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Application of the optical method for determining of the RMS roughness of porous glass surfaces

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Abstract

The application of an optical method for characterizing surface roughness is presented. This method was used for an examination of porous glass surfaces. The expressions relating the root mean square rms (σ) of a surface to its specular reflectance at normal incidence are used for $\sigma \ll \lambda$, (λ – wavelength). For light of sufficiently long wavelength the decrease in the measured specular reflectance due to the surface roughness depends only on the root mean square (rms) height of the surface irregularities. On the basis of reflectance spectra, one can determine σ for the porous glass surfaces after technological processes. The measured reflectance spectra were compared with calculated ones for which the scattered component of light was taken into account. The parameters rms determined from the optical method are comparable to those obtained from atomic force microscopy examinations.

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1. Introduction

Surface microstructure of porous glasses strongly depends on the local composition of glass and the technology of its preparation. The surfaces usually exhibit roughness. The heights and diameters of the surface heterogeneities may be described by means of different statistical distributions, i.e. they are more or less inhomogeneous. The reflectance of an electromagnetic wave depends on a state of the surface, on its roughness characterized by the root mean square roughness σ or other parameters. Several examinations of the relation between the roughness of metal surfaces or ground glass surfaces and the specular or diffuse reflectance have been reported [1–5]. Bennett and Porteus pointed out that the root mean square of the surface roughness could be determined on the basis of specular reflectance measurements [6]. This method can be applied when $\sigma \ll \lambda$, λ denotes the wavelength. Therefore, a degree of the suitable smoothness is required. The reflectance is more sensitive to the surface roughness than the transmittance. Previously this method was used to examine glass surfaces polished by different methods [6].

The relation between the specular reflectance and the root mean square of roughness is obtained from the treatment of the electromagnetic wave reflection from a rough surface derived by Davis [7]. In this model of a surface, the following conditions have been satisfied:

1. the root mean square roughness σ, defined as a root mean square deviation of the surface from the mean surface level is small compared with the wavelength λ,
2. the surface is perfectly conducting and hence would have a specular reflectance of unity if it is perfectly smooth,
3. the distribution of heights of the surface irregularities is Gaussian about the mean,

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4. the autocovariance function of the surface irregularities is also Gaussian with the standard deviation σ_a.

The conditions 3 and 4 mean that the surface irregularities in the plane of the surface and in the direction perpendicular to the surface are homogeneous.

If the surface is illuminated with a parallel beam of the monochromatic light, the reflectance is divided into two components; one from the specular reflectance and the other connected with scattering. Davis obtained the following expression for the specular reflectance of the rough surface at the normal incidence [7]:

$$R_s = R_0 \exp\left[-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right], \quad (1)$$

where R_0 denotes the reflectance of a perfectly smooth surface of the some conducting material. If the reflