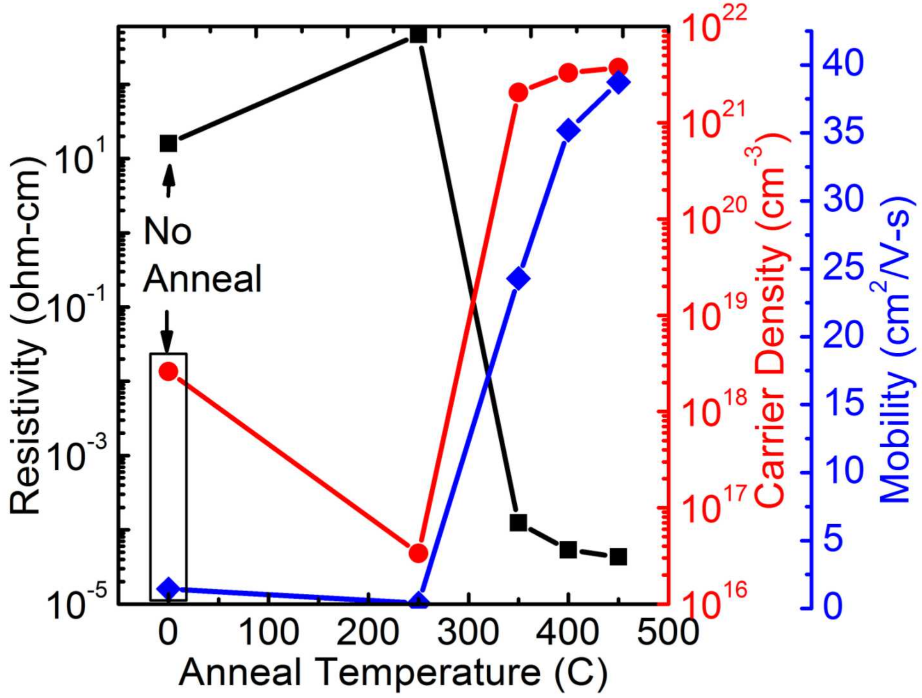


N_2 Anneal of NiOx



- Since annealing environment is inert, stoichiometry remains constant and crystallinity improves with annealing
- Specifically oxygen vacancies decrease leading to less strain and few electron donor sites
- As the strain decreases mobility increases
- Oxygen vacancies decrease at the same time leading to a reduction in carrier density
- Carrier density drops by several orders of magnitude leading to an overall increase in resistivity
- Raman spectroscopy can be used to measure lattice quality and thus mobility through the Raman peak linewidth

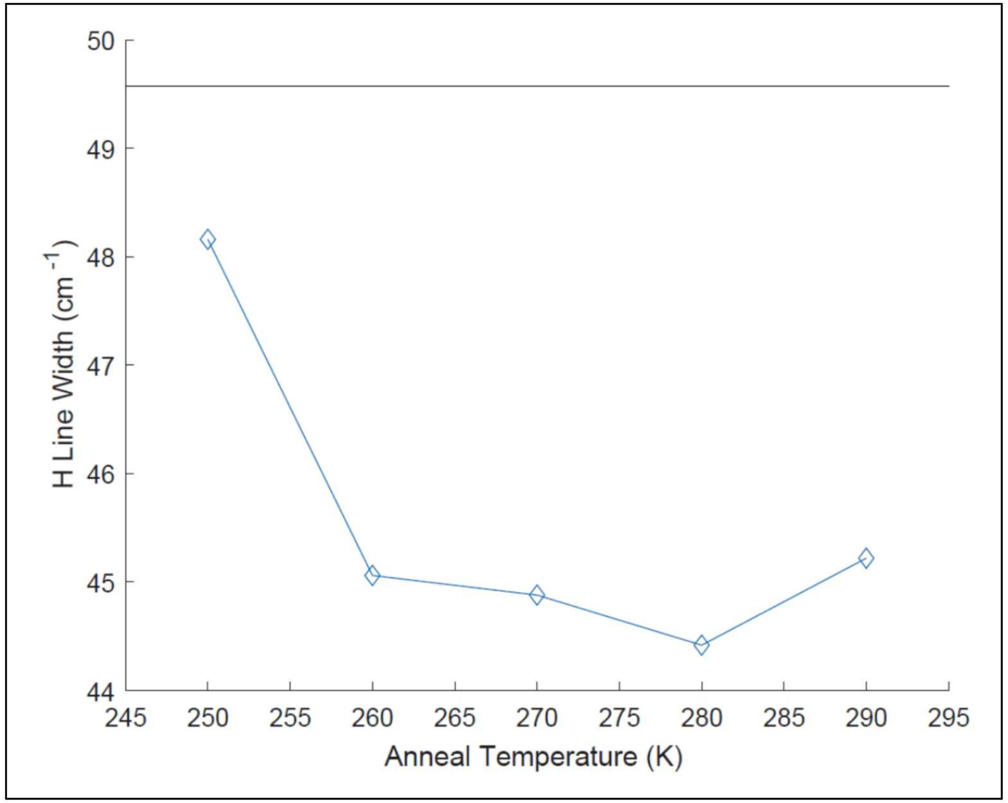
FG Anneal of NiO_x

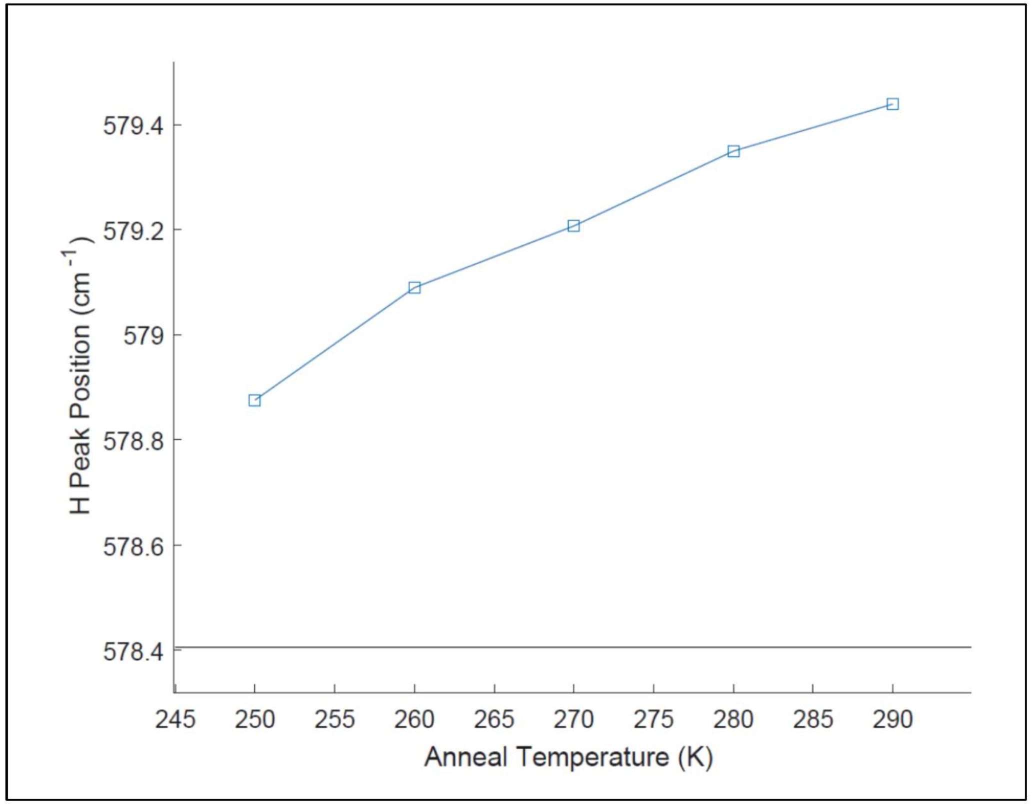


- FG anneal changes both the stoichiometry and lattice quality simultaneously
- At 250 C anneal carrier density decreases because NiO_x become closer to NiO.
- Leads to a sharp reduction in carrier density and thus increase in resistivity
- At 350 C carrier density increases due to oxygen vacancies while crystallinity increases due to anneal leading to increase in mobility
- Eventually, carrier density plateaus due to constant stoichiometry, but mobility increases due to improved lattice structure

