Sellmeier representation of the dispersion of longpass optical filter glasses

Ralf Biertümpfel*; Steffen Reichel*

* SCHOTT AG, Hattenbergstraße 10, D-55122 Mainz, Germany

mailto:Ralf.Biertuempfel@schott.com

The refractive indices versus wavelength of optical transparent glasses are measured at a few wavelengths only. In order to calculate the refractive index at any wavelength, a so-called Sellmeier series is used as an approximation of the wavelength dependent refractive index. Such a Sellmeier representation is known to be valid for optical transparent glasses, however, in the past this was not used for absorbing optical filter glasses.

Our results prove that the Sellmeier representation is even valid for the high absorbing regions of optical filter glasses. By combining refractive index measurements of the two measurements techniques “minimum deviation” and “prism coupling” it is possible to obtain accurate coefficients for the Sellmeier formula. The results of those Sellmeier coefficients are presented for a several longpass filter glasses.

1 Introduction

The exact description of the wavelength dependent function of the refractive index is essential for an optimized design for sophisticated optical applications. Digital cameras use an IR cut filter to ensure good color rendition and image quality. In order to reduce ghost images by reflections and to be nearly angle independent absorbing filter glass is used, e.g. blue glass BG60 from SCHOTT. Nowadays digital cameras improve their performance and so the IR cut filter needs to be improved and thus the accurate knowledge of the refractive index (dispersion) of the used glasses must be known. But absorbing filter glass is not transparent in certain ranges of the electromagnetic spectrum. Thus the use of the Sellmeier formula was in question in the past. Additionally, it is very difficult to measure the refractive index in the absorption region of filter glass.

2 Theoretical background

The simple classical oscillator model can be used for describing the interaction between light and glass (matter). If an electro-magnetic light wave hits matter, then the electric field of the light forces the electrons inside the matter to oscillations. These electron oscillations in turn re-emit light (like an antenna). The incident light and the re-emitted light interact with each other and the superposition of both waves travel with a different speed of light compared to the incident light wave [1], [2]; [3].

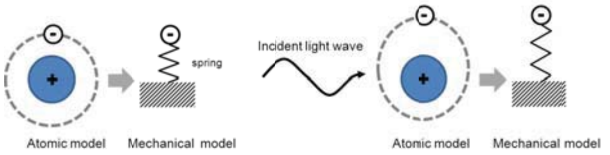

Fig. 1 *Simple model of an atom and its mechanical model where a spring “bounds” the electron to the positive charged nucleus (left). Right: the electron cloud is deformed by the electric field of the incident light wave and its mechanical model used in the classical oscillator model (Lorentz-Drude model) [4].*

It is well known that the refractive index of optical glasses can be approximated using this model with three oscillators; see [4] and [5]. The real part of the refractive index n can be represented by the well-known Sellmeier formula: (equation 1)

$$n^2(\lambda) = 1 + \sum_{i=1}^{3} \frac{B_i \lambda^2}{\lambda^2 - C_i} \tag{1}$$

The parameters B_i and C_i are the so called Sellmeier coefficients. Of course this is valid if the imaginary part of the refractive index is much small than the real part:

$$Im(n) \ll Re(n)$$

The imaginary part of the refractive index is a function of the absorption (internal transmittance T_i) of the glass at a certain thickness d:

$$Im\big(n(\lambda)\big) = -\frac{\lambda}{4\pi}\frac{1}{d} ln(T_i) \tag{2}$$

For example the longpass filter glass RG610 has an internal transmittance $T_i = 10^{-20}$ at 441 nm and 3 mm thickness resulting in an imaginary part of the refractive index of $Im(n) = 5{,}1 \cdot 10^{-04}$ – the real part of the refractive index is $Re(n) = 1{,}524$. This imaginary part is still small compared with the real part, thus, a Sellmeier representation makes sense for highly absorbing filter glasses.

3 Measurement techniques

The highest accuracy for measuring the refractive index can be obtained by Fraunhofer’s method of minimum deviation, see [7]. However, the glass must have sufficient high transmittance at a thickness of 5 mm.

The so called prism coupling [6] method does not require any minimum transmittance, however, its accuracy is limited.

Although the accuracy is different for both methods we find a good agreement between the fitted Sellmeier formulas obtained from both measurements, see figure 2.

