Characterization of Silicon Carbide Crystal used for Electro Optic Experiments

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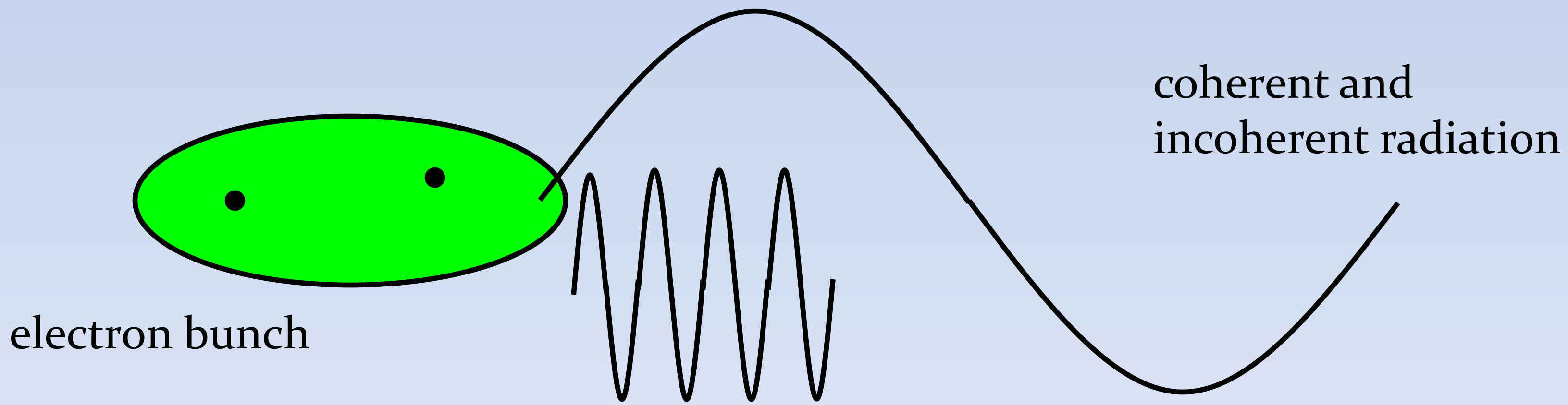
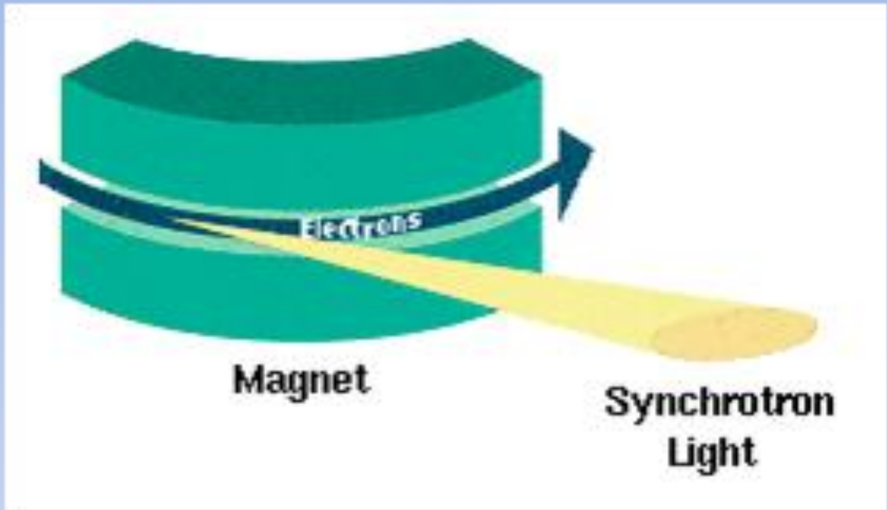
- Big picture: want to measure longitudinal distribution of charge within an electron bunch using its own radiation.
- EO effect: measure the effect of bunch radiation on the crystal instead of using a thermal detector.



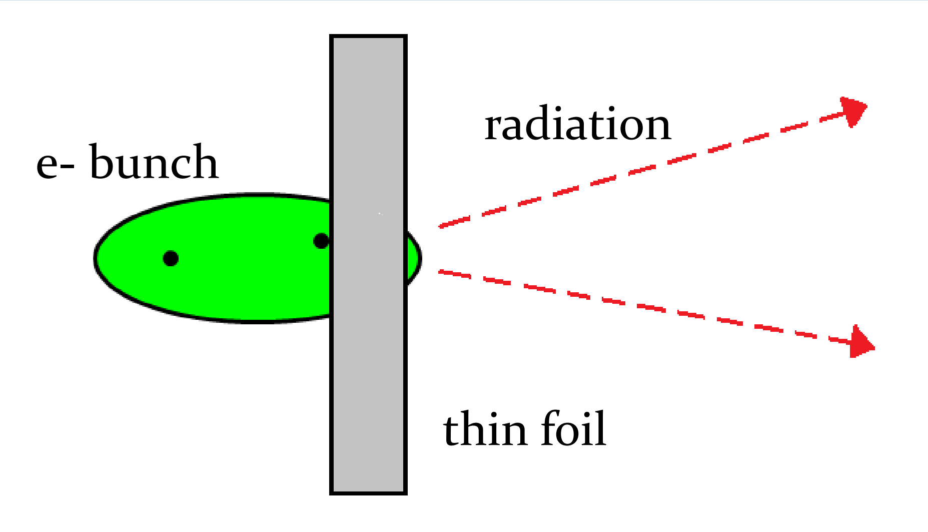
Synchrotron and Transition Radiation

- Synchrotron: forward beaming into cone of width $1/\gamma$.

