Dispersion of the birefringence of quartz, magnesium fluoride, and sapphire

MASTER'S THESIS DEFENSE 6-28-24

MICHAEL GARTMAN

Problem statement

- Refractive index (and therefore birefringence) data on all three materials is extant in the literature
  - Birefringence data needs to be an order of magnitude or more accurate than index data
    - Snell's Law – an error in index of 0.001 for an air-glass interface, when the glass is N-BK7, and the initial AOI is 25 degrees, induces an error in refraction of ~40 arcsec (0.194 mrad)

Rotating HWP between parallel polarizers	
Error in birefringence	dBm
0.001	0.4
1E-5	27.5
5E-6	32
2E-6	40

Ellipticity of QWP output	
Error in birefringence	Ellipticity
0.001	0.64
1E-5	0.96
5E-6	0.98
2E-6	0.99

Materials/Applications

- Waveplates have variety of uses/applications
  - Tolerancing application dependent
    - Optical isolator v. atomic clock
- Quartz
  - Durable, broadly transparent, widely available
- Magnesium fluoride
  - More broadly transparent than quartz in the UV and the MIR
- Sapphire
  - More durable than quartz and more broadly transparent
    - Less broadly transparent than MgF_2

Methods

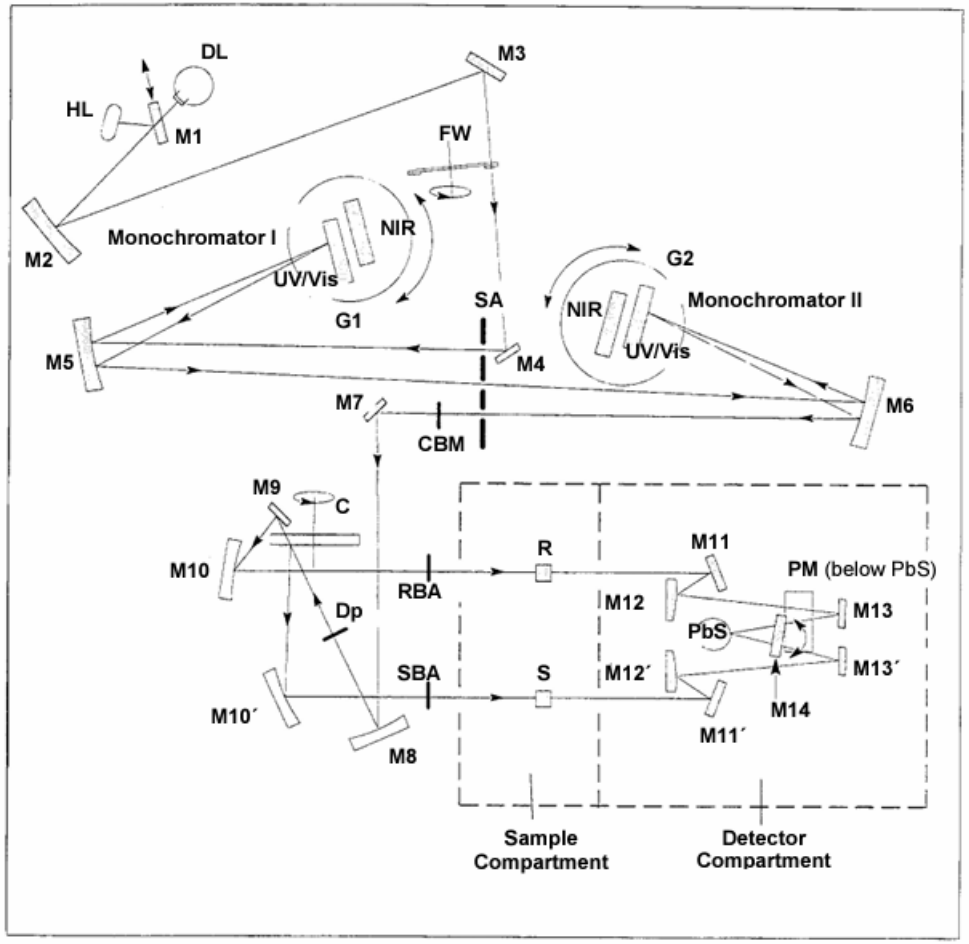
- Measure polished parts in spectrophotometer between parallel polarizers
  - Calculate birefringence from peaks/troughs
  - Fit dispersion formula to birefringence
- Test AR-coated parts with laser sources, optical spectrum analyzer, using Mueller matrix polarimeter/Stokes polarimeter
  - Compare measured birefringence with this technique against first technique
  - Temperature adjust both results to same baseline
  - AR coating avoids Fabry-Perot effects

