Physical and electrical characterization of RF-sputtered ITO films for use as solar cell electrodes as well as interlayers in low-resistance MIS contacts in Ge/Si transistors

Koosha Nassiri Nazif, Haydee Pacheco

Mentors: Maurice Stevens (SNF), Vijay Narasimhan (IM), Pranav Ramesh

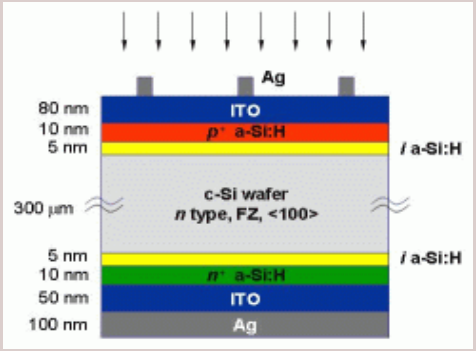
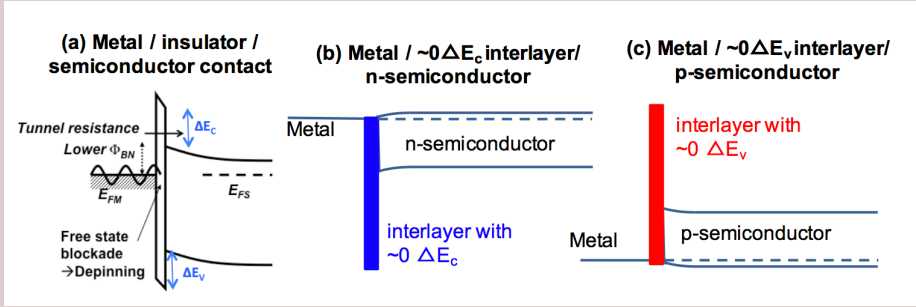
ENGR 241, Fall 2017

Contents

- Motivation
- Process Overview
- Design of Experiments (DOE)
- Repeatability Tests
- Final Results
- Summary

Contents

Motivation

	Solar Application	MIS Contact Application
Usage	Transparent Electrode 	Interlayer in MIS contact 
Thickness	50-100 nm	10-30 nm
Parameters to optimize	1. Maximum conductivity (Carrier Concentration) 2. Maximum optical transmission over the solar spectrum (AM 1.5) **Note**: These 2 objectives could oppose each other, i.e. more carriers (conductivity) will cause more absorption and thus decrease transmission.	

Contents

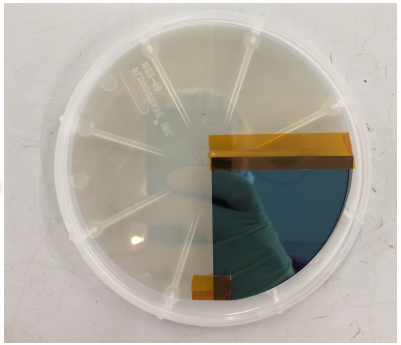
- Motivation
- **Process Overview**
- Design of Experiments (DOE)
- Repeatability Tests
- Final Results
- Summary
- Future Work

Process Overview - Sputtering

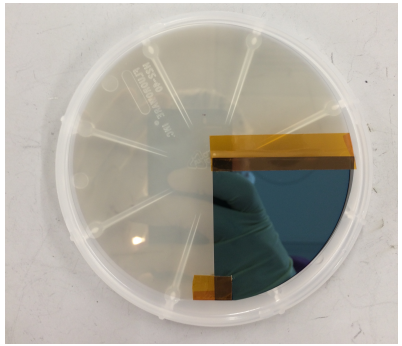
Glass Wafers + Silicon Quarter Wafers

Lesker Sputter

ITO Deposition



Process Overview - Measurements



- Thickness (Alphastep - profilometer)
- Sheet Resistance (Prometrix - 4-point probe)
- Transmission (Jasco - spectrophotometer)
- Stoichiometry (PHI V3 - XPS)
- Carrier Concentration (Hall Measurement tool in room 152 – Repeatability Issue)

Contents

- Motivation
- Process Overview
- **Design of Experiments (DOE)**
- Repeatability Tests
- Final Results
- Summary
- Future Work

Design of Experiments (DOE)

- **Factors**
  - Pressure (3 mTorr – 5 mTorr)
  - Power (50 W – 100 W)
  - O_2/Ar Ratio (0 – 0.05)
  - Substrate Bias (0 – 50 V)

  2^4 = 16 Exp. → DOE → 5 Exp.