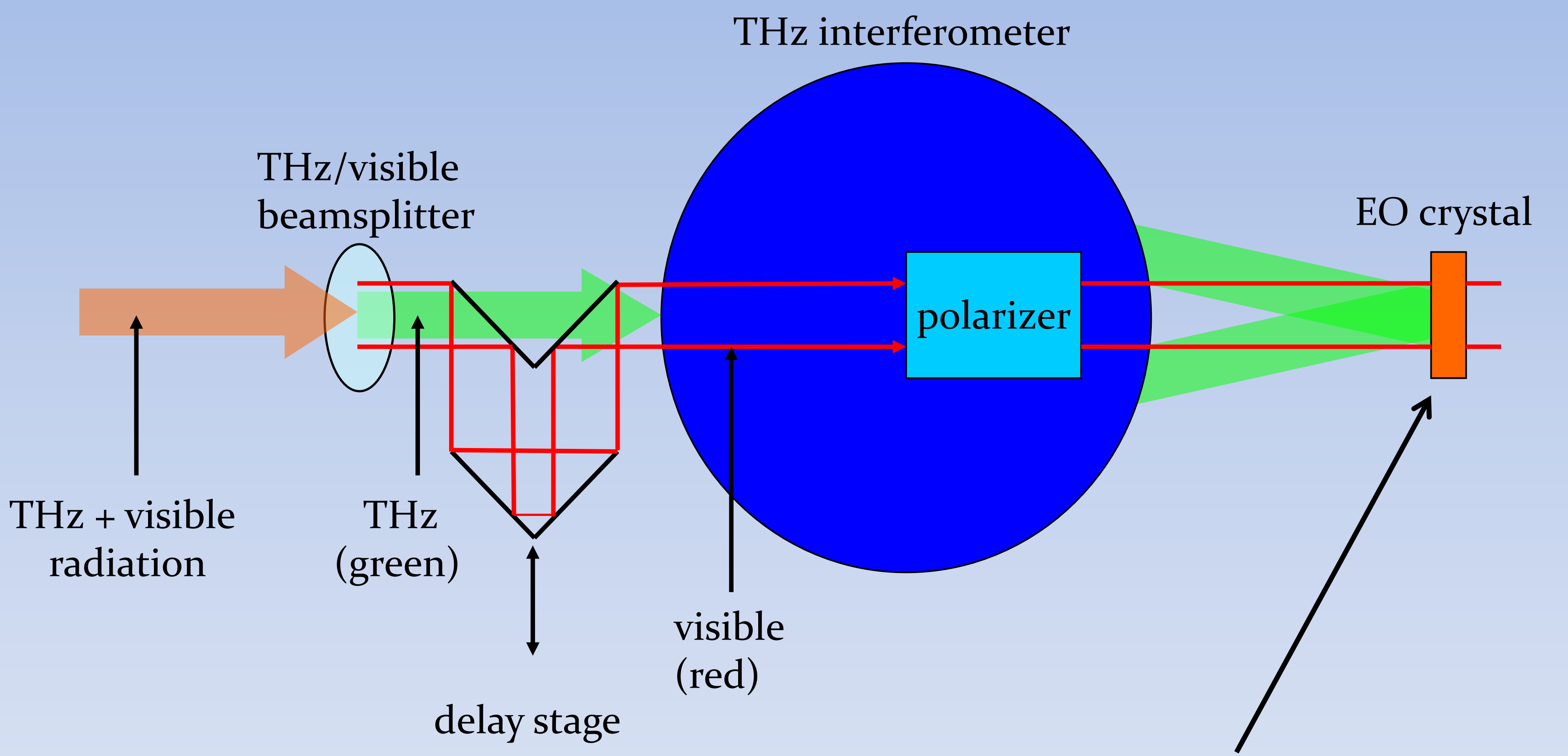


- Transition: charged particles cross boundary of two different dielectric media.

  Forward beaming, cone width $1/\gamma$.



