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Temperature Dependence of the Direct Bandgap of InSb

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Jaden R. Love, and Stefan Zollner

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College of Arts and Sciences, Department of Physics

Outline

- Scientific language
- What is InSb?
- Electromagnetic spectrum and band gap
- Expectations
- Experiment, equipment and sample preparation
- Data and corrections
- Analysis
- Conclusions and future work

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Temperature Dependence of the Direct Bandgap of InSb

Melissa Rivero

In collaboration with: Dr. Stefan Zollner, Carola Emminger, Cesy Zamarripa and Jaden R. Love

Experiments that go to low and/or high temperatures

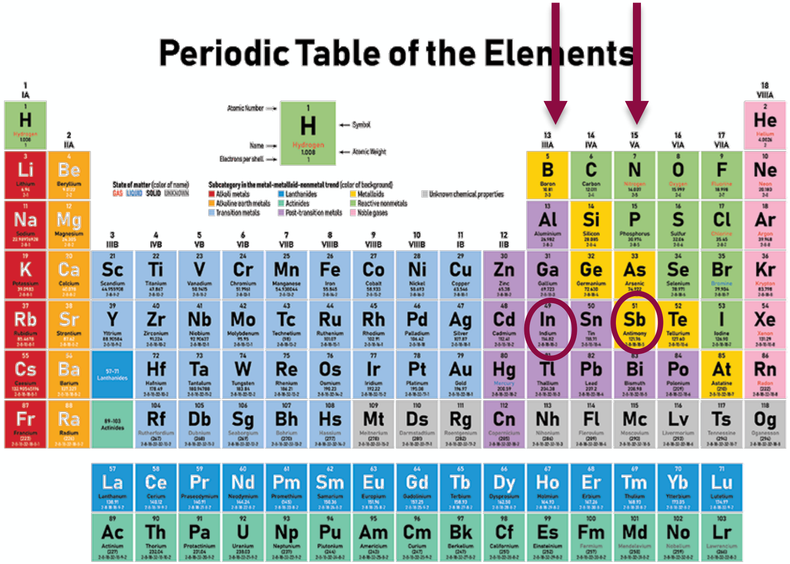
Minimum amount of energy required for an electron to break free of its ground state

Indium Antimonide: narrow-gap semiconductor material from the III-V group

Undergraduate, Department of Physics

What is InSb?

- Indium Antimonide: narrow-gap semiconductor material from the III-V group.

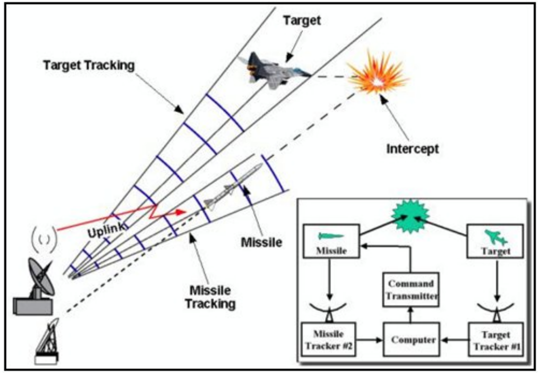


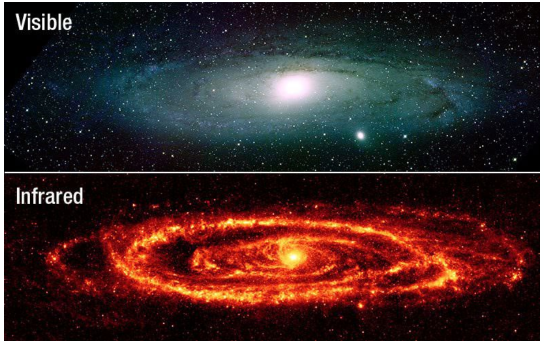
Examples (III-V):

GaSb (gallium antimonide)
InAs (indium arsenide)
GaP (gallium phosphide)

What is InSb?