  8 Exp. to observe 3rd order interactions

  - Temperature (Room Temperature – 270 °C)
    - Excluded from the initial screening
      - due to the complexities involved with the heating system
- **Responses**
  - Resistivity (Minimize)/Carrier Concentration (Maximize)
  - Absorption Coefficient (Minimize)/Optical Transmission (Maximize)
    - Averaged over the solar spectrum (AM 1.5)

Design of Experiments (DOE) – Initial Results

Exp. #	Pressure (mTorr)	O_2/Ar Ratio	Power (W)	Subs. Bias (V)	Deposition Rate (nm/min)	Resistivity (ohm.cm)	Abs. Coeff. (1e4*cm^{-1})
1	5	0.05	100	50	0.82	8.67	6.57
2	5	0.05	50	50	0.43	7.48	7.42
3	5	0	100	0	2.50	2.3e-3	5.49
4	5	0	50	0	1.08	3.9e-3	6.57
5	3	0	100	0	1.78	7.2e-4	6.02
6	3	0	50	0	1.00	5.8e-4	4.98
7	3	0	100	50	1.53	4.8e-4	4.97
8	3	0	50	50	0.81	5.3e-4	5.49

Design of Experiments (DOE) - Analysis

Transmission

Source	LogWorth	PValue
O2/Ar ratio	0.542	0.28708
Pressure	0.309	0.49038
Power	0.289	0.51444
Subs. Bias	0.145	0.71642

Resistivity

Source	LogWorth	PValue
O2/Ar ratio	11.730	0.00000
Pressure	1.617	0.02416
Power	0.372	0.42457
Subs. Bias	0.087	0.81845

Predicted Optimal Recipe

Pressure (mTorr)	O_2/Ar Ratio	Power (W)	Subs. Bias (V)
3	0	100	50

Pressure (mTorr)	O_2/Ar Ratio	Power (W)	Subs. Bias (V)
3	0	100	50

- O_2/Ar ratio and then pressure have significant effects on resistivity values.
- High p-values in the transmission data
  - Semi-random distribution - no particularly significant factor
  - The predicted optimal recipe for transmission is not reliable.

Contents

- Motivation
- Process Overview
- Design of Experiments (DOE)
- **Repeatability Tests**
- Final Results
- Summary
- Future Work

Repeatability Tests

Exp. #	Pressure (mTorr)	O_2/Ar Ratio	Power (W)	Subs. Bias (V)	Resistivity (ohm.cm)		
					1st Run	2nd Run	3rd Run
					Target 2	Target 1	Target 2
					Low Base Pressure	High Base Pressure	Low Base Pressure
2	5	0.05	50	50	7.48	13.2	N/A
4	5	0	50	0	3.9e-3	9.8e-03	3.52e-3
7	3	0	100	50	4.8e-4	1.75e-03	6.42e-4
8	3	0	50	50	5.3e-4	1.82e-03	8.45e-4

Resistivity data is repeatable

- Resistivity data is self-consistent through the 3 runs.
- High Base Pressure (and switch to target 1) increases the resistivity by a factor of ~2-4.

Repeatability Tests

Exp. #	Pressure (mTorr)	O_2/Ar Ratio	Power (W)	Subs. Bias (V)	Abs. Coefficient (1e4*cm^{-1})		
					1st Run	2nd Run	3rd Run
					Target 2	Target 1	Target 2
					Low Base Pressure	High Base Pressure	Low Base Pressure
2	5	0.05	50	50	7.42	6.98	N/A
4	5	0	50	0	6.57	4.58	7.20
7	3	0	100	50	4.97	4.64	7.90
8	3	0	50	50	5.49	8.30	5.08