Instrumentation

AxoScan polarimeter

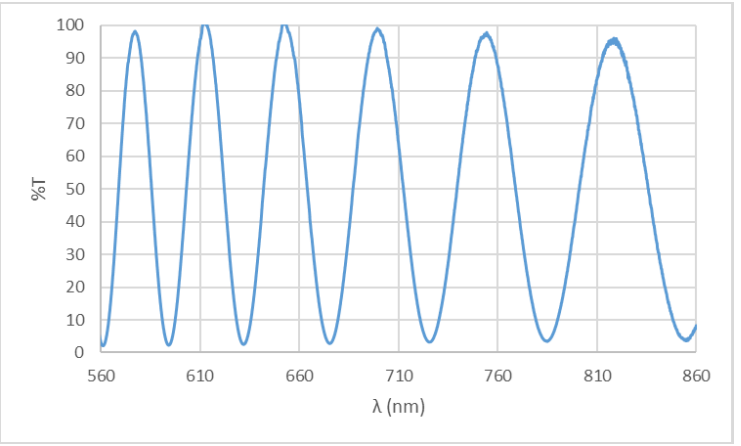
PAX polarimeter

PerkinElmer Lambda 950 spectrophotometer optical system

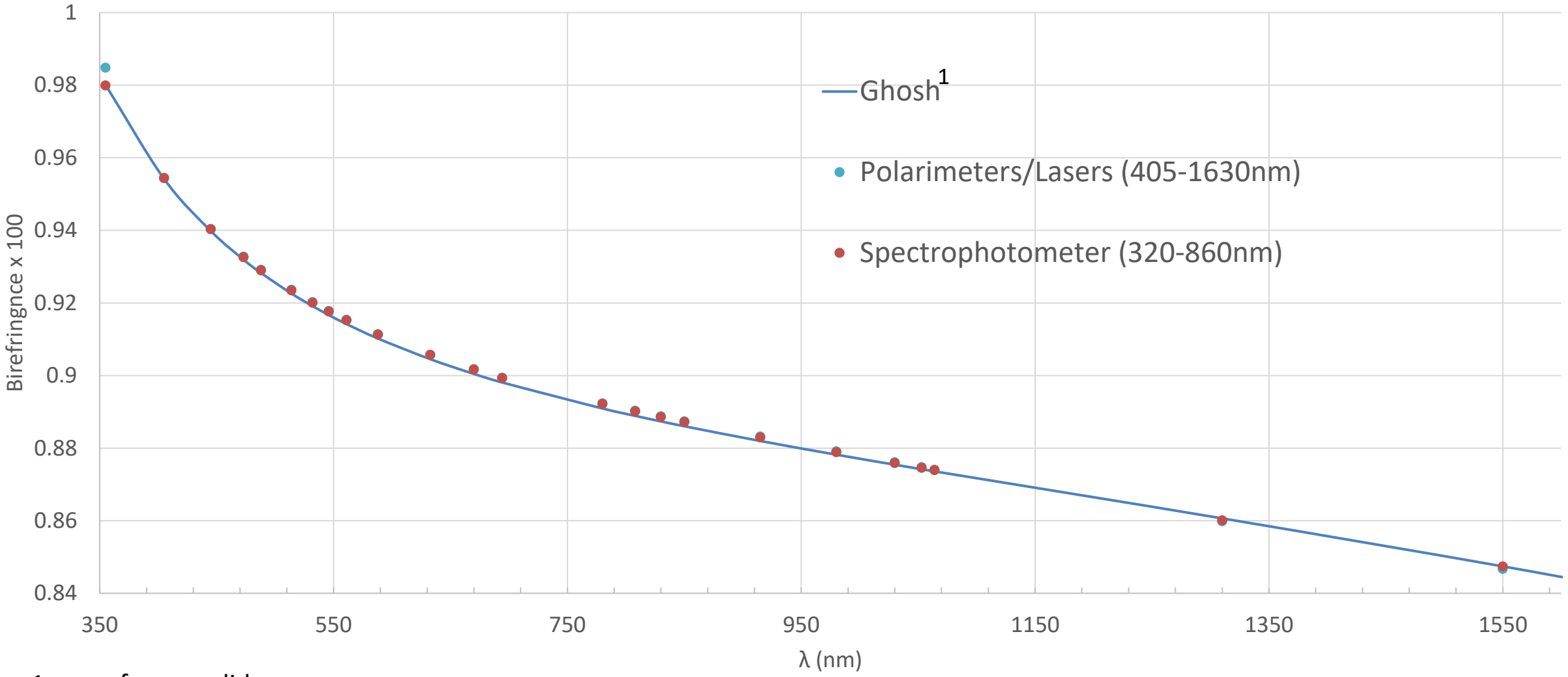


Data collected

- Spectrophotometer scans of quartz, MgF_2, and sapphire between parallel polarizers
- Dispersion of birefringence calculated from above
- All three materials tested on AxoScan/PAX polarimeter at laser wavelengths
- Tested dispersion of birefringence models against polarimeter data
  - Best agreement for quartz (<3E-6)
  - Agreement for sapphire (<4E-6)
  - Agreement for MgF_2 (<6E-6 over AxoScan range, <4E-5 over entire range)
- Comparison of dispersion of birefringence for both methods with existing literature
  - Ghosh for quartz
  - Malitson for sapphire
  - Dodge for MgF_2
  - See reference slide
- Change in retardance with temperature at 632.8nm
  - For each material

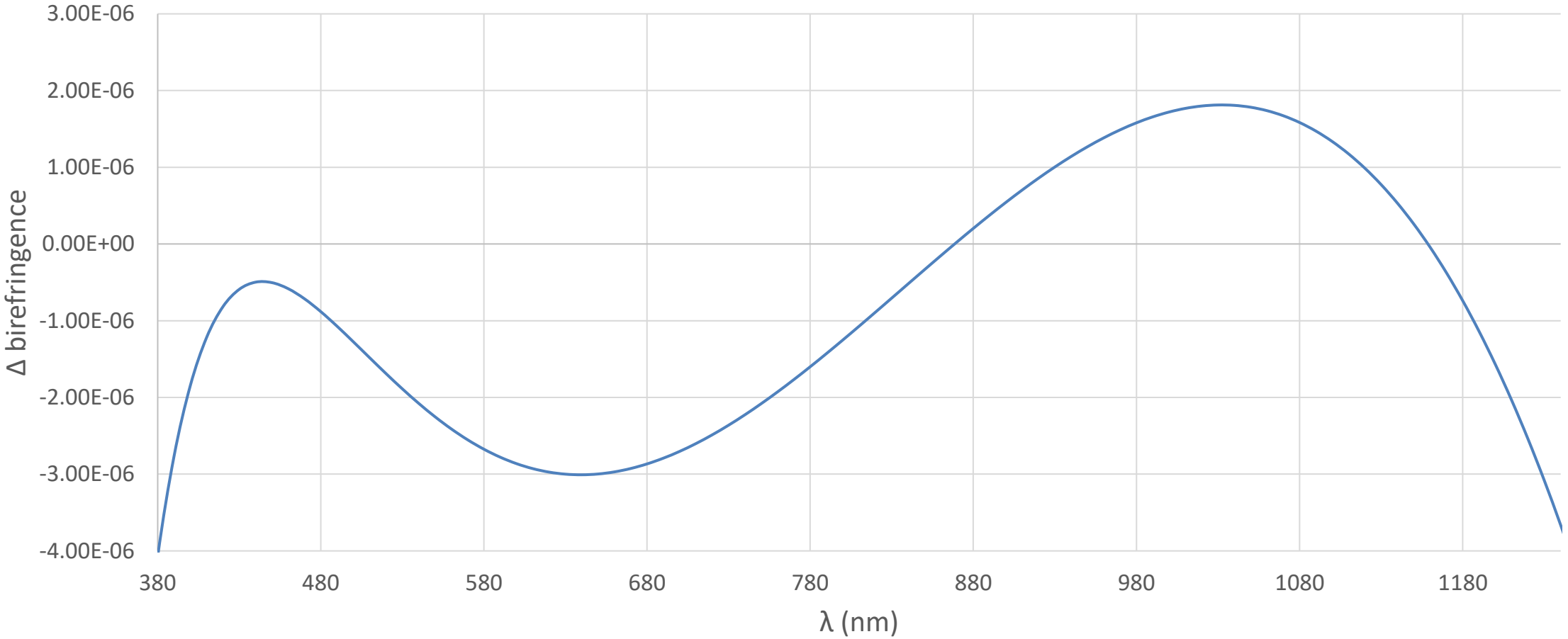


Birefringence comparison (quartz)

