Optical Properties of Fused Quartz

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This technical note reviews experimental studies reporting (1) the spectral index of refraction k_λ and (2) the absorption index k_λ of fused quartz over the spectral range from 0.2μm to 15μm. It is an excerpt of Ref. [1]. Excel spreadsheets containing the data and the Figures are available upon request at from Laurent Pilon at pilon@seas.ucla.edu.

1 Index of Refraction of Fused Quartz

Table 1summarizes the references reporting experimental values of the real part of the complex index of refraction of fused quartz at room temperature along with the spectral range covered from the relationships: Different correlations for the real part of the complex index of refraction of fused quartz as a function of wavelength have been suggested in the literature [3, 4, 11] for different spectral regions. Rodney and Spindler [3] suggested an expression for n_λ over the spectral range from 0.347 to 3.508 μm at 31^{o}C while Tan and Arndt [11] proposed another equation in the spectral region from 1.44 to 4.77 μm at temperatures ranging from 23.5 to 481^{o}C. Over the spectral range from 0.21 to 3.71 μm at 20^{o}C, Malitson [4] fitted experimental data

Table 1: Summary of the experimental data reporting the real part of complex index of refraction of fused quartz at room temperature.

Reference	Wavelengh range
[2]	$1.31\mu\text{m} \leq \lambda \leq 4.84\mu\text{m}$
[3]	$0.35\mu\text{m} \leq \lambda \leq 3.51\mu\text{m}$
[4]	$0.21\mu\text{m} \leq \lambda \leq 3.71\mu\text{m}$
[5]	$2.1\mu\text{m} \leq \lambda \leq 14.\mu\text{m}$
[6]	$8.13\mu\text{m} \leq \lambda \leq 9.63\mu\text{m}$
[7]	$7.84\mu\text{m} \leq \lambda \leq 12.90\mu\text{m}$
[8]	$0.2\mu\text{m} \leq \lambda \leq 3.4\mu\text{m}$
[9]	$7.14\mu\text{m} \leq \lambda \leq 11.11\mu\text{m}$
[10]	$7.14\mu\text{m} \leq \lambda \leq 50.00\mu\text{m}$

with the following three-term Sellmeier equation,

$$(n_\lambda)^2 = 1 - \frac{0.6961663\lambda^2}{\lambda^2 - (0.0684043)^2} \frac{0.4079426\lambda^2}{\lambda^2 - (0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2 - (9.896161)^2} \quad (1)$$

Moreover, Tan [12] confirmed the validity of Equation (1) for wavelengths up to 6.7 μm. Therefore, due to its wide range of validity (from 0.21 to 6.7 μm) at room temperature, Equation (1) will be used in the present study. Figure 1 shows the variations of the real part of the complex index of refraction n_λ of fused quartz as a function of wavelength λ as reported in the literature and summarized in Table 1.

2 Absorption Index of Fused Quartz

The absorption coefficient or the imaginary part of the refractive index of fused quartz in the near-infrared (up to 3.5 μm) depends strongly on the purity of the fused quartz [5, 13, 14] and in particular on the hydroxyl content [5, 14]. The value of the extinction index k_λ was not always directly available from the literature and had to be recovered from spectral transmittance or emittance measurement data. Table 2 lists the references reporting experimental data for fused quartz at room temperature with the spectral range covered, the thickness of the sample, and the measurements performed to recover k_λ. The value of k_λ can be recovered from the normal spectral

