SPECTROSCOPY

COMPLEX REFRACTIVE INDEX MEASUREMENTS ON BOROSILICATE GLASS IN ULTRA-WIDE SPECTRAL RANGE

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Borosilicate glasses are widely used in various fields of technology. In particular, optical windows from a borosilicate crown glass K108 are often utilized in optical and optoelectronic devices. An important application are windows for the protection of optoelectronic devices from microwave (MW) frequency interference, in which a conductive film of indium tin oxide is deposited on the borosilicate glass substrate.

In the present work, we investigated interaction of electromagnetic radiation with the borosilicate glass K108 and determined its complex refractive index $\tilde{n} = n + ik$ where n is the refractive index and k is the extinction coefficient. All the samples were fabricated at TYDEX, LLC, Saint Petersburg, Russia [1]. Reflection and transmission spectra were measured in an ultra-wide spectral range which covers optical, terahertz (THz) and MW frequency regions. Four different spectrometers were used. As far as we know, similar studies that would cover such a wide range of radiation frequencies have not previously been carried out on any glasses or crystals.

In each spectral region, an appropriate experimental technique was used. In the MW region (frequencies from 2.5 to 24 GHz), the transmission and reflection spectra were measured in such a way that Fabry–Pérot oscillations were detected. Then n and k were found using the Airy formulas.

In the THz region (frequencies of 0.1–1.6 THz), the method of time-domain spectroscopy was used. The transmitted waveform recorded for the sample of 3 mm thickness in a time interval of 130 ps contained the first echo signal. The waveform recorded without sample was used as a reference. The magnitude and phase of the complex transmission function were found after computing the complex Fourier transform of the transmitted waveforms [2]. Spectral dependencies of n and k were determined from the phase spectrum and magnitude spectrum, respectively.

The radiation reflection and transmission in the optical spectral region (0.75–1000 THz) were studied by means of a Fourier-transform infrared spectrometer and diffraction grating spectrophotometer. The spectral resolution was chosen to suppress Fabry–Pérot interference in the glass plate under study. If the transmittance exceeds 0.01, the determination of the n and k spectra turns out to be the simplest (the reduced Airy formulas are appropriate). In the case of lower transmittance, which was observed at the frequencies from 0.75 to 69 THz, both n and k were determined from the reflection spectrum only using a method based on the Kramers-Kronig relation [3].

Finally, we determined spectral dependencies of the real part, $\mathrm{Re}\varepsilon = n^2 - k^2$, and imaginary part, $\mathrm{Im}\varepsilon = 2nk$, of the dielectric permittivity of the glass over the entire studied frequency range (2.5 GHz — 1000 THz). There are three bands of anormal dispersion on the spectral curve of $\mathrm{Re}\varepsilon$. In these bands, the refractive index decreases with increasing frequency. Each band of anormal dispersion is related to a strong absorption band which is characterized by a high value of $\mathrm{Im}\varepsilon$. The first absorption band is rather wide (from 1.2 to 4.5 THz). It can be attributed as so-called Boson peak [4]. Two other absorption bands represent sharp peaks at the frequencies of 13.7 and 30.0 THz. They are associated with the lattice-vibration modes, namely, Si-O-Si bending mode and Si-O stretching one [3]. Similar peaks are a common feature of the silicate glasses while their exact spectral positions determined in the present study are a “fingerprint” of the borosilicate crown glass K108. The results of the study can be used to develop protective windows for optoelectronic and photonic devices.

[1] TYDEX. Available online: http://www.tydexoptics.com/ (accessed on 17 September 2022).

[2] L. Duvillaret, F. Garet, J.-L. Coutaz, Highly precise determination of optical constants and sample thickness in terahertz time-domain spectroscopy, Appl. Optics, **38**, pp. 409-415 (1999).

[3] D. W. Lane, The optical properties and laser irradiation of some common glasses, J. Phys. D: Appl. Physics, **23**, pp. 1727–1734 (1990).

[4] V. L. Gurevich, D.A. Parshin, H. R. Schober, Anharmonicity, vibrational instability, and the boson peak in glasses, Phys. Rev. B, **67**, pp. 094203-1–094203-10 (2003).