Setup of the Experiment

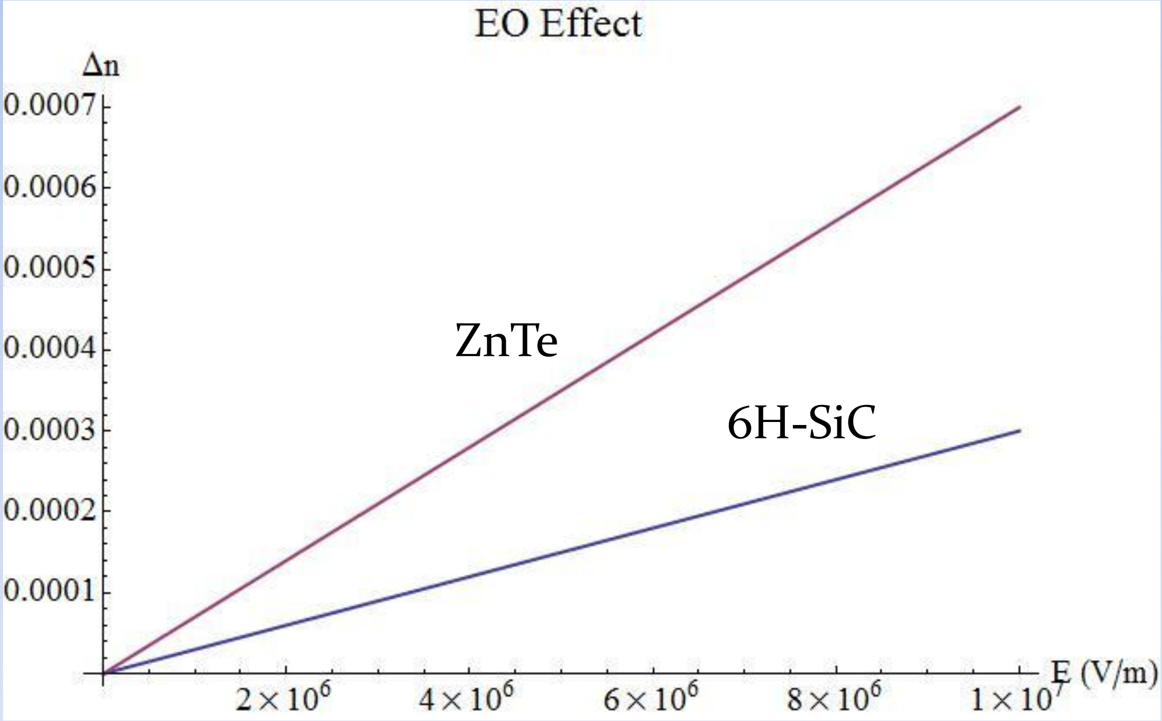


My part in this project: characterize the electro-optic crystal (6H-SiC).

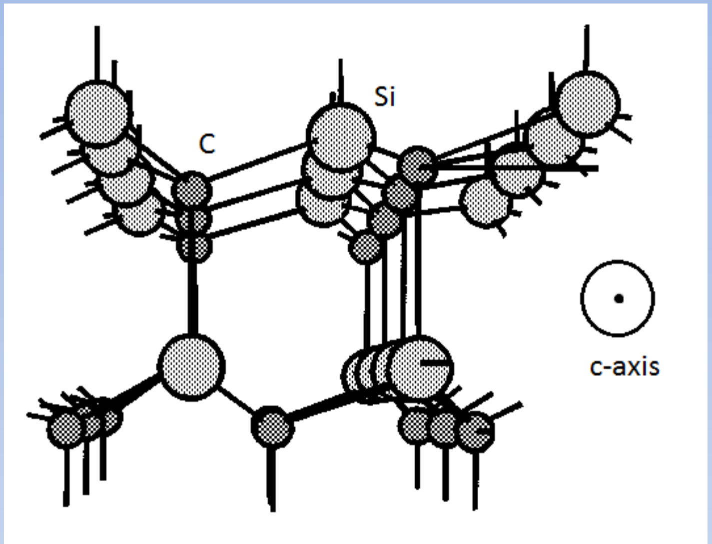
Electro-Optic (EO) Effect

- Change in the refractive index of a crystal due to the presence of an electric field.

- Depends on strength and direction of E-field, and crystal symmetry.
- Linear effect is dominant. Quadratic (Kerr) effect is negligible for a nonzero linear effect.
- Right: data taken from simulations of EO effect on hexagonal Silicon Carbide.



Unique Characteristics of 6H-SiC

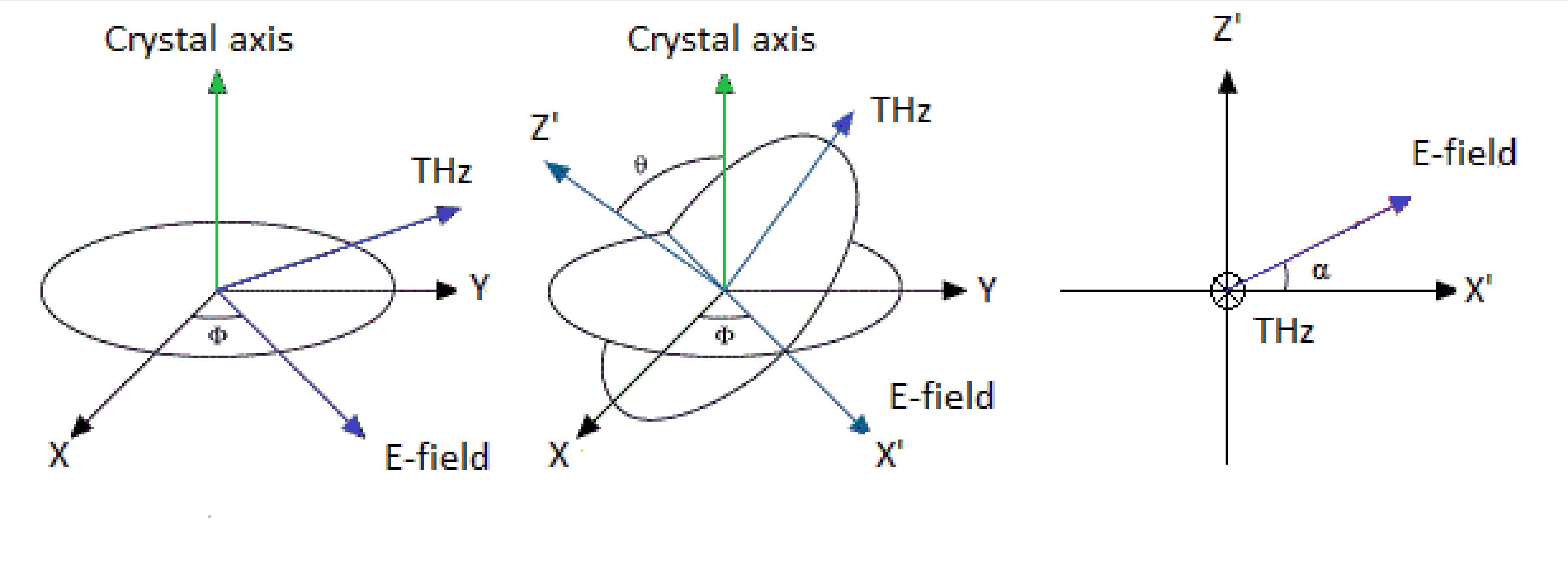


Material	ω_{TO} (THz)	EO coefficient (pm/V)	Symmetry
ZnTe	5.3	4.25	$4\bar{3}m$ cubic
GaP	10.98	1.0	$4\bar{3}m$ cubic
3C-SiC	24	2.7	$4\bar{3}m$ cubic
6H-SiC	24	2.7 ?	6mm hexagonal

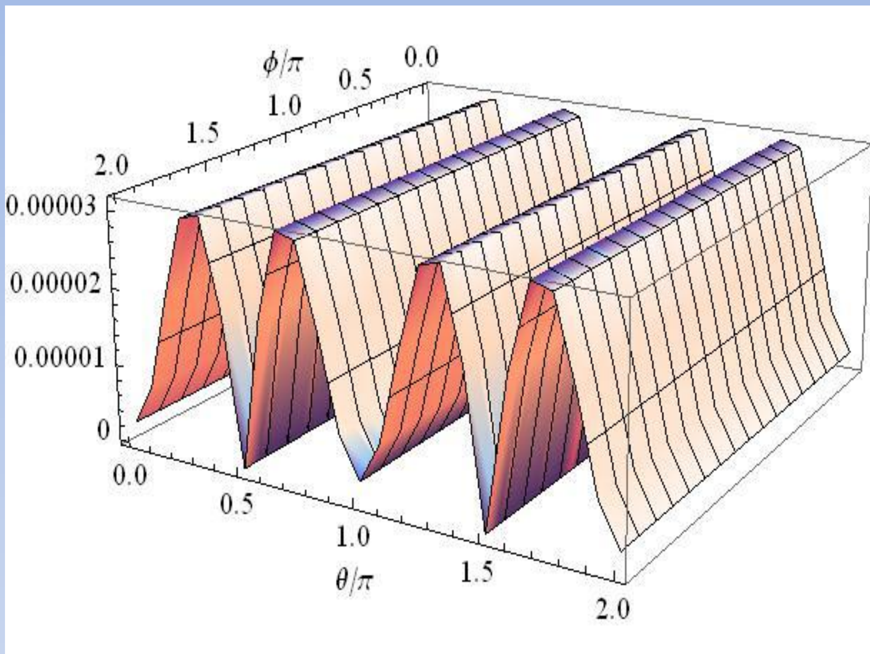
- Hexagonal symmetry: previously studied crystals were mostly cubic
- Crystal is uniaxial: crystallographic axis points in stacking direction
- Each crystal has transverse optical lattice oscillations; for 6H-SiC this is at a very high frequency
- Electro-optic coefficients not accurately known for 6H-SiC (known for 3C-SiC)

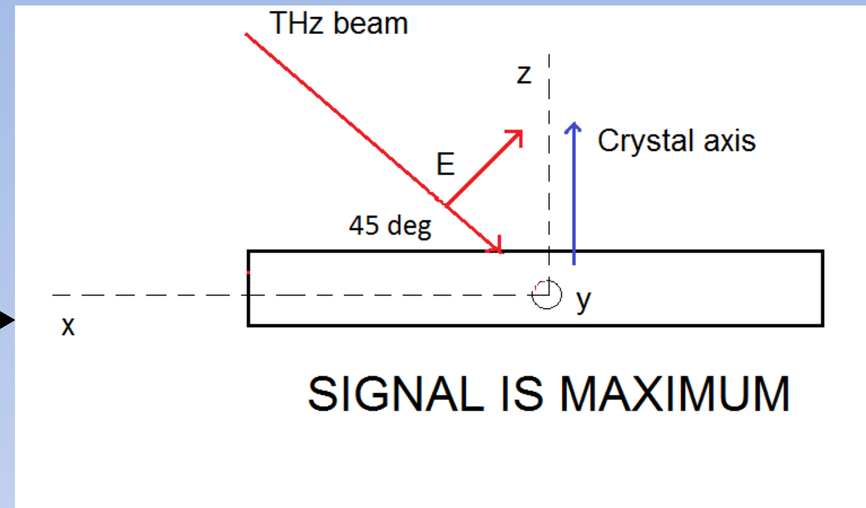
First Goal: Find Optimal Crystal Orientation

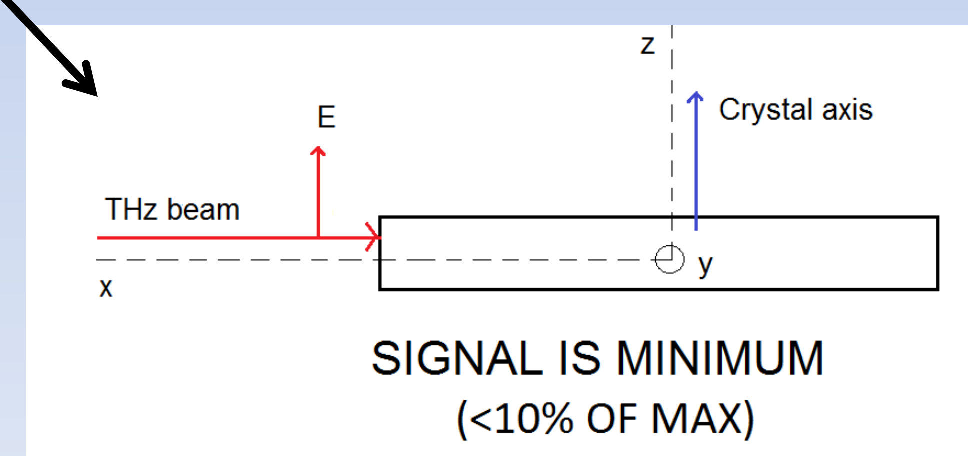
- Run simulations with varying orientations of the crystal with respect to the electric field.
- Find the orientation where Δn is maximum.
- Tricky: 6H-SiC already has an anisotropic refractive index without any E-field.