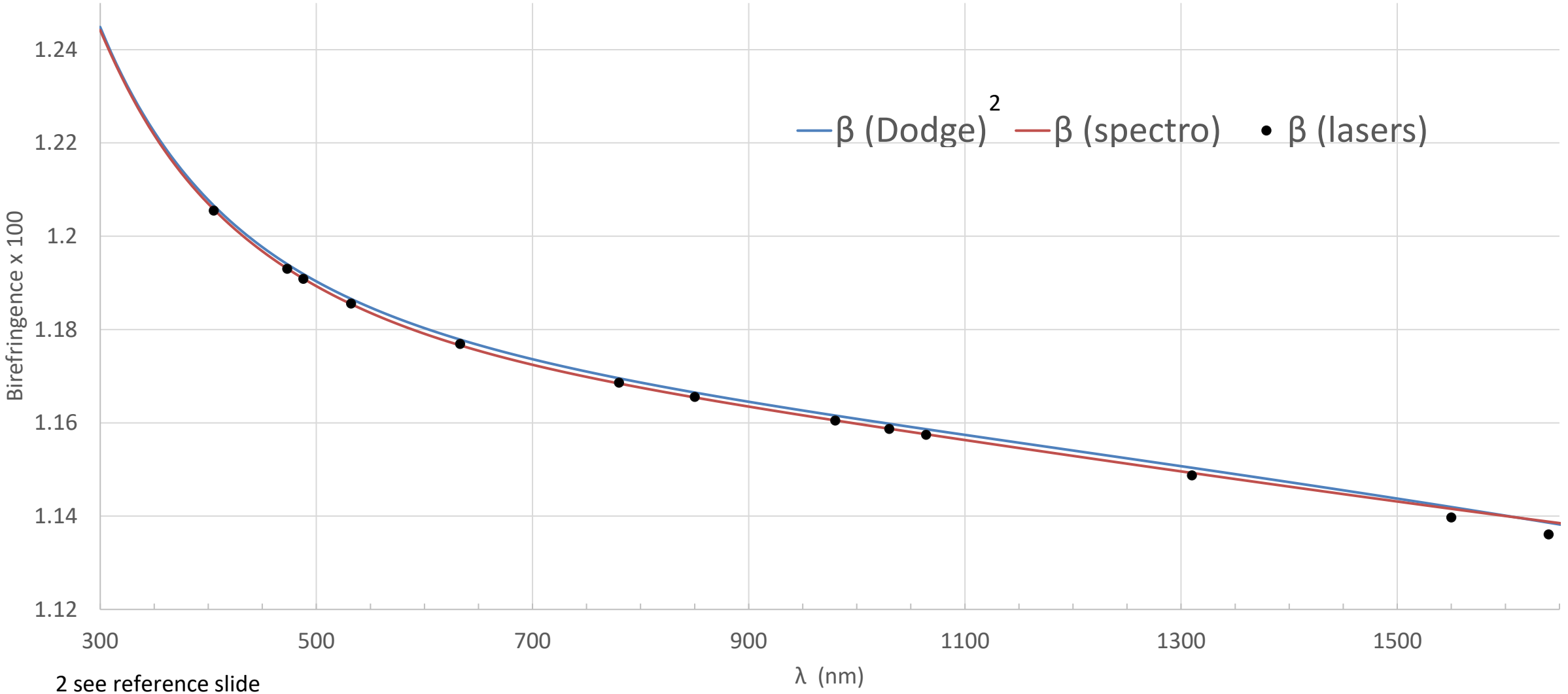


1 see reference slide

Birefringence measurement comparison (quartz)