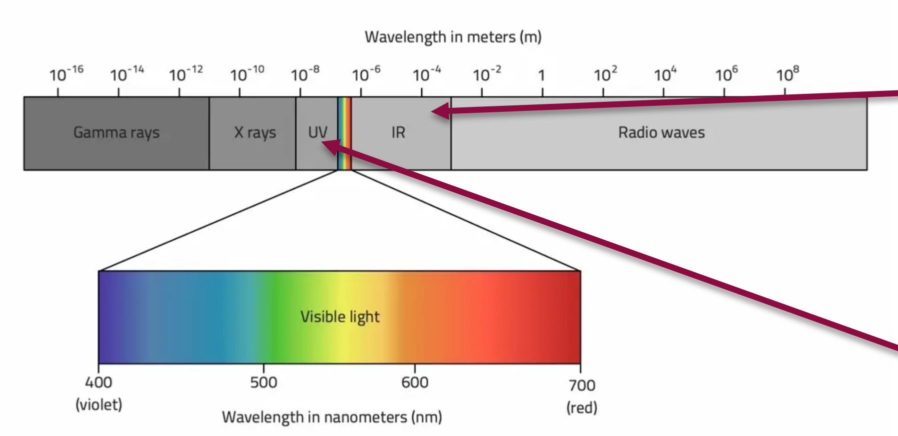
- Used in infrared detectors, including thermal imaging cameras, FLIR systems, infrared homing missile guidance systems, and in infrared astronomy.

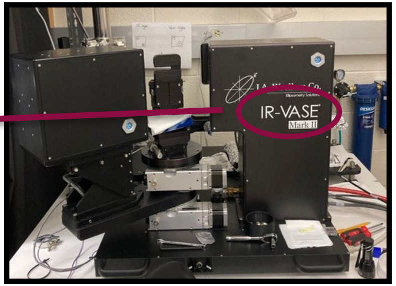




Electromagnetic Spectrum

- Range of frequencies of electromagnetic radiation and their respective wavelengths and **photon energies**.



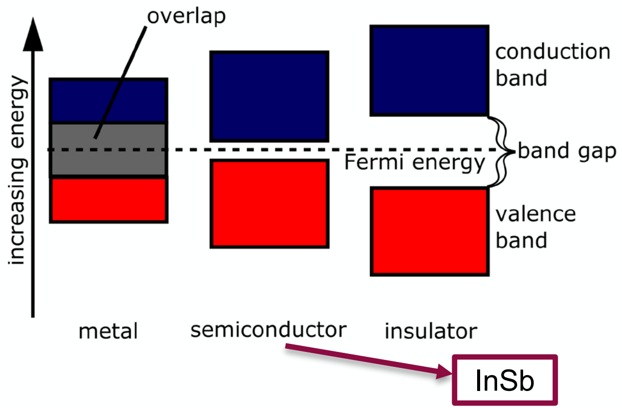


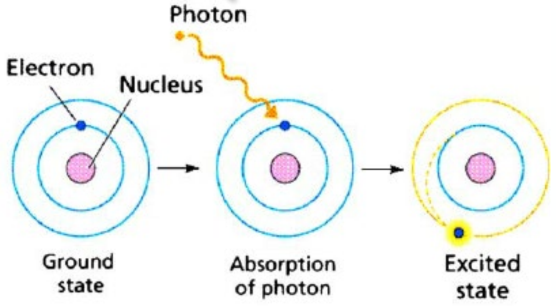
J.A. Woollam IR-VASE

J.A. Woollam V-VASE

Band Gap

- The band gap is **the minimum amount of <u>energy</u> required for an electron to break free of its bound state**. When the band gap energy is met, the electron is excited into a free state, and can therefore participate in conduction.





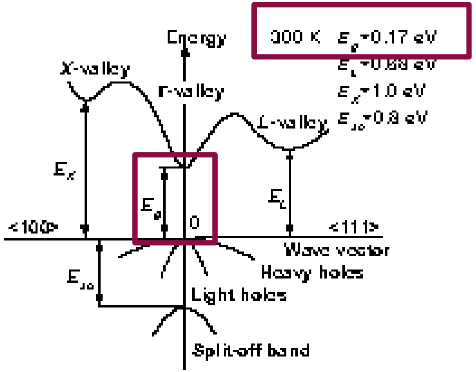
Expectations (1/3)

- Measurement of the dielectric function of bulk InSb from 80 to 700 K near the direct band gap (E_0)

Bulk InSb

80 to 700 Kelvin
-193.5 to 426.85 Celsius
-315.67 to 800.33 Fahrenheit

Comparison



Direct Bandgap at 300 K (room temperature): ~0.17 eV

Expectations (2/3)

- Using FTIR spectroscopic ellipsometry in an ultra-high vacuum (UHV) cryostat with diamond windows.

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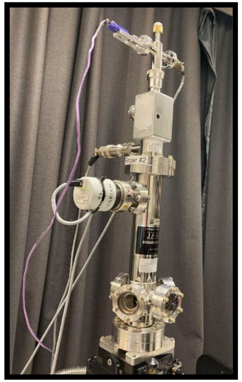
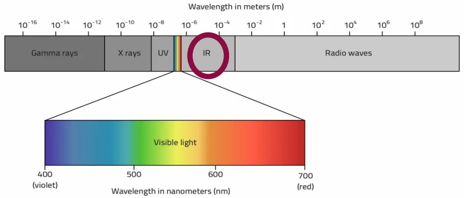
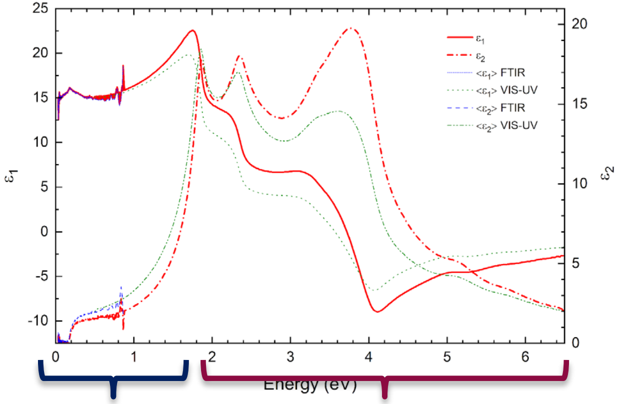


Cryostat with diamond windows



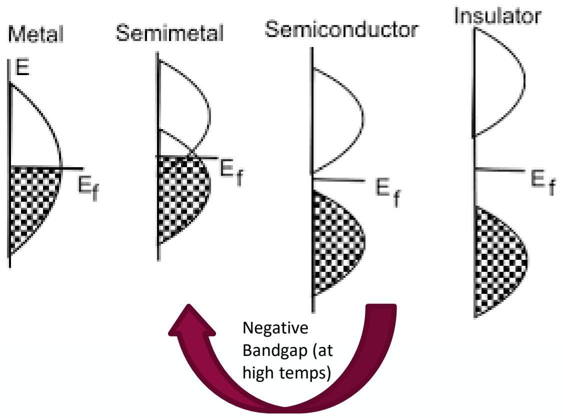
Energies: 1.24 meV to 1.7 eV

VIS-UV and FTIR spectra (dielectric functions) After oxide correction



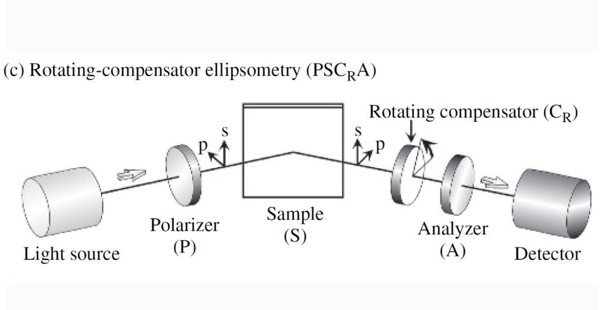
Expectations (3/3)

- Calculations indicate that InSb should undergo a topological phase transition from semiconductor to semi-metal (and topological insulator) at 600 K (negative band gap).