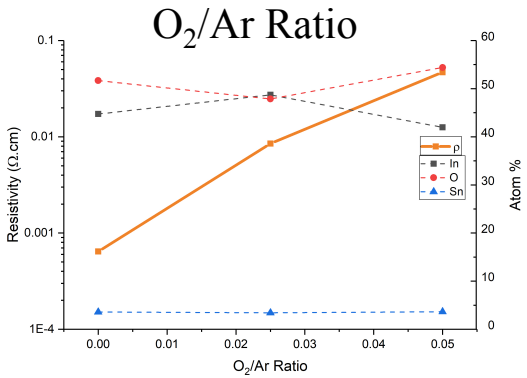
Transmission data is not completely repeatable

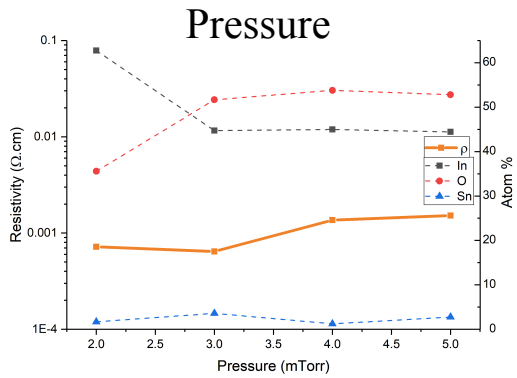
The reason is the semi-randomness nature of the transmission data, as verified by the high p-values.

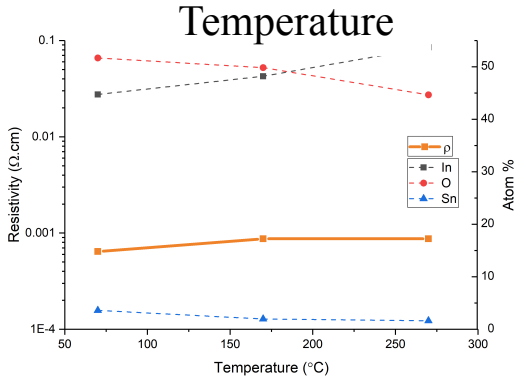
Contents

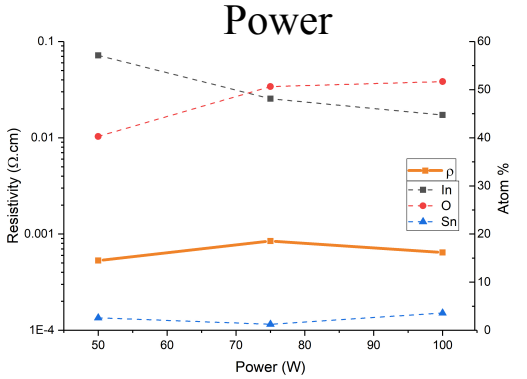
- Motivation
- Process Overview
- Design of Experiments (DOE)
- Repeatability Tests
- **Final Results**
- Summary
- Future Work