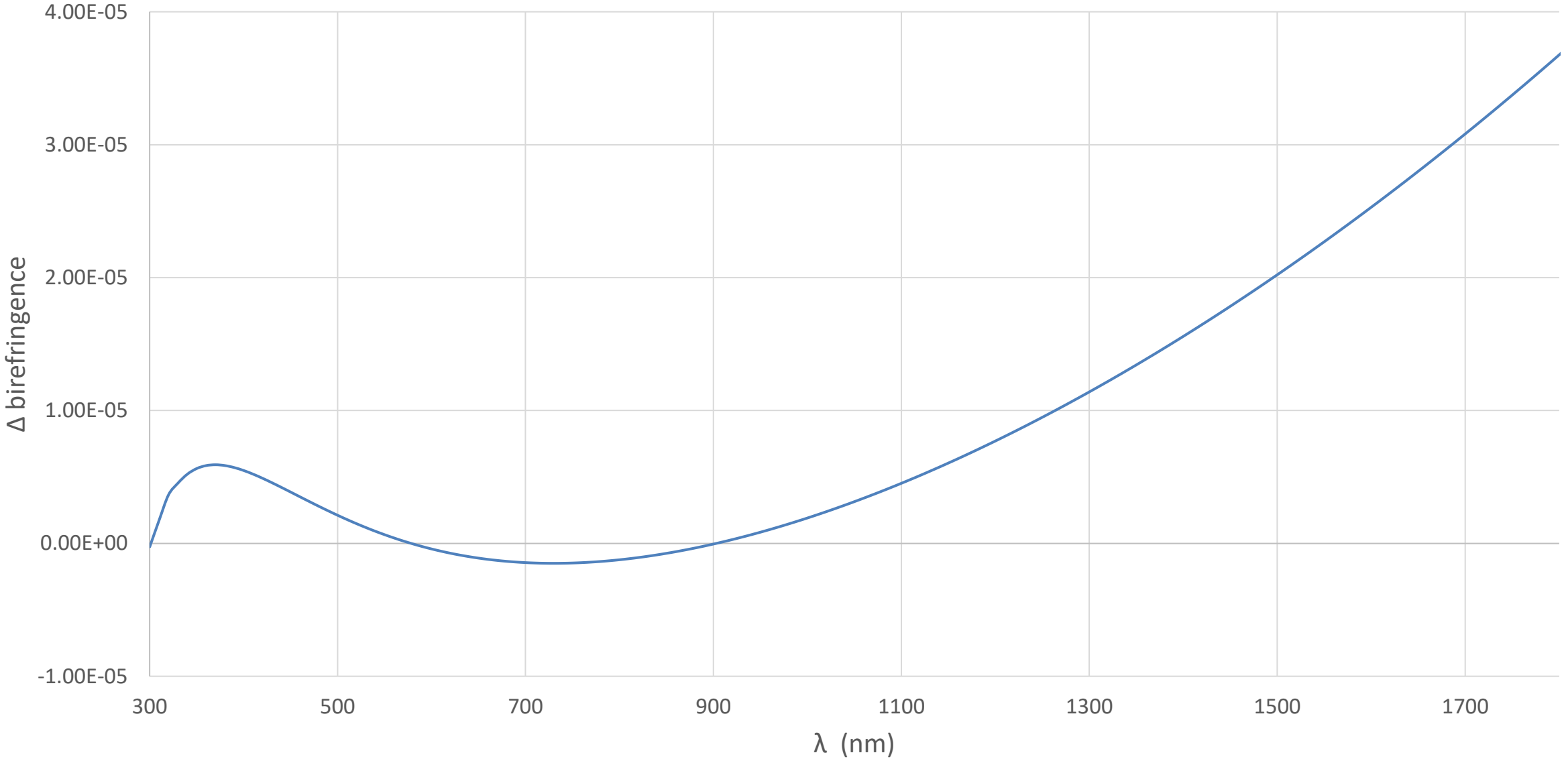


Birefringence comparison (magnesium fluoride)

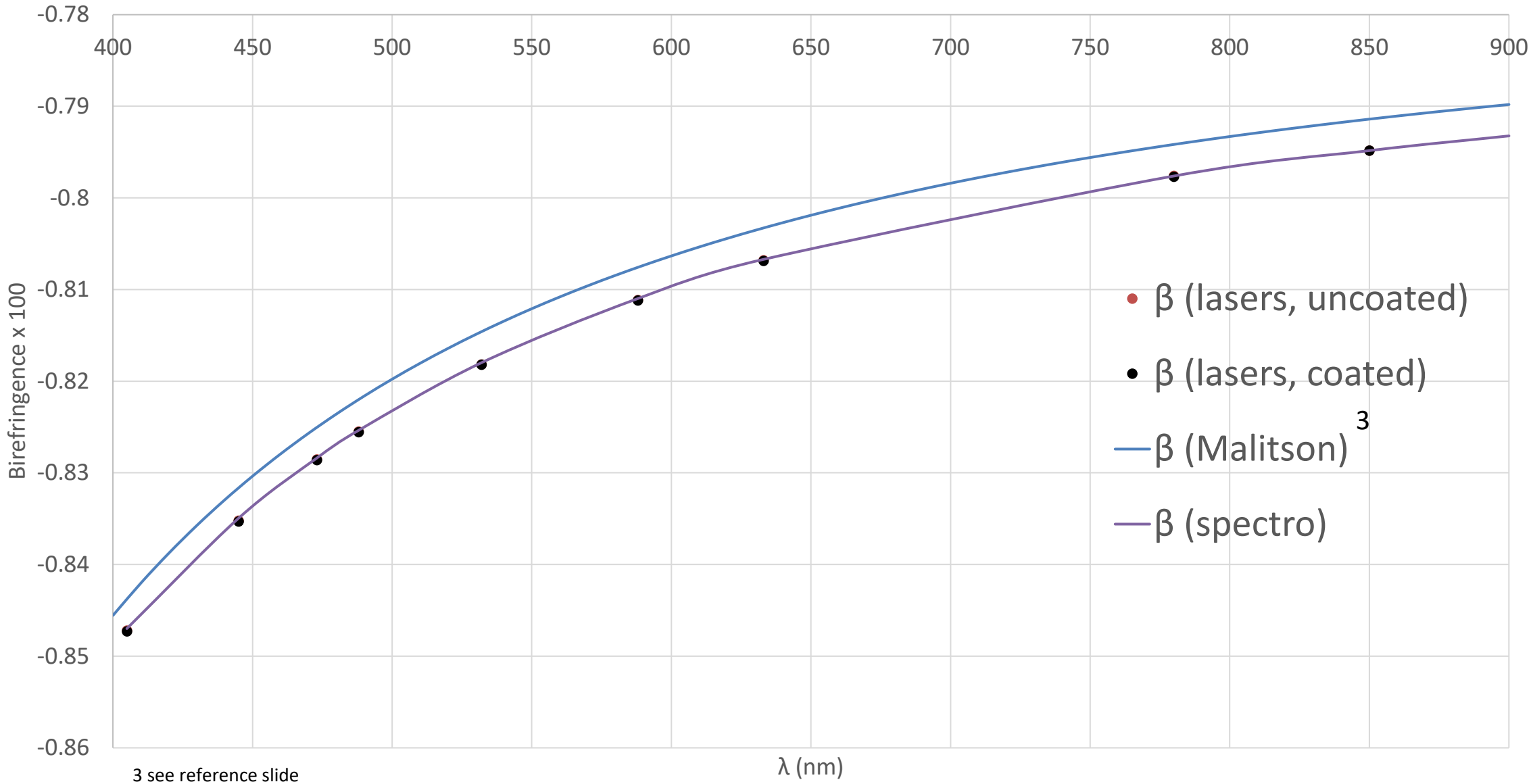


2 see reference slide

Birefringence measurement comparison (magnesium fluoride)

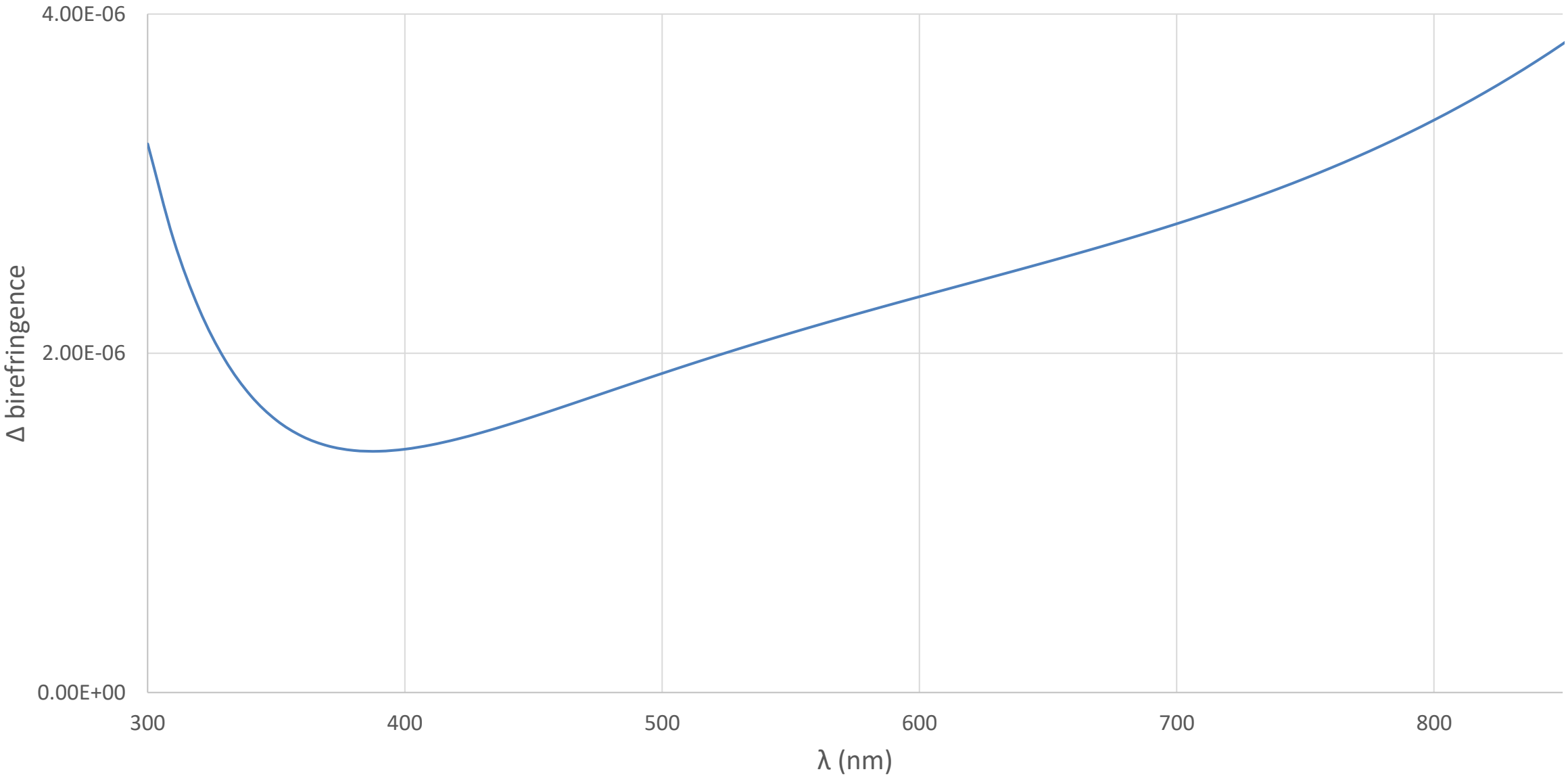


Birefringence comparison (sapphire)



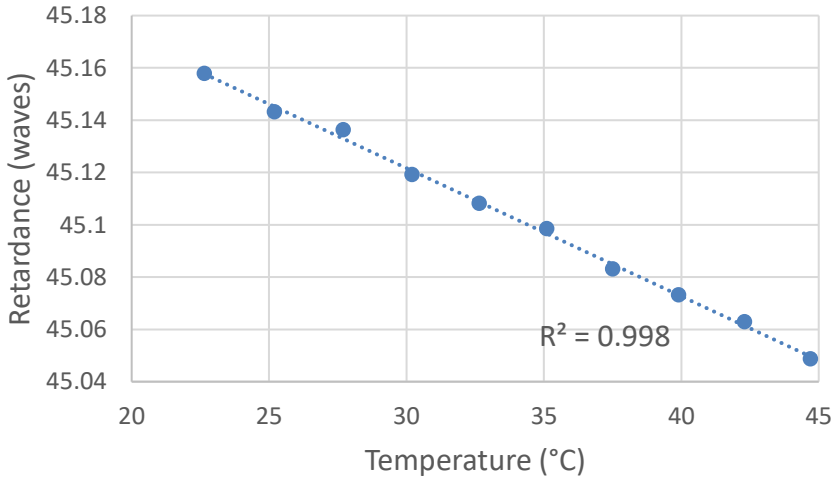
3 see reference slide

Birefringence comparison (sapphire)



Temperature

- Value of birefringence changes with temperature
  - – dn_o/dT and dn_e/dT change at different rates
    - True for all three materials in this work
  - – Measured retardance of single plate of each material at 632.8nm from room temperature (22-25 degrees C) to 45 degrees C
  - – Results correspond with previously reported data
  - – Values used to adjust measured retardance to 20 degrees C



Tolerances/Uncertainties

- For spectrophotometer:
  - –1E-5 to 3E-6
    - Varies with λ and material
- For polarimeter/laser setup:
  - –3E-6 for AxoScan, 6.5E-6 for PAX
    - Majority of error budget for AxoScan – potential thickness error of plates measured
    - Majority of error budget for PAX – potential measurement error of polarimeter
    - Majority (2/3) of remainder from tolerance of thermometer

Other sources of uncertainty

- Orientation of optic axis with respect to crystal face
  - Nominally <6 arcmin for quartz, MgF_2, <12 arcmin for sapphire
    - On the order of 3E-8 if within nominal value
- Collimation of laser beam in AxoScan
  - Multi-mode fiber, simple collimator
- Alignment of PAX Polarimeter from 850-1630nm
  - Aligned with visible light through collimator for those wavelengths
- Alignment of plates in spectrophotometer
  - Aligned with white light
- Determination of peaks/troughs
  - Curve fitting, or distance between points of equal %T

Summary

- Although birefringence is the difference of the extraordinary and the ordinary index (n_e-n_o), birefringence data needs to be at least two orders of magnitude more accurate than typical index data
  - 1E-5 or better, as opposed to 0.001 for refractive index
- Quartz, magnesium fluoride, and sapphire are commonly used materials for waveplates
  - Data measured here (using two different methods) corresponds with each other within tolerances, as well as with the literature for quartz and magnesium fluoride
  - Sapphire data has correspondence between both methods here, but not existing literature
    - Conjecture: different growth methods

References

- 1 Ghosh: DOI: 10.1016/S0030-4018(99)00091-7
- 2 Dodge: DOI: 10.1364/AO.23.001980
- 3 Malitson: DOI: 10.1364/JOSA.62.001336

Acknowledgments

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