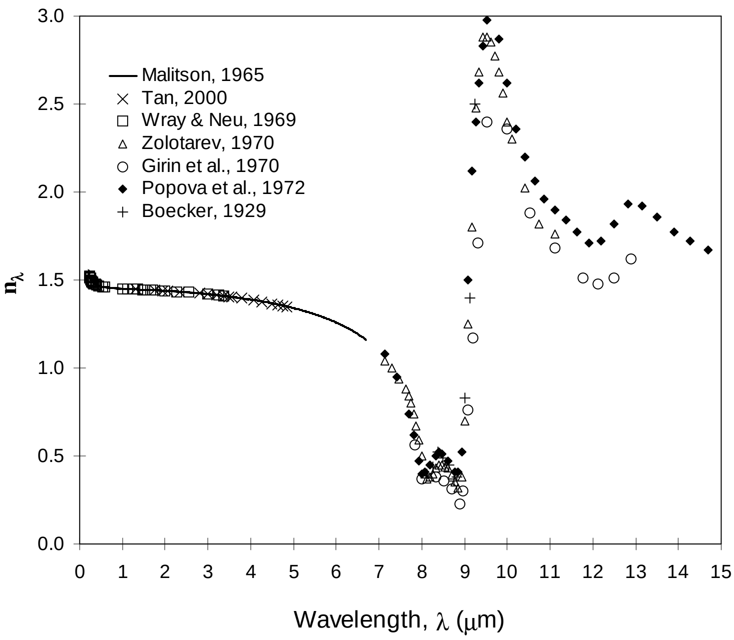

Figure 1: Real part of the complex index of refraction of fused quartz n_λ.

transmittance data $T_{0,\lambda}$ based on the relationship between $T_{0,\lambda}$ and k_λ in which multiple reflections are accounted for [17]

$$T_{0,\lambda}(L) = \frac{(1-\rho_\lambda)^2 e^{\kappa_\lambda L}}{1-(\rho_\lambda)^2 e^{2\kappa_\lambda L}} \quad (2)$$

where L is the thickness of the layer, ρ_λ and α_λ are the spectral reflectivity of the interface and the spectral absorption coefficient of fused quartz, respectively, and are given by

$$\rho_\lambda = \frac{(n_\lambda - 1)^2}{(n_\lambda + 1)^2} \quad (3)$$

$$\text{and} \qquad \kappa_\lambda = \frac{4\pi k_\lambda}{\lambda} \quad (4)$$

This expression can be solved as a quadratic in the exponential factor and after some algebraic manipulation obtain the following expression for k_λ as a function of the real part of the complex index of refraction n_λ, the sample

Table 2: Summary of the experimental data reporting the imaginary part of complex index of refraction of fused quartz at room temperature.

Reference	**Wavelengh range**	Comments
[5]	$3.63\mu\text{m} \leq \lambda \leq 14.\mu\text{m}$	
[6]	$8.13\mu\text{m} \leq \lambda \leq 9.63\mu\text{m}$	
[7]	$7.84\mu\text{m} \leq \lambda \leq 12.90\mu\text{m}$	
[9]	$7.14\mu\text{m} \leq \lambda \leq 11.11\mu\text{m}$	
[15]	$0.22\mu\text{m} \leq \lambda \leq 3.5\mu\text{m}$	Data extracted from spectral absorption coefficient
[10]	$7.14\mu\text{m} \leq \lambda \leq 50.00\mu\text{m}$	
[16]	$3.0\mu\text{m} \leq \lambda \leq 14.0\mu\text{m}$	Data extracted from normal emittance measurements at $T = 313K$ (curves 1 on p. 406)
[16]	$7.14\mu\text{m} \leq \lambda \leq 50.00\mu\text{m}$	Data extracted from normal transmittance measurements at $T = 298K$(curves 1, 6, 14, 15, 18, 20, and 29 on p. 423)

thickness d, and the sample spectral normal transmittance $T_{0,\lambda}$,

$$k_\lambda = -\left(\frac{\lambda}{4\pi L}\right) ln \left[\frac{\sqrt{(1-\rho_\lambda)^4 + 4\rho_\lambda^2 T_{0,\lambda}} - (1-\rho_\lambda)}{2\rho_\lambda^2 T_{0,\lambda}}\right] \tag{5}$$

The imaginary part of the complex index of refraction k_λ can also be determined from measurements of the spectral normal emittance $\epsilon_{\lambda,0}$ using the following expression [18],

$$k_\lambda = \left(\frac{\lambda}{4\pi L}\right) ln \left[\frac{1-\rho_\lambda - \rho_\lambda \epsilon_{\lambda,0}}{1-\rho_\lambda - \epsilon_{\lambda,0}}\right] \tag{6}$$

