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# Refractive Index of Photo-thermo-refractive Glass

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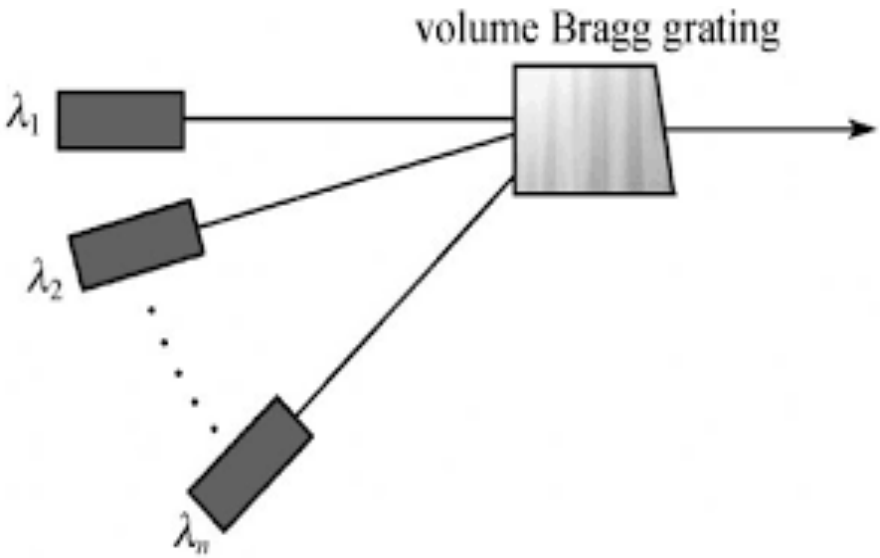
# Motivation

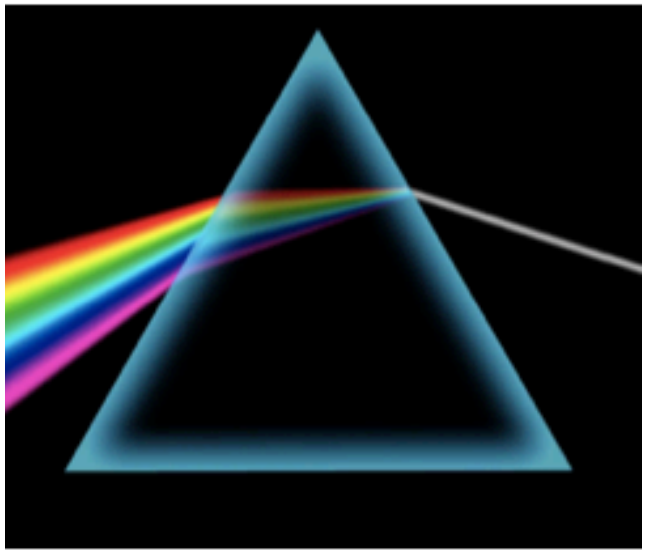
**Single fiber lasers limited to ~10 kW**

**Higher power** → **Beam combination**

**Methods**

1. **Coherent Beam Combining (CBC)**
2. **Spectral Beam Combining**



https://www.dkfindout.com/us/science/light/splitting-light/

# Volume Bragg Gratings

- Used in holographic optics
  - Holography
  - Mirrors
  - Laser wavelength stabilization
  - Notch filters
  - Fiber optics

- Spectral beam combination
  - Used in high powered laser arrays
  - Combines several laser inputs of slightly different wavelengths into a single output

http://holocenter.org/wp-content/uploads/martina-mrongovius_hover_2004.jpg

# Glass Processing

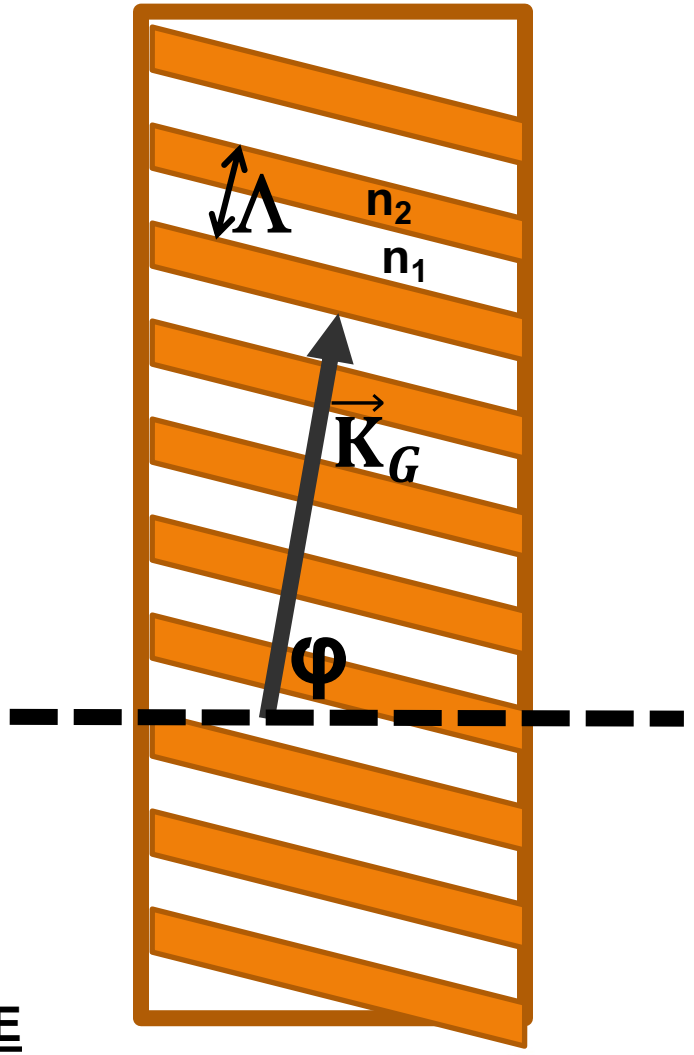
- Photo-thermo-refractive glass is composed of $15Na_2O$-$5ZnO$-$4Al_2O_3$-$70SiO_2$-$5NaF$-$1KBr$-$0.01Ag_2O$-$0.01CeO_2$

- The glass is initially exposed to a UV interference pattern
  - The cerium absorbs the UV
  - Forms crystallization centers
  - Produces a “latent image”

- The glass is then heated for a period of time
  - Other ionic compounds crystallize at the crystallization centers
  - The UV-exposed areas have smaller refractive indices
  - Creates a pattern or phase diffraction grating

# Characterization of VBRs

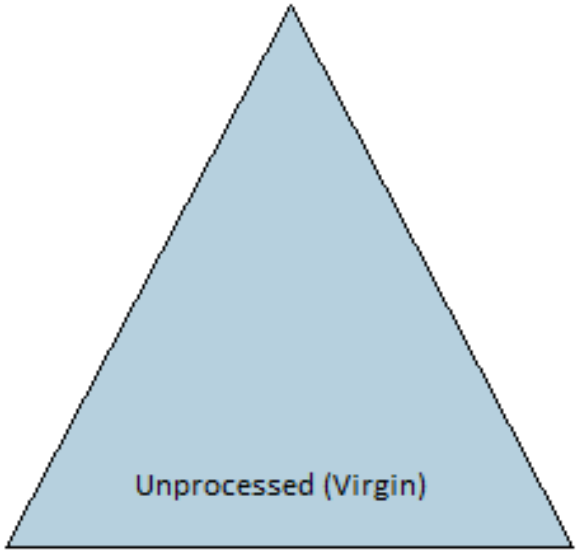
1. Grating thickness
2. Average refractive index of the medium
3. Grating period-$\Lambda$
4. Grating inclination angle- $\varphi$
5. Amplitude of the refractive index modulation-
   - $\delta n = n_1 - n_2$

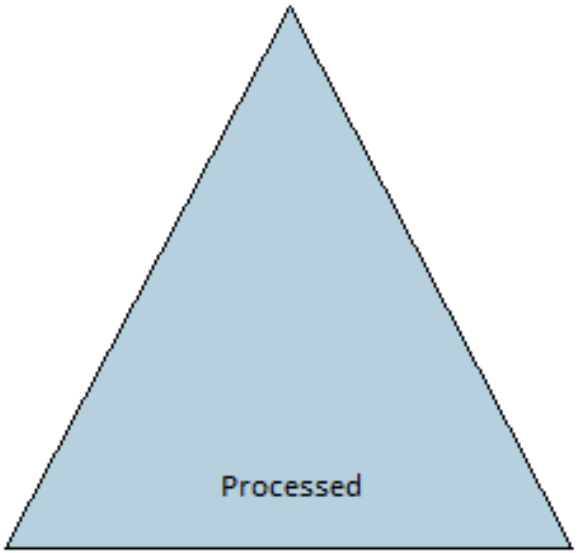



I.V. Ciapurin, L.B. Glebov, V. I. Smirnov, Proc. SPIE v5742

# Experiment

- Obtained IPG processed and unprocessed glass samples, each with apex angles of ≈ 60°
- Determined the refractive index of each sample from .4 to 4.6 microns
- Determined the refractive index dependence on temperature at wavelengths from .4 to 2.3 microns: $\frac{\partial n}{\partial T}$

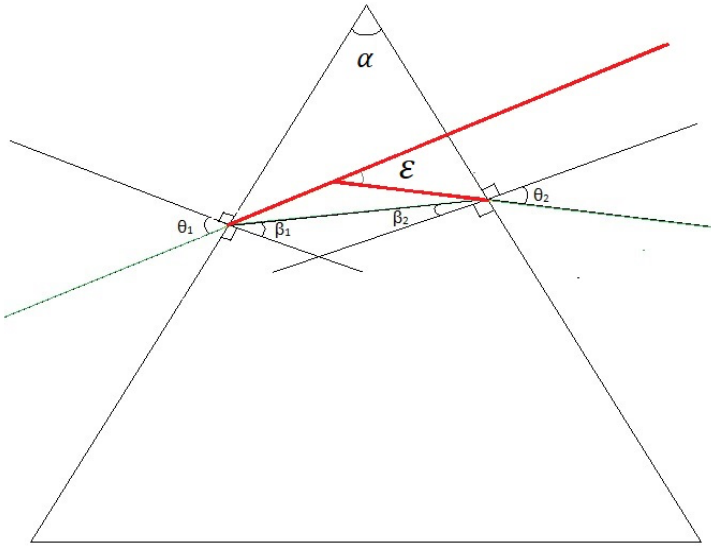


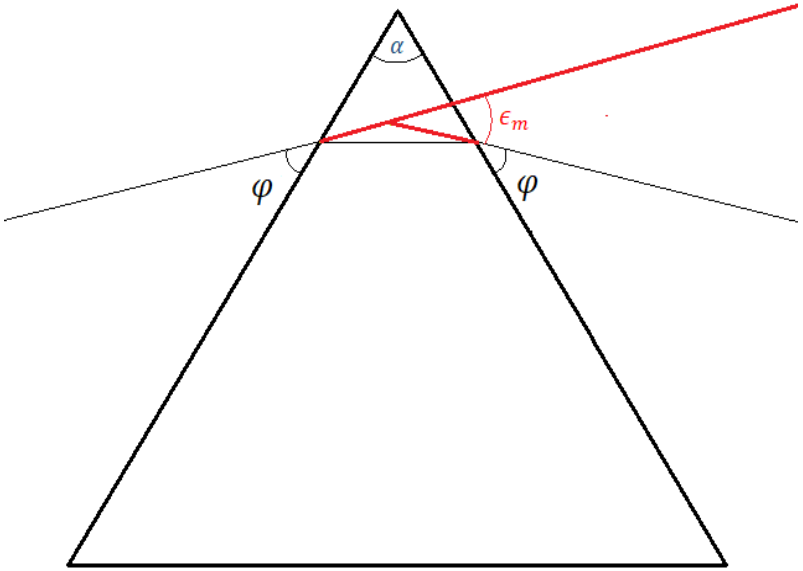



# Method of Minimum Deviation

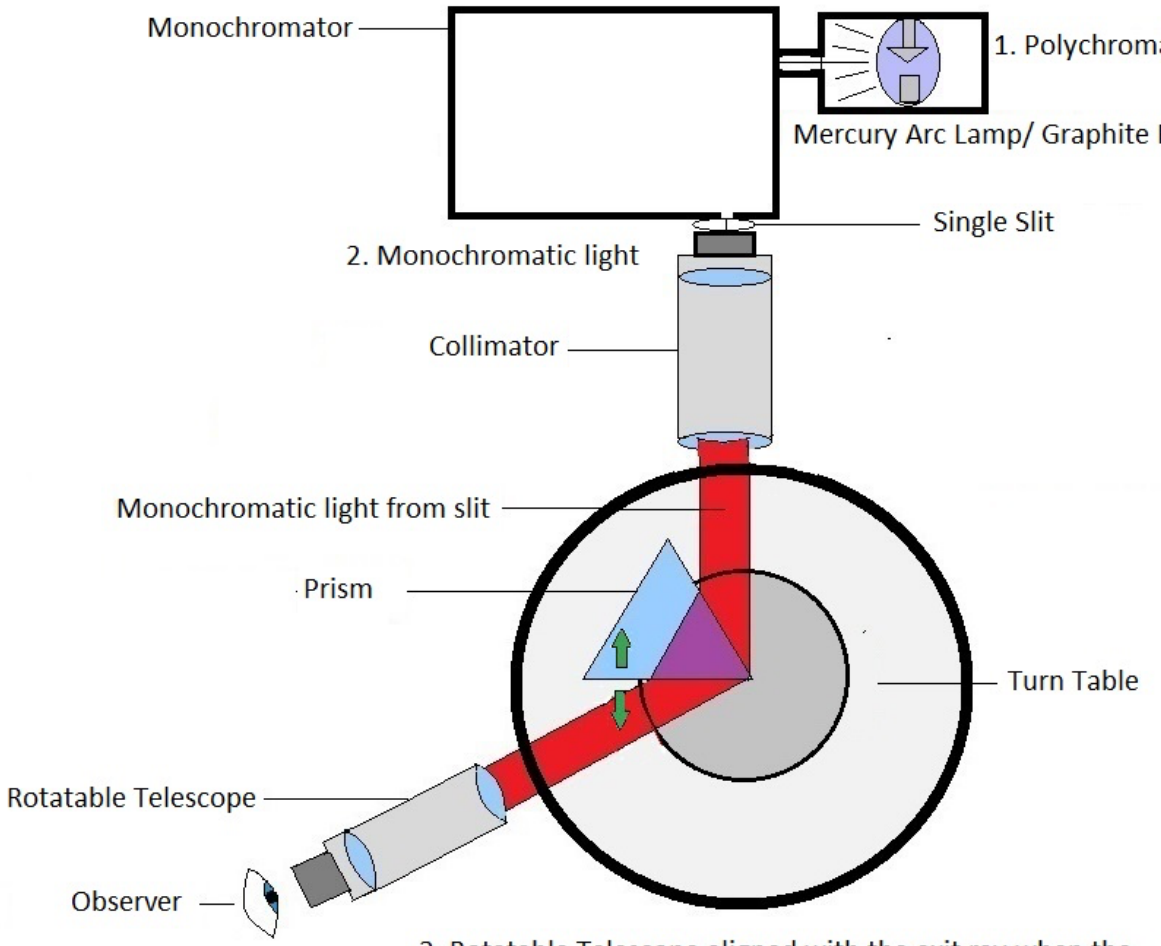
$$\epsilon = \theta_1 + \theta_2 - \alpha$$
$$\beta_1 + \beta_2 = \alpha$$
$$sin\theta_1 = nsin\beta_1$$
$$sin\theta_2 = nsin\beta_2$$

It can be shown that $n = \frac{sin\left(\frac{\epsilon_m + \alpha}{2}\right)}{sin\left(\frac{\alpha}{2}\right)}$



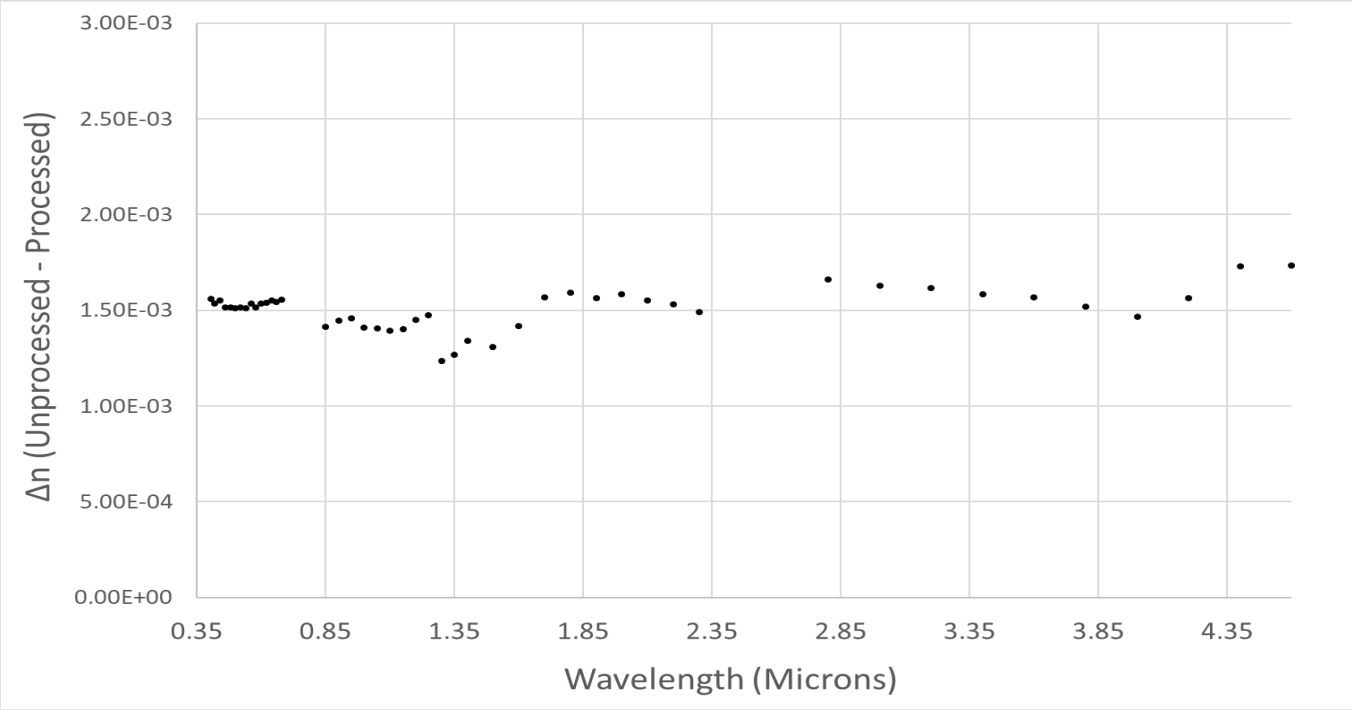



# Diagram of the apparatus




3. Rotatable Telescope aligned with the exit ray when the minimum angle of deviation is found

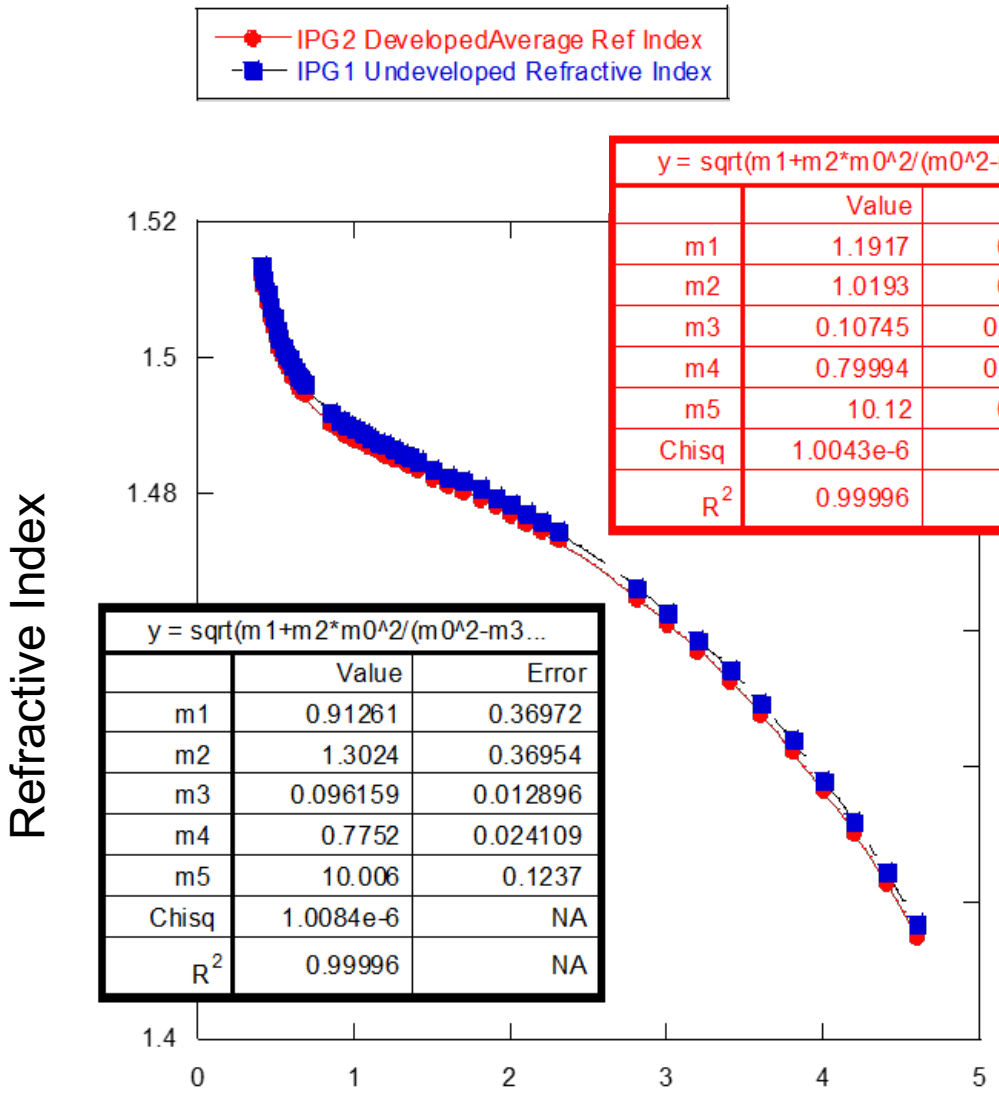
# Change in RI vs Wavelength




$$dn = \frac{\partial n}{\partial \varepsilon} d\varepsilon + \frac{\partial n}{\partial \alpha} d\alpha$$

Error was calculated using the equation $\sigma_n = \sqrt{\left(\frac{\cos\left(\frac{\varepsilon+\alpha}{2}\right)}{\sin\left(\frac{\alpha}{2}\right)}\sigma_\varepsilon\right)^2 + \left(\frac{\sin\left(\frac{\varepsilon}{2}\right)}{\sin^2\left(\frac{\alpha}{2}\right)}\sigma_\alpha\right)^2}$

# Sellmeier Modeling




| y = sqrt(m1+m2*m0^2/(m0^2-m3... | Value | Error |
|---|---|---|
| m1 | 1.1917 | 0.22887 |
| m2 | 1.0193 | 0.22868 |
| m3 | 0.10745 | 0.011234 |
| m4 | 0.79994 | 0.024347 |
| m5 | 10.12 | 0.12341 |
| Chisq | 1.0043e-6 | NA |
| $R^2$ | 0.99996 | NA |

| y = sqrt(m1+m2*m0^2/(m0^2-m3... | Value | Error |
|---|---|---|
| m1 | 0.91261 | 0.36972 |
| m2 | 1.3024 | 0.36954 |
| m3 | 0.096159 | 0.012896 |
| m4 | 0.7752 | 0.024109 |
| m5 | 10.006 | 0.1237 |
| Chisq | 1.0084e-6 | NA |
| $R^2$ | 0.99996 | NA |

$$n^2 = A + B\frac{\lambda^2}{\lambda^2 - {\lambda_1}^2} + C\frac{\lambda^2}{\lambda^2 - {\lambda_2}^2}$$

| Constant | IPG 1 (Unprocessed) | IPG 2 (Developed) |
|---|---|---|
| A | 0.9126 | 1.1917 |
| B | 1.3024 | 1.0193 |
| C | 0.7752 | 0.7999 |
| $\lambda_1$ | 0.0962 | 0.1075 |
| $\lambda_2$ | 10.0060 | 10.1200 |

# Summary

1. Measured the effect of UV exposure and annealing on the refractive index of PTR glass at wavelengths between 0.4 and 4.6 microns

2. The change in index after processing was .0015 over the entire spectrum—analogous to determining refractive index modulation amplitude

3. Sellmeier coefficients were calculated using a nonlinear curve fitting procedure (Levenburg-Marquardt) which fit the data to within ±.0002