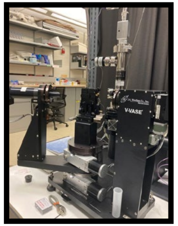


Experiment and Equipment

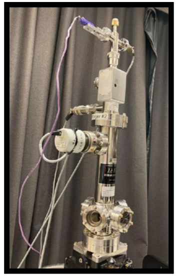
- Non-destructive, noncontact, and non-invasive optical technique based on the change in the polarization state of light as it is reflected obliquely from a thin film sample.
- Uses a model-based approach to determine thin film, interface, and surface roughness thicknesses, as well as optical properties.

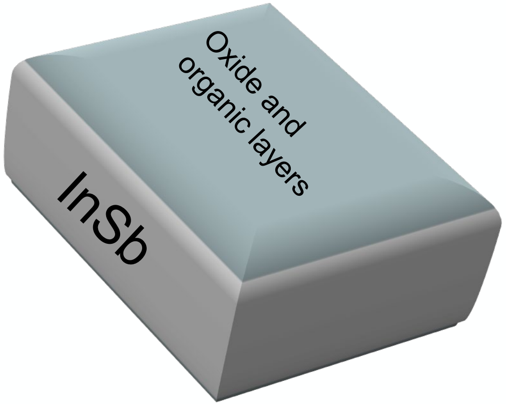


Spectroscopic Ellipsometry


J.A. Woollam V-VASE


J.A. Woollam IR-VASE


Cryostat with diamond windows

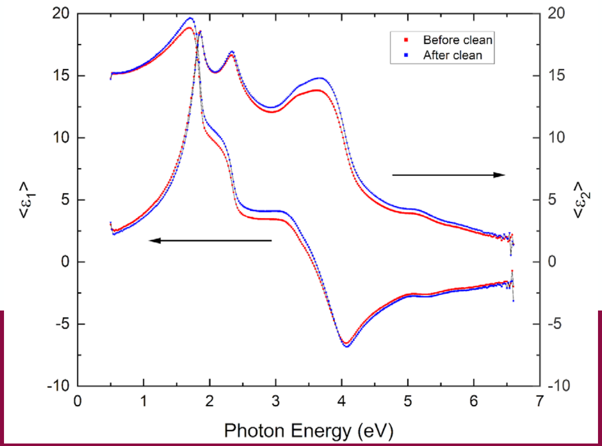


Sample preparation

- InSb cleaning process (on a Branson Ultrasonic Cleaner):

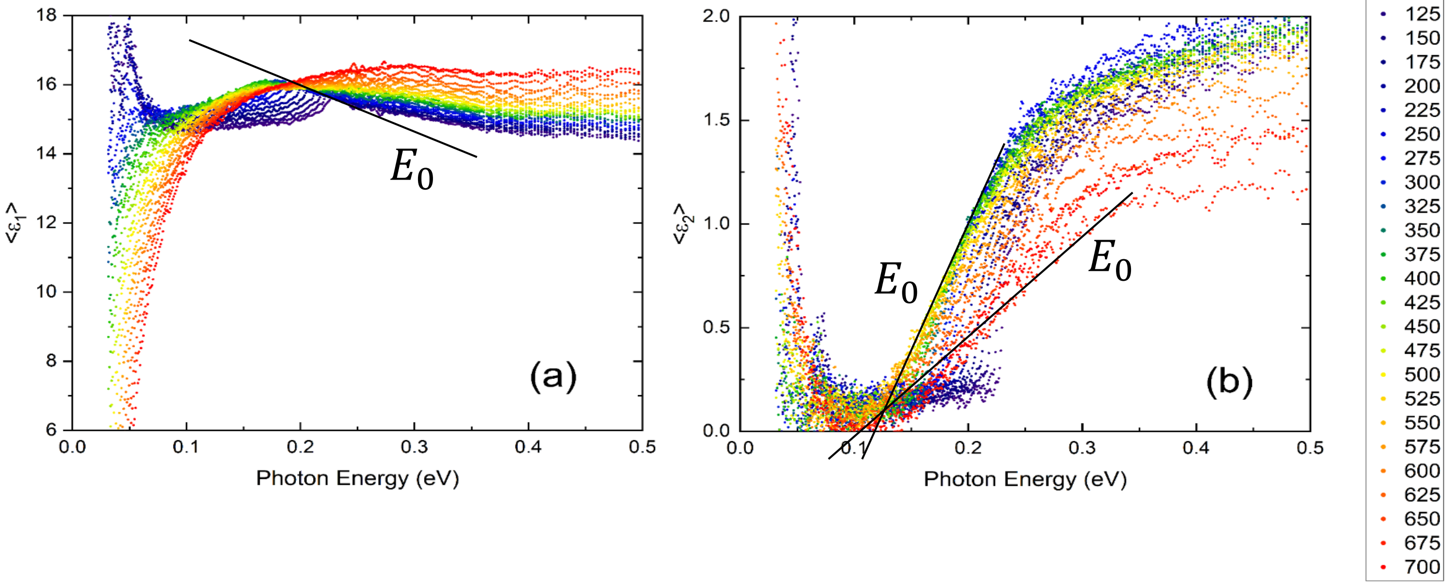
Indium antimonide sample was cleaned using water and isopropanol on the ultrasonic cleaner for 15 minutes on each to remove organic layers before the temperature dependent ellipsometry measurements.