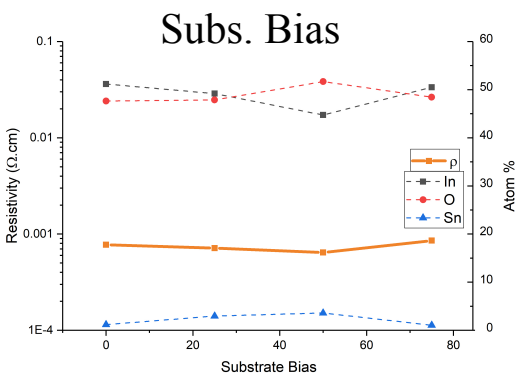
Final Results – Resistivity Trends





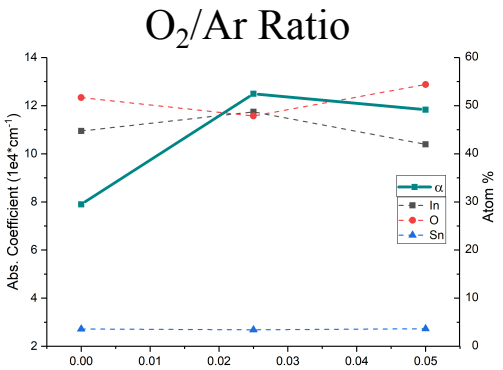


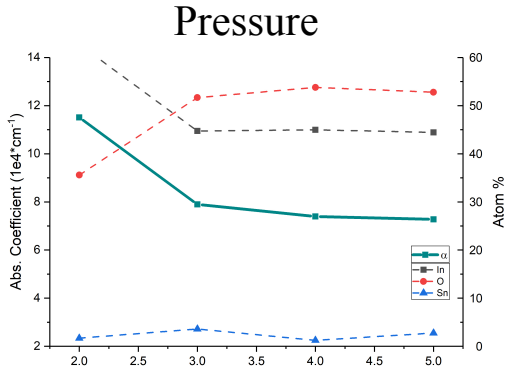


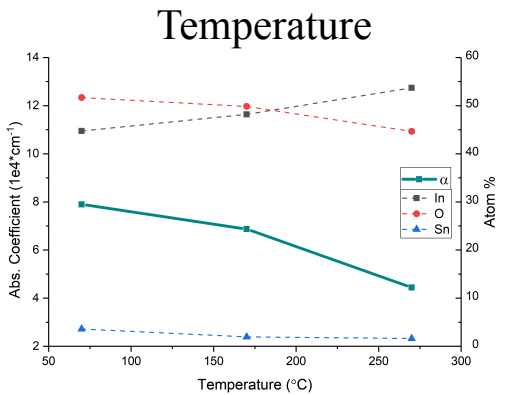


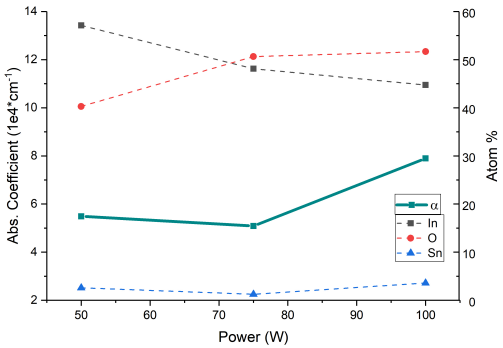
Optimal Resistivity Recipe	
O_2/Ar Ratio	0
Pressure	3 mTorr
Power	100 W
Subs. Bias	50 V
Temperature	~ 70 °C
Resistivity	4.8e-4 ohm.cm