Raman Results

- Line width decreases with crystallinity

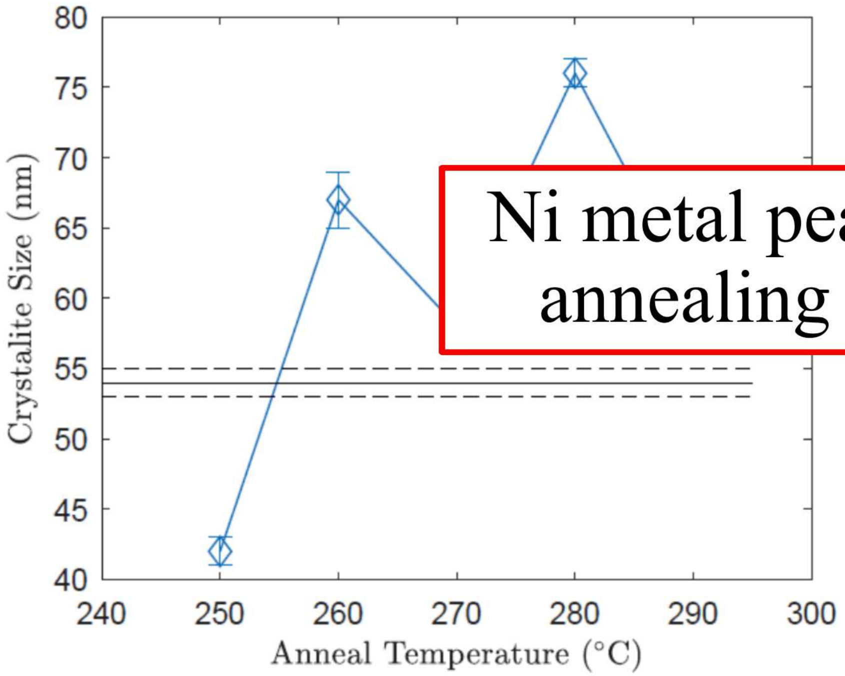


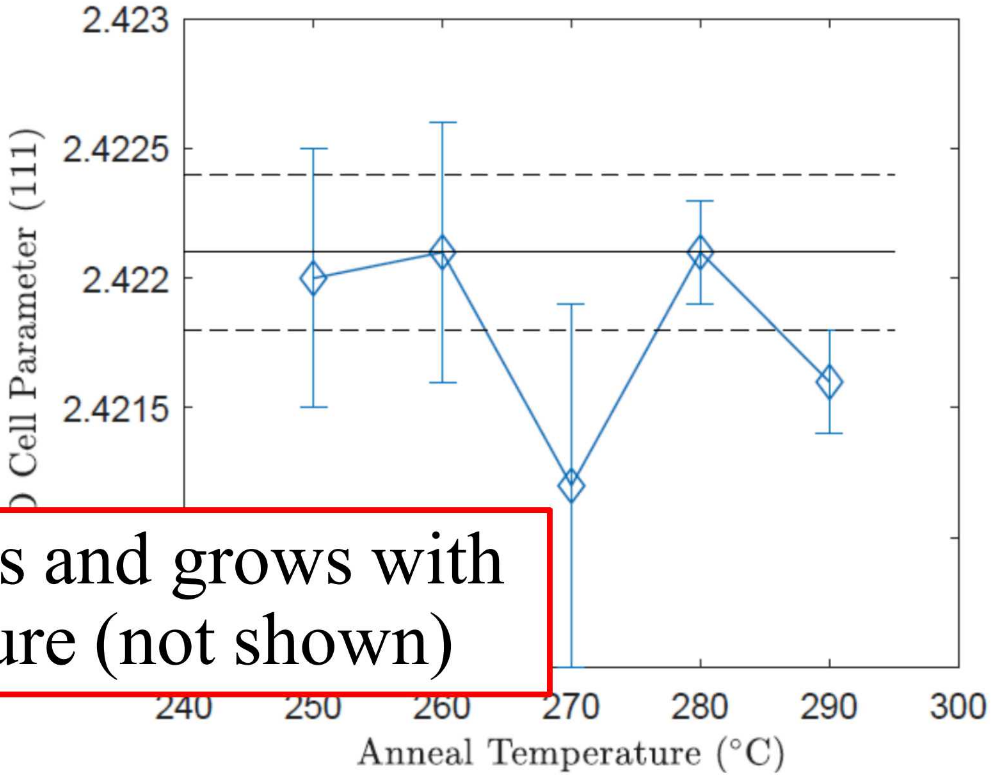


- Often vibrations soften (peak position decreases) with disorder

XRD Results

- General increase in crystallite size





Ni metal peak appears and grows with annealing temperature (not shown)

- No trend in NiO cell parameter size

Summary

- Forming gas anneal decreases oxygen content of NiOx as determined by XRD
- Raman measurements suggest crystallinity improves with FG anneal
- Sample 4 (280 C) needs to be remade
- Need Hall measurements of ALL samples
- Will collect Raman and TDTR on ALL samples
- Changes in thermal conductivity due to reduced lattice disorder and stochiometery
- Need samples with resistivities of 2e-4 Ω cm or lower to see change in thermal conductivity due to charge carriers
- Need samples annealed between 300 and 500 C
- Please measure resistivities before shipping samples. We can predict the thermal conductivity change from the resistivity.

Lorentz number

Electrical conductivity

$$\kappa_e = LT\sigma$$

Temperature