	Oxide Thickness (Å)
Before Clean	28.2
After Clean	22.5



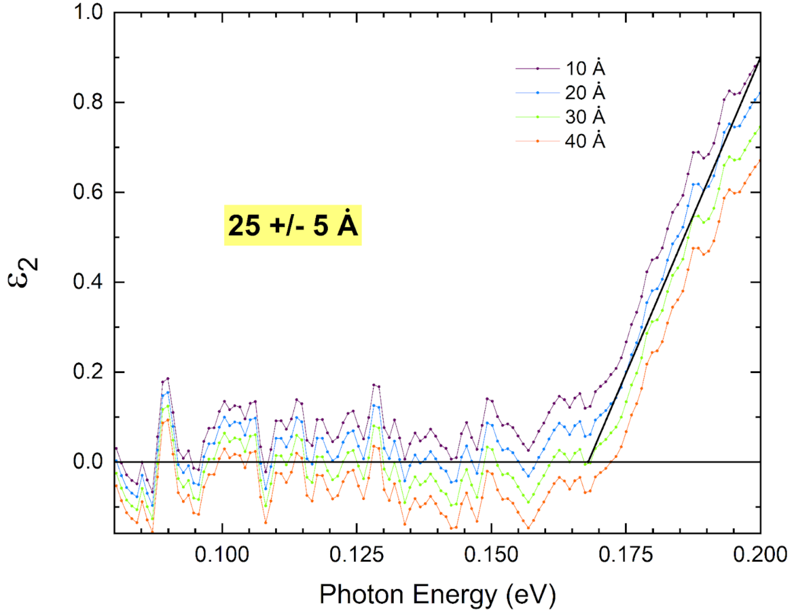
Data and Corrections

Pseudo Dielectric Functions ("raw" data)