Figure 2 shows the variations of the imaginary part of the complex index of refraction k_λ of fused quartz as a function of wavelength λ as reported in the literature or derived from Equations (5) and (6) and summarized in Table 2. Note, that computation of the complex part of the index of refraction k_λ from transmittance and emittance measurements lead sometimes to negative values, particularly in the spectral region where fused quartz is very weakly absorbing (from 0.2 to 4.0 μm). This indicates that in this region, data should be used with care since the experimental uncertainty for k_λ is very large and k_λ effectively vanishes as revealed in Figure 3 with a linear scale.

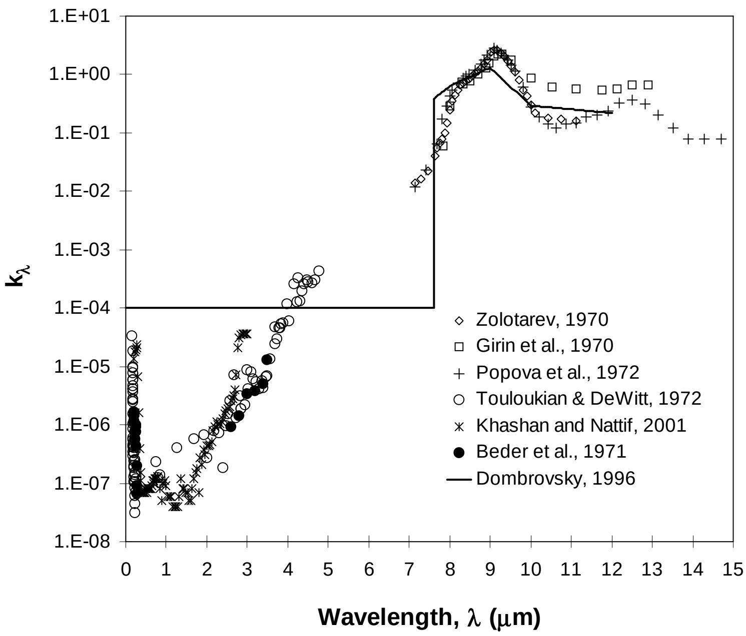

Figure 2: Imaginary part of the complex index of refraction of fused quartz k_λ.

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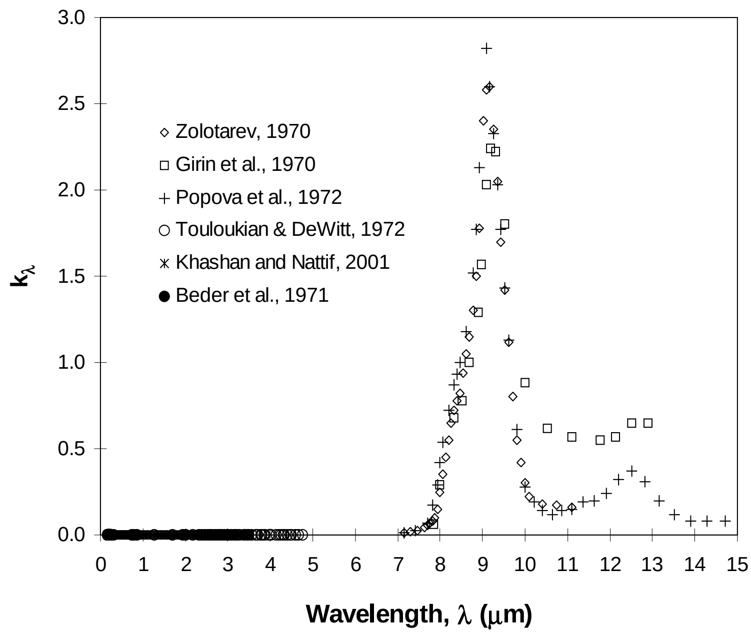

Figure 3: Imaginary part of the complex index of refraction of fused quartz k_λ plotted with a linear scale.

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