DGaO Proceedings 2014 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2014-B006-0
submitted: 23. Jul. 2014 published: 15. Aug. 2014

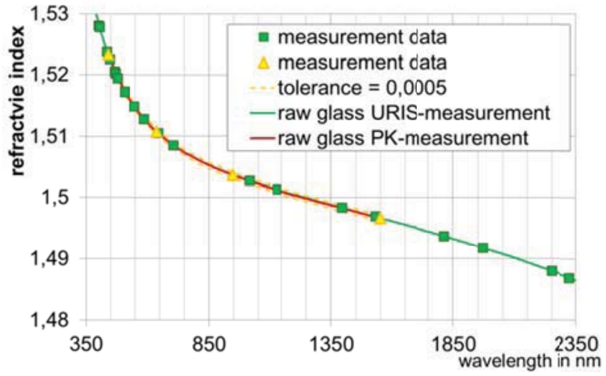

Fig. 2 *measurement data of the methods "minimum deviation" and "prism coupling" are indicated by squares and triangles respectively. The resulting curves of the Sellmeier approximation have neglectable differences*

The following analysis shows that the results may be combined, in order to calculate accurate Sellmeier coefficients. This is valid even in the case of absorbing filter glass

4 Analysis of the measured data

Long pass filter glass is produced in two steps. First a glass is molten which is transparent from UV to NIR. In a second heat treatment (so called "stricking" process) small nanocrystals of semiconductor material grow within the glass matrix. These semiconductor crystals add the long pass filter property to the glass. In other words, before the stricking the glass is nearly transparent and after the stricking the glass has high absorption for short wavelengths although the chemistry of the glass has not changed.

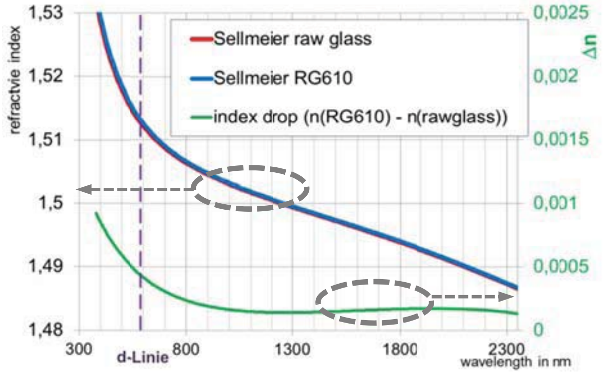

Fig. 3 *The red and blue curves correspond to the scale on the left and depict the refractive index final filter glass and raw glass respectively. The green curve corresponds to the scale on the right visualizing the small difference between the red and the blue graphs.*

When measuring the refractive index using both methods before and after the stricking, we find no significant differences. Figure 3 depicts the result of the Sellmeier approximation calculated from both measurement techniques for the final filter glass RG610 and its precursor (= glass before stricking process). The difference is shown as a green curve with secondary ordinate (on the right).

Such an index drop is known for all glass types: when a particular glass is cooled at different cooling rates, this will result in a so called index drop.

5 Results

The table 1 lists the Sellmeier coefficients of the measured data from both methods for three types of long pass filter glasses. Because these coefficients are calculated as a mathematical fit of measured data, they are accurate within the wavelength range of the measurements. Out of this wavelength range one cannot estimate the quality of the Sellmeier approximation.

Please note: the coefficients C1 to C3 of table 1 are specified in units of micrometers, thus, the wavelength λ in equation 1 must be used in micrometers as well.

	OG550	**RG610**	**RG780**
B1	1,242645	1,2245934	0,4066485
B2	0,009749	0,0300384	0,9852082
B3	0,640132	0,5524192	0,3548363
C1 in µm²	0,009773	0,0091624	0,0113905
C2 in µm²	0,0441	0,0433862	0,0120503
C3 in µm²	81,65719	70,755321	55,081195

Tab. 1 *Sellmeier coefficients of long pass filter glasses valid in a range from 380 nm to 2400 nm.*

Acknowledgement

We like to thank Ralf Reiter for his support for this work. Also thanks to Christian Sinn for his fruitful comments.

References:

[1] Born M., [Optik], reproduction by Edward Brothers, see chapter 8, Ann Arbor, MI, USA (1943)

[2] Born M., Wolf E., [Principles of Optics]; 7th ed. Cambridge, 1999

[3] Hecht, E., [Optik], 2nd edition, Oldenbourg Verlag, München, Germany (1999)

[4] Siegman, A., [Lasers], University Science Books, Sausalito, CA, USA (1986)

[5] Reichel, S. and Biertümpfel, R., "Optical glass - refractive index change with wavelength and temperature", SPIE Photonics Europe, paper 9131-16 accepted for publication, Brussels, Belgium (2014)

[6] Onodera H., Awai, and I., Ikenoue, J., "Refractive-index measurement of bulk materials: prism coupling method", Applied Optics, Vol. 22 No. 8, 1194-1197 (15th April 1983)

[7] Hartmann, P., Englert, M., and Reichel, S., "Optical glass - refractive index change with wavelength and temperature", SPIE Photonics Europe, paper 9131-16 accepted for publication, Brussels, Belgium (2014)