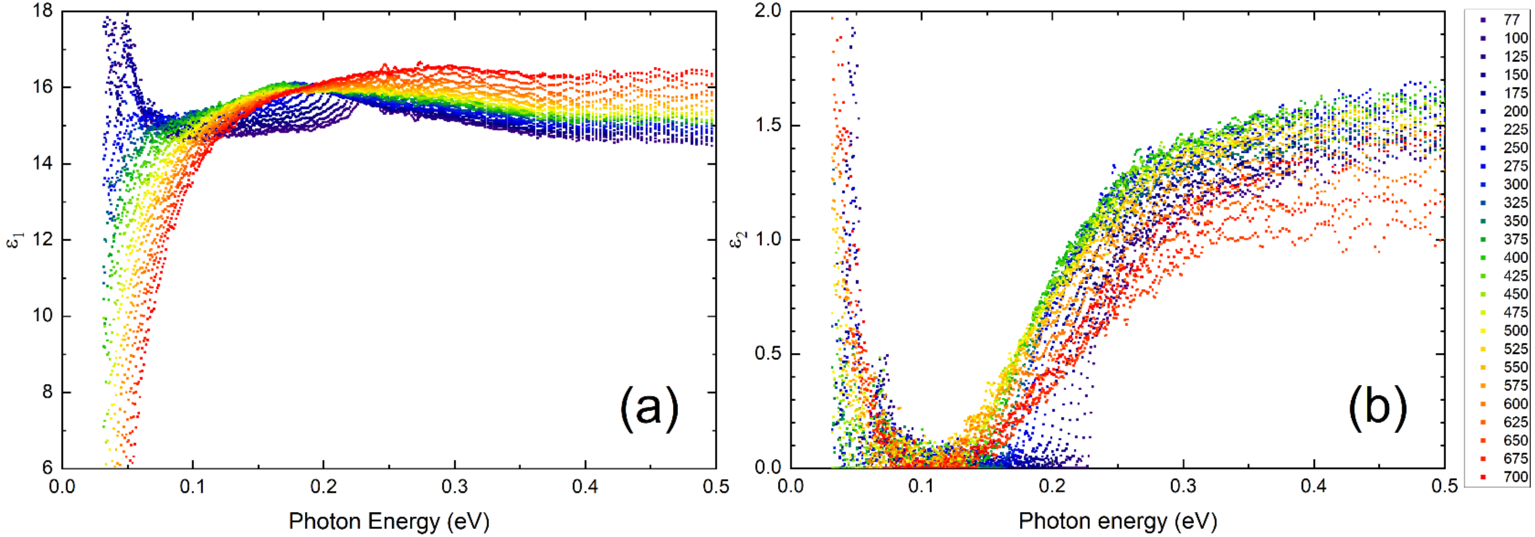


E_0= Bandgap

Oxide Correction



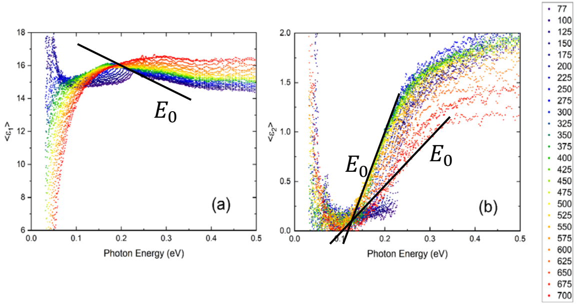
Dielectric Functions

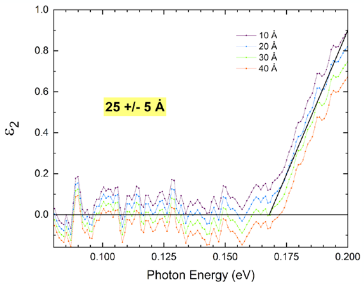


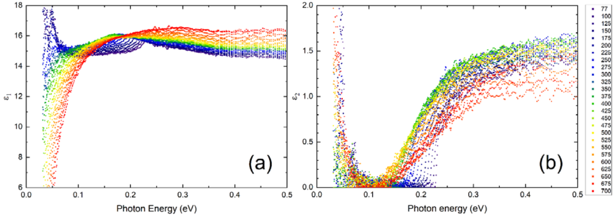
Pseudo Dielectric Functions ("raw" data)

Oxide Correction

Dielectric Functions







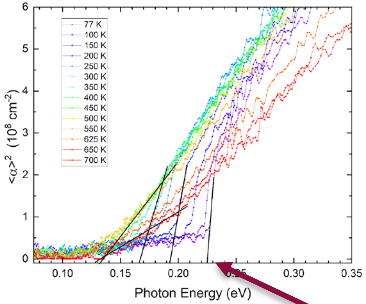
Analysis

- How did the bandgap change through temperatures?