Results: Optimal Crystal Orientation

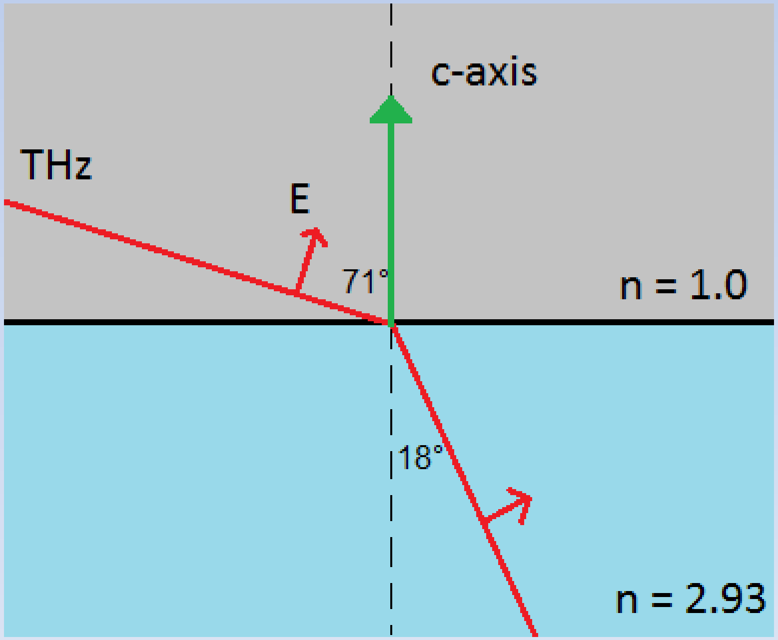






Results: Optimal Crystal Orientation

- Optimal orientation of crystal is with c-axis at 45° with respect to THz radiation.
- Need to consider refraction: our solutions are for the orientation INSIDE the crystal
- Best option: use a 6H-SiC crystal cut at the 45° angle to get maximum result



- With our sample, it is IMPOSSIBLE to get 45° inside crystal
- Best we can get is ~19.9°, refracted from grazing incidence (get 34% of max signal)
- Can also get ~18.8°, refracted from Brewster's angle (get 33% of max signal)

Second Goal: Phase Velocity / Group Velocity Study

- To maximize EO effect, THz pulse and visible pulse should strike crystal at same time and travel at same speed.

- EO response measures the signal of one frequency in THz region (travelling at phase velocity) with travelling pulse in visible region (at group velocity).

- Goal: match visible group velocity with THz phase velocity
  - Remember $v_{phase} = \frac{\omega}{k} = \frac{c}{n}$

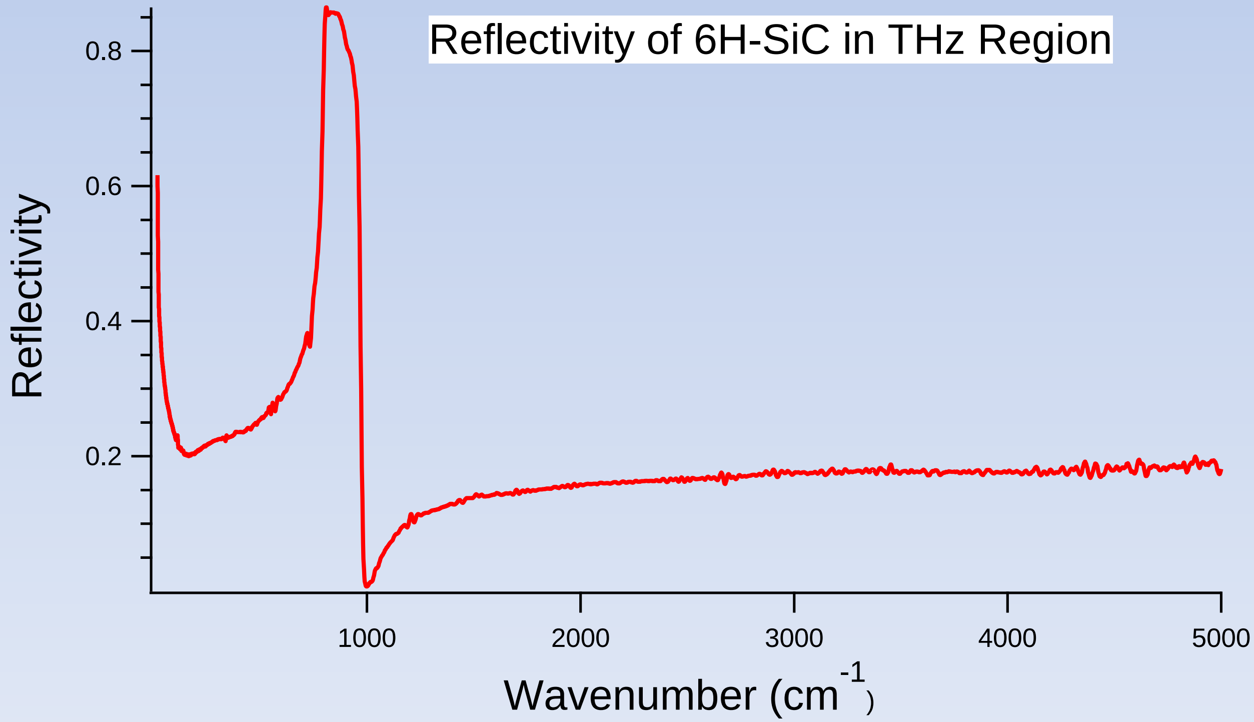
$$v_{group} = \frac{d\omega}{dk} = \frac{c}{n}(1 + \frac{\lambda}{n}\frac{dn}{d\lambda})$$

THz Phase Velocity: Reflection Measurements

- Reflectivity measurements: used Bomem spectrometer
  - Use various light sources and beam splitters to cover wide spectral range