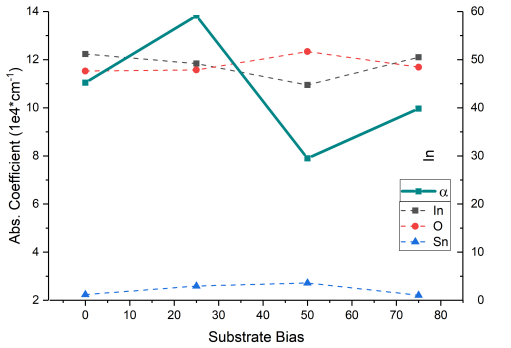
Final Results – Transmission Trends





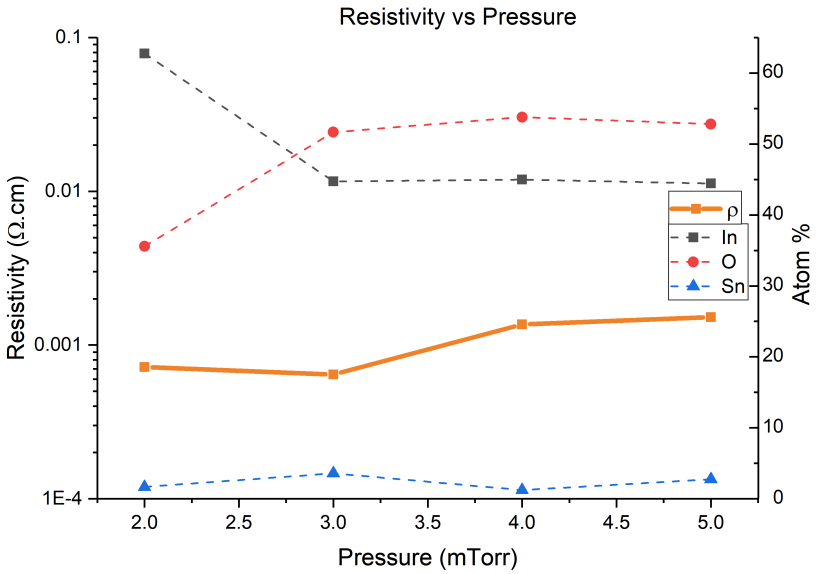


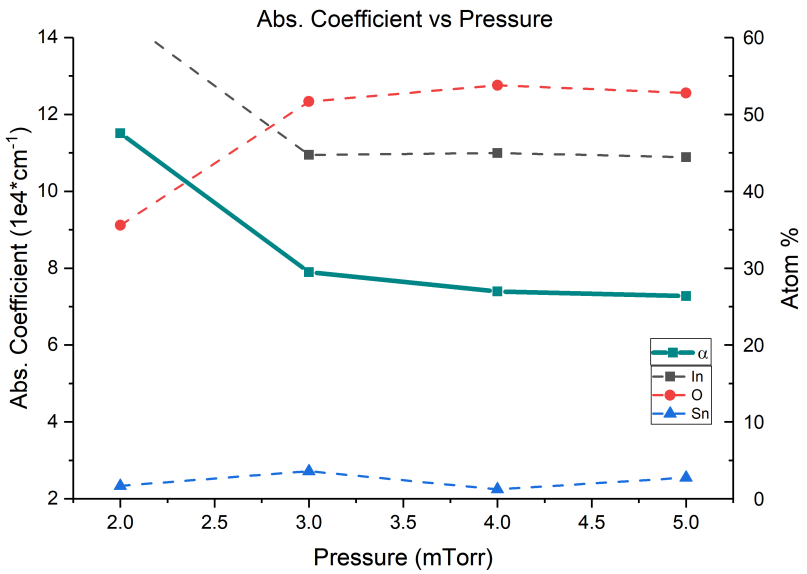




Optimal Transmission Recipe	
O_2/Ar Ratio	0
Pressure	3 mTorr
Power	100 W
Subs. Bias	50 V
Temperature	270 °C
Abs. Coeff.	44400 cm^{-1}

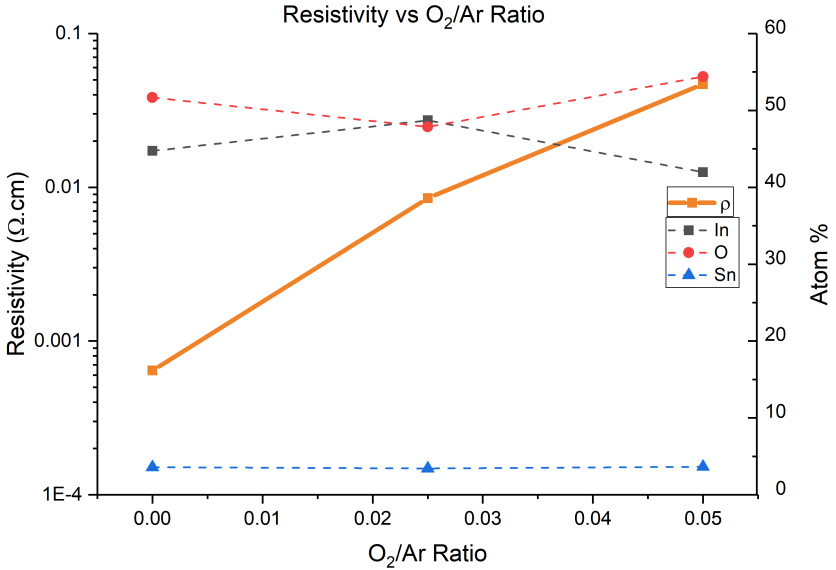
Final Results - Effect of Pressure

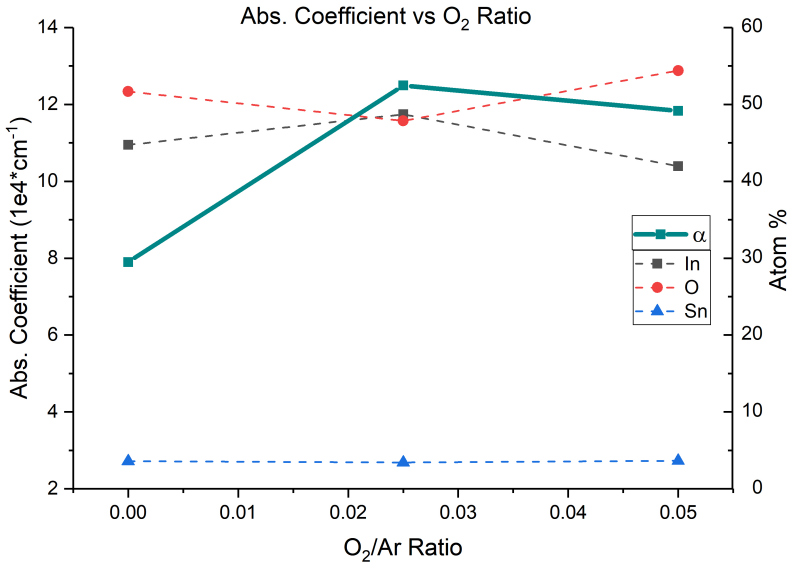




More Sn (Tin) → More conductivity
More Oxygen → More Transmission

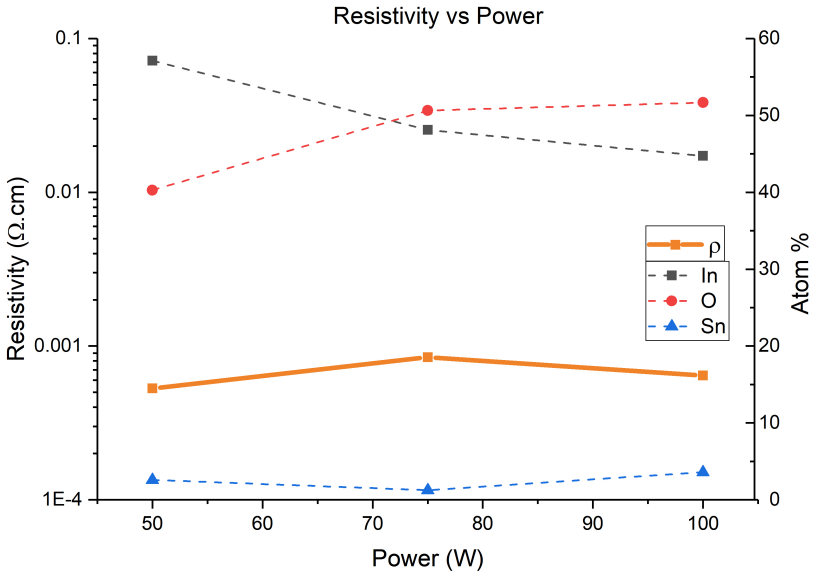
Final Results - Effect of O_2/Ar Ratio

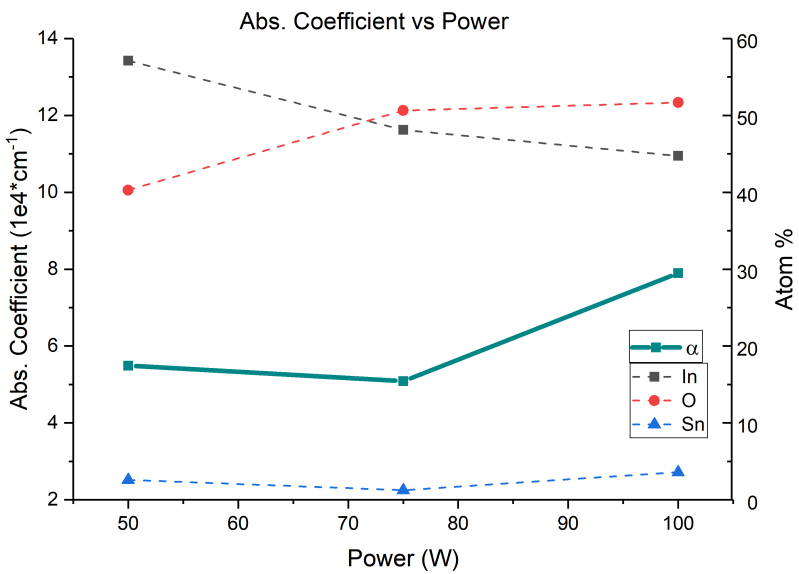




More Sn (Tin) → More conductivity
More Oxygen → More Transmission

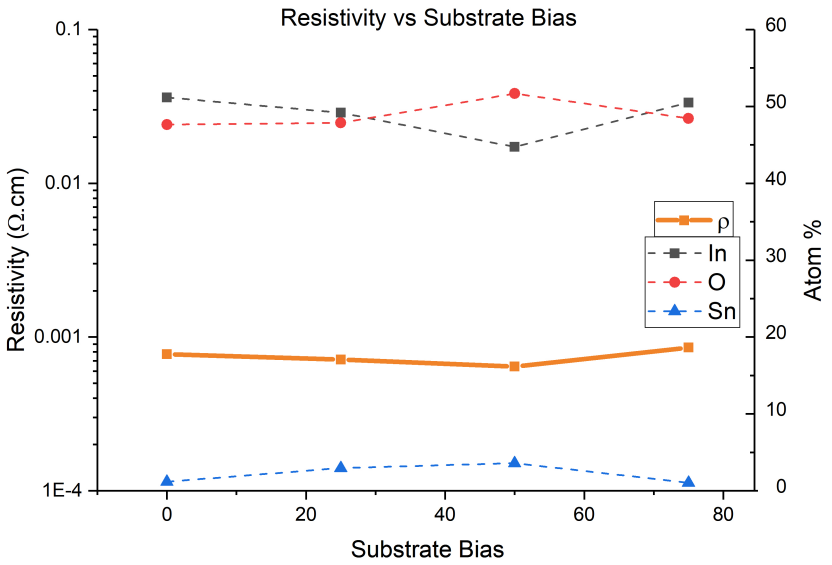
Final Results - Effect of Power

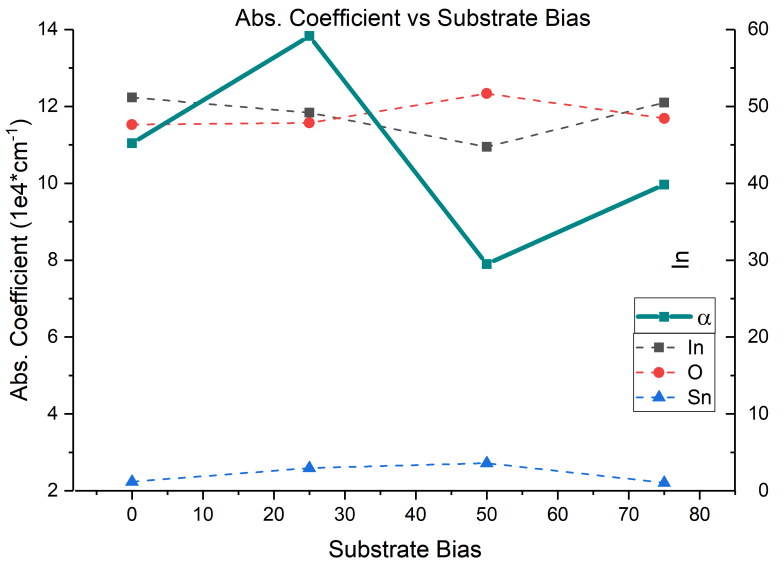




More Sn (Tin) → More conductivity
More Oxygen → More Transmission

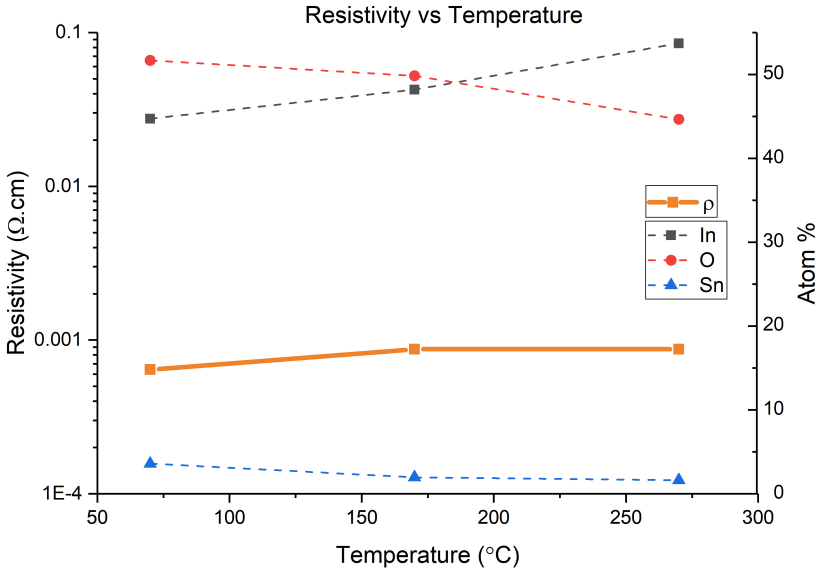
Final Results - Effect of Substrate Bias

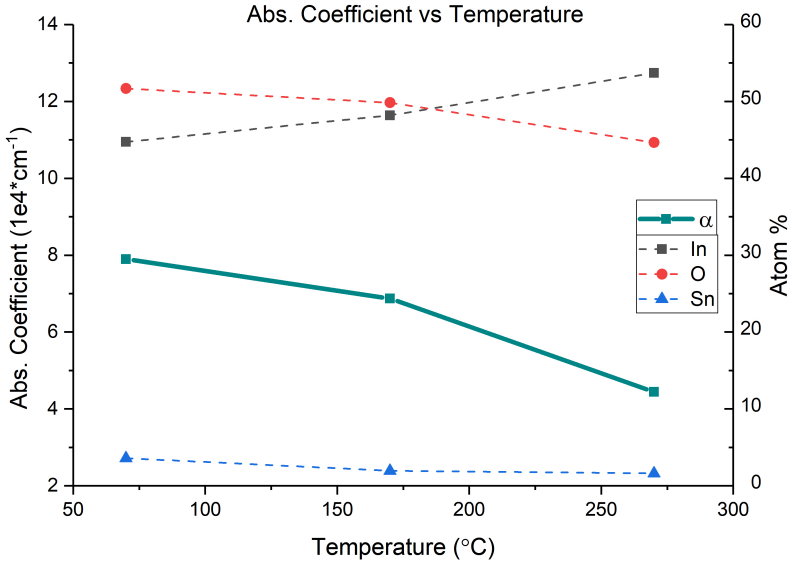




More Sn (Tin) → More conductivity
More Oxygen → More Transmission

Final Results - Effect of Temperature





More Sn (Tin) → More conductivity

Less Oxygen → More Transmission

- Effect of Annealing

Contents

- Motivation
- Process Overview
- Design of Experiments (DOE)
- Repeatability Tests
- Final Results
- **Summary**
- Future Work

Summary

- Optimal Recipes

Optimal Resistivity Recipe	
O_2/Ar Ratio	0
Pressure	3 mTorr
Power	100 W
Subs. Bias	50 V
Temperature	~ 70 °C
Resistivity	4.8e-4 ohm.cm

Optimal Transmission Recipe	
O_2/Ar Ratio	0
Pressure	3 mTorr
Power	100 W
Subs. Bias	50 V
Temperature	270 °C
Abs. Coeff.	44400 cm^{-1}

- More Sn → More conductivity
- More Oxygen → More Transmission
- More Annealing (Heating) → More transmission

Contents

- Motivation
- Process Overview
- Design of Experiments (DOE)
- Repeatability Tests
- Final Results
- Summary
- **Future Work**

Future Work

- Accurate Hall Measurements done at INTERMOLECULAR
  - Thanks to Vijay Narasimhan
- Fabricating MIS contacts using our optimal resistivity recipe
  - Done by Pranav Ramesh

Acknowledgement

- SNF Staff
- E 241 Class
- Our mentors
  - Maurice Stevens
  - Vijay Narasimhan
  - Pranav Ramesh

Q&A

Thank you!

koosha@stanford.edu

haydee.pacheco@stanford.edu