Tauc Plot:

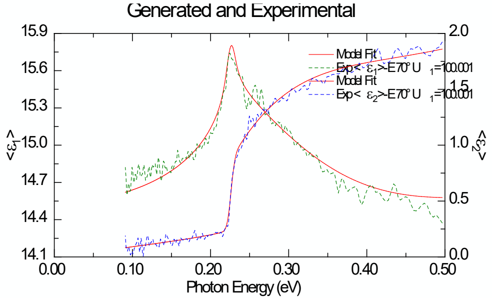
$$\alpha(E) = A\sqrt{E - E_g}$$

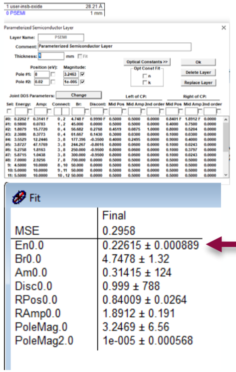
Need linear region, not possible



Computed manually

Parametric-Semiconductor Model:





Based on computer model

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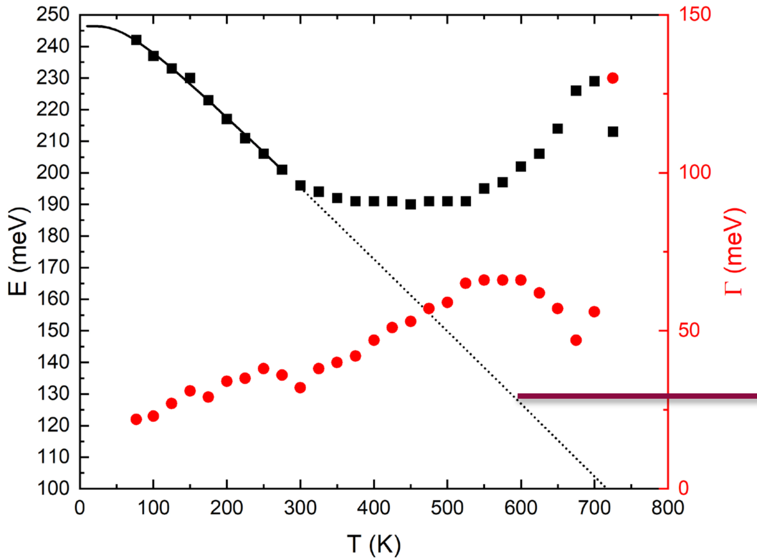
Direct Bandgap vs. Temperature

Band gap



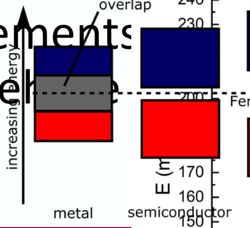
Broadening

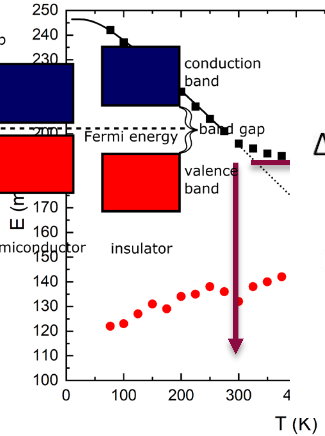
Bose-Einstein Model

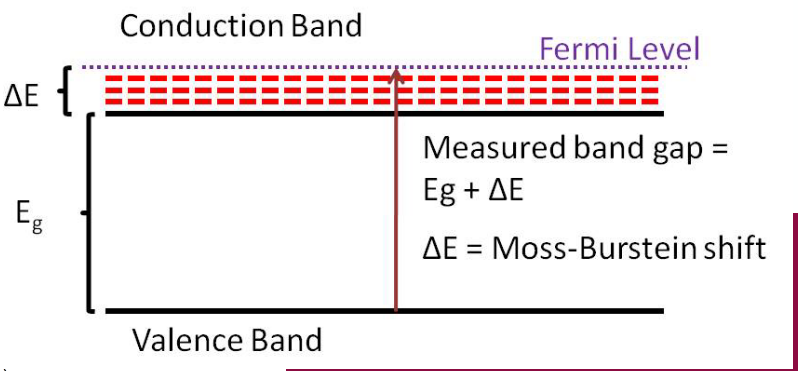
$$E_g(T) = a - b\left[1 - \frac{2}{e^{\frac{\theta}{T}} - 1}\right]$$