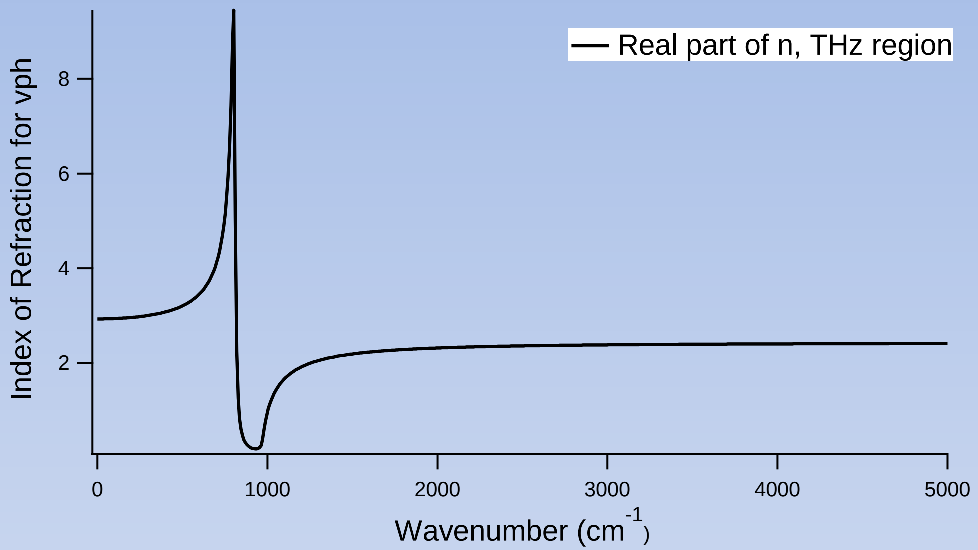
- Drude-Lorentz model for dispersion in dielectrics:

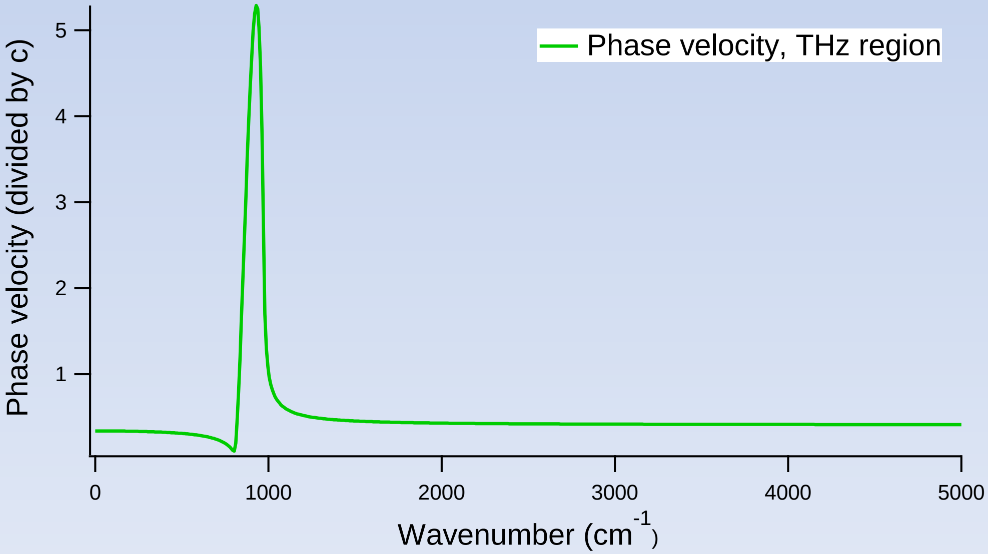
Measure reflectivity ⟶ Fit to DL model ⟶ Dielectric Function → Refractive Index



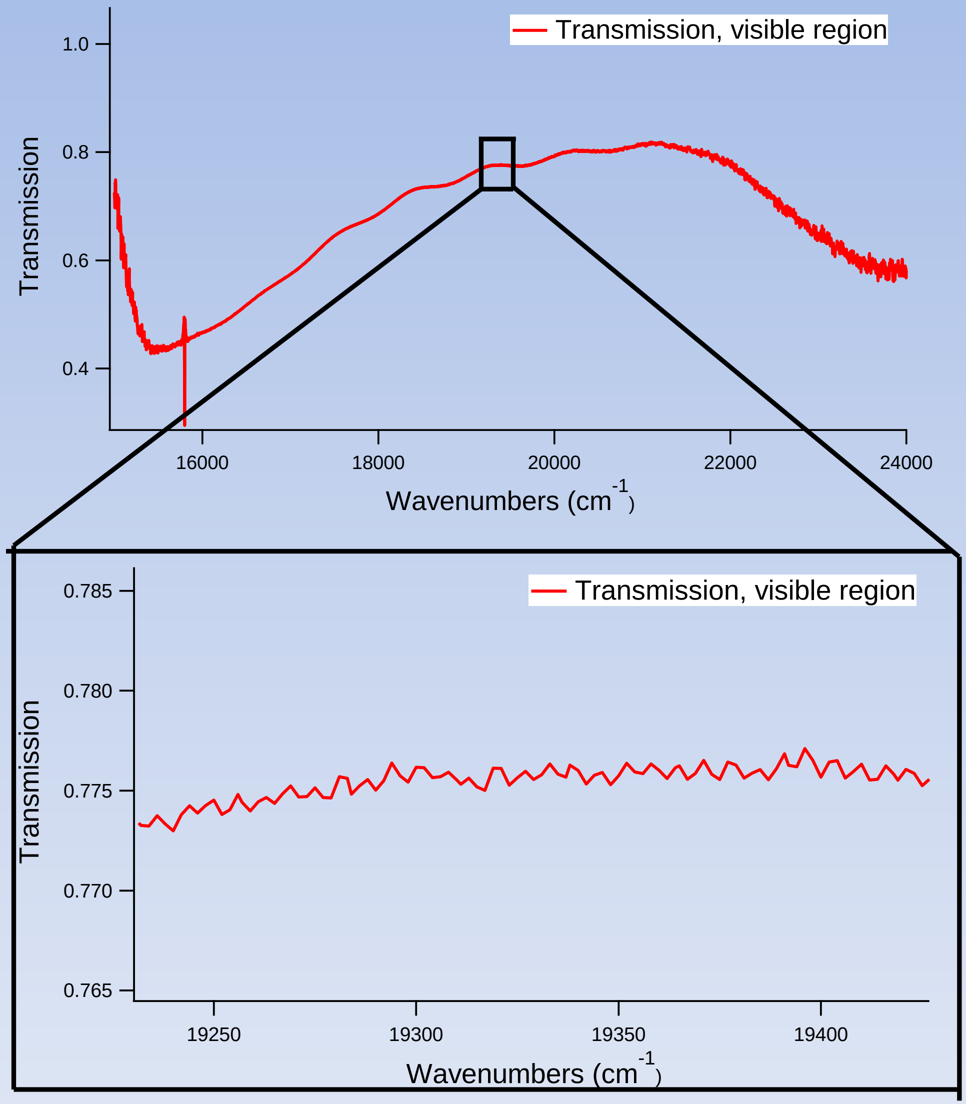
THz Phase Velocity: Reflection Measurements