Conclusions

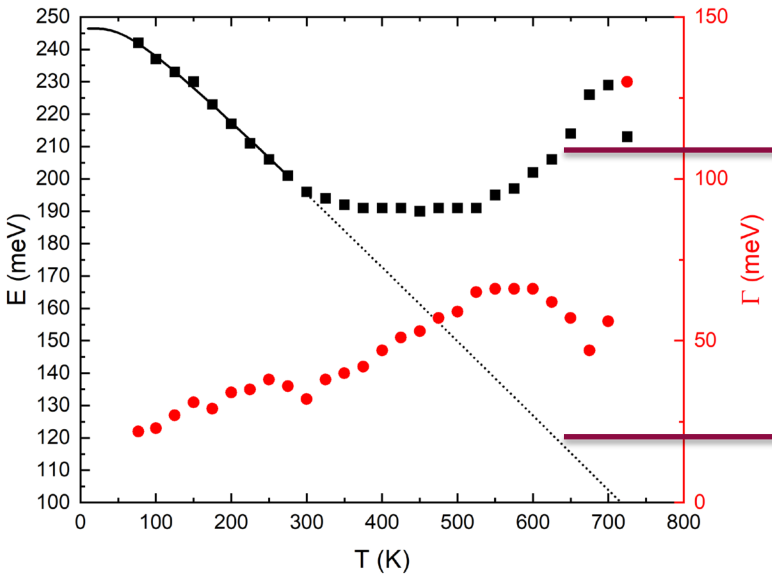
- Dielectric function of InSb was measured from 80 to 700K with an oxide correction of 25 +/- 5 Å
- Band gap is difficult to determine:
  1. Parametric semiconductor model shows great results
- Band gap shrinks with increasing temperature:
  1. Follows Bose-Einstein relationship up to 300 K, stays constant up to 550 K and increases with temperature.
  2. Thermal (rs.
- First measurements
- InSb would be possible.







Direct Bandgap vs. Temperature



Experimental data

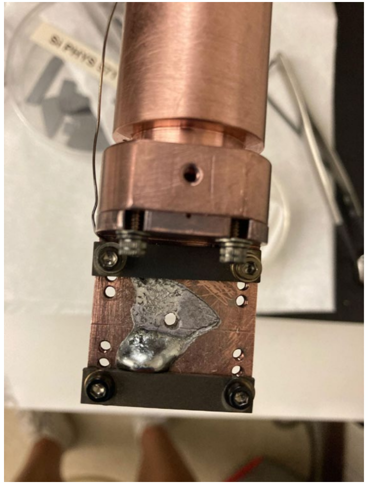
Expected behavior

Sad ending

- Unfortunately, the InSb sample melted at 750 K, but melting point is 800 K…

Before

After



Future work:
Repeat experiment at high temperatures below 750 K

Thank you!

Questions?

References

- [1] C. L. Littler and D. G. Seiler, Appl. Phys. Lett. **46**, 986 (1985).
- [2] S. T. Schaefer, S. Gao, P. T. Webster, R. R. Kosireddy, and S. R. Johnson, J. Appl. Phys. **127**, 165705 (2020).
- [3] http://www.ioffe.ru/SVA/NSM/Semicond/InSb/bandstr.html
- [4] S. Zollner, S. Gopalan, and M. Cardona, Solid State Commun., **77**, 485 (1991).

- https://www.pveducation.org/pvcdrom/pn-junctions/band-gap
- http://www.ioffe.ru/SVA/NSM/Semicond/InSb/bandstr.html
- https://www.horiba.com/ind/scientific/technologies/spectroscopic-ellipsometry/spectroscopic-ellipsometry/
- http://solidstate.mines.edu/videonotes/VN_9_3.pdf
- https://en.wikipedia.org/wiki/Infrared
- https://energyeducation.ca/encyclopedia/Band_gap