- Model gives dielectric function, easy to find index of refraction.
- Strong lattice oscillation at 24.2 THz, which is 2 – 5 times greater than common cubic samples.
- Small source of error in model: our SiC sample had some conductivity.
- Conductivity term removed from model. Experiment could be re-done with cooled sample to remove conductivity.





Visible Group Velocity: Transmission Measurements

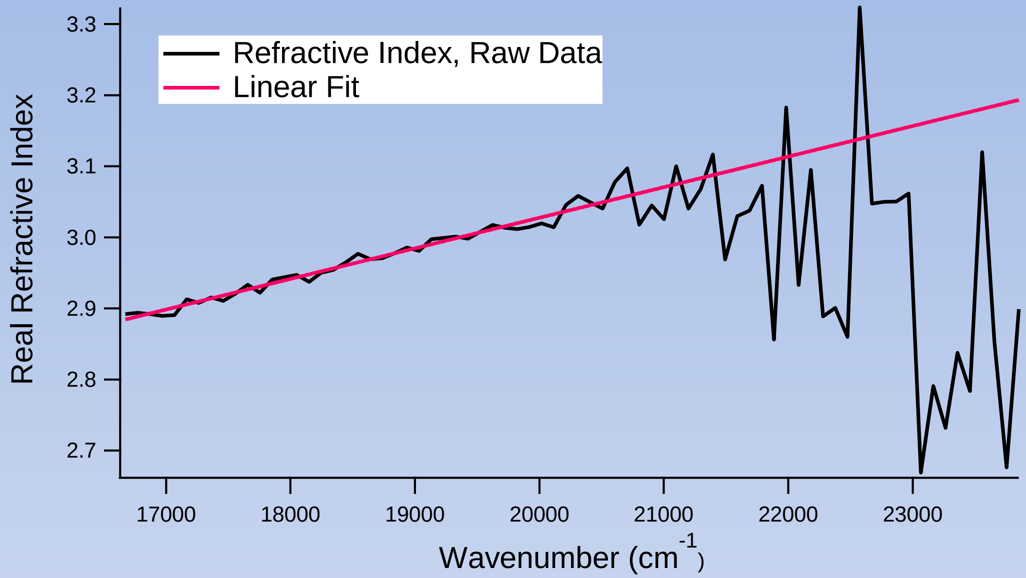


- Same spectrometer, take transmission spectrum in visible range :
  good data from ~415 nm – 666 nm
- Thin film interference spectrum gives refractive index dispersion
- Increase signal-to-noise ratio by using color filter. If matching condition falls outside of range, use another filter.

Visible Group Velocity: Transmission Measurements

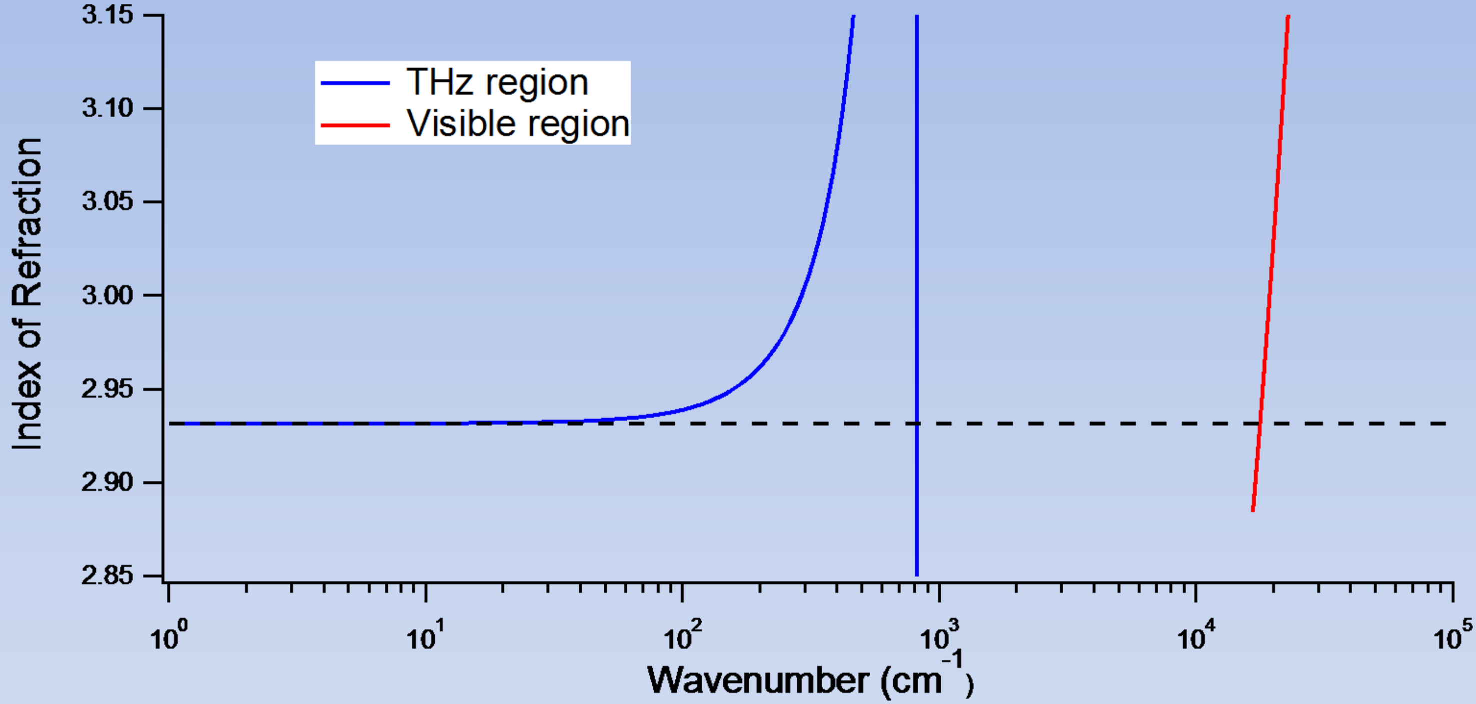
- Fit sine wave to each segment of transmission spectrum, get frequency-dependent index of refraction

- Range of good data even smaller due to noise in oscillations



- With index of refraction in both regions, we can find the exact wavelength where phase velocity/group velocity match

Phase Velocity / Group Velocity Match



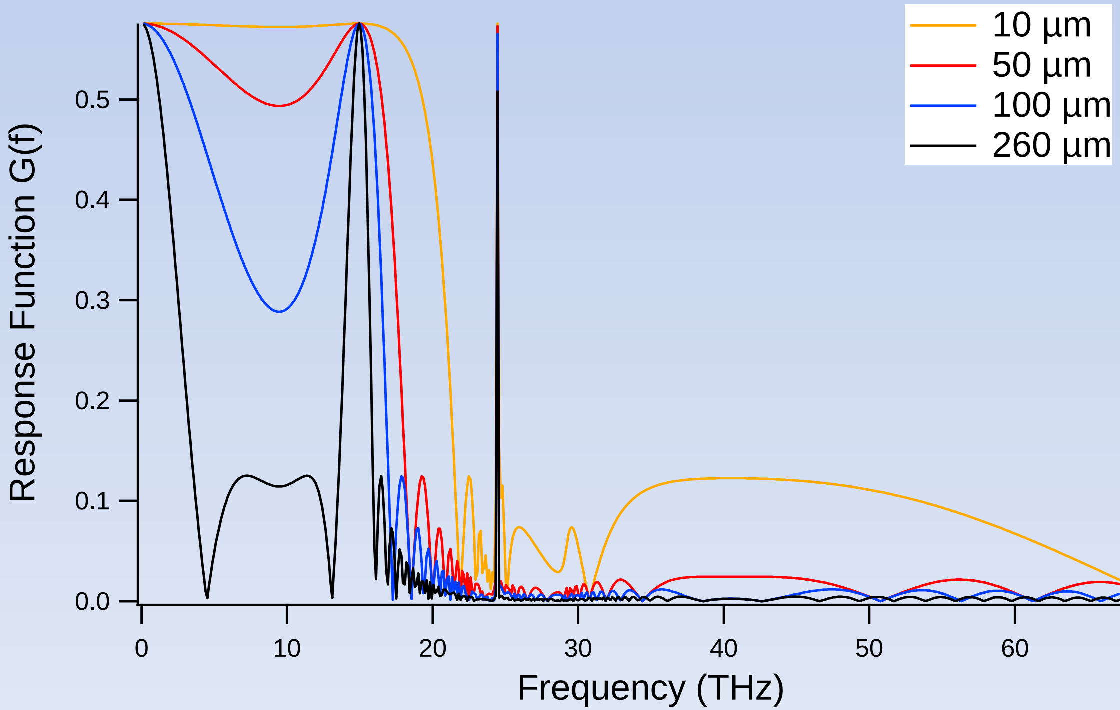
- Match fell within region of good data, at 17,773 wavenumbers = 562 nm
- This means using a visible wavelength of 562 nm will maximize the EO signal

EO Response Function

- Electro-optic response function, G(f), measures the signal of one frequency in THz region (travelling at phase velocity) with travelling pulse in visible region (at group velocity).

- Good match in phase/group velocity: high value of G(f)

- Always a drop off at TO lattice vibrations



Conclusions

- Using 6H-SiC for EO experiments
  - Optimal orientation: if crystal is cut at 45°, THz radiation should be incident normally on that surface
  - If crystal is not cut that way, use grazing incidence or Brewster's angle (incident angle of 71°, get 33% of max signal)
  - Usable THz range is large (< 24.2 THz) due to large TO oscillation frequencies (< 5 or 11 THz for previously studied crystals)
  - Visible pulse should be near 562 nm to maximize response

- Moving Forward / What can be Improved
  - Improve model in THz region by removing conductivity
  - Measure electro-optic coefficients to improve optimal orientation code
  - Obtain similar model for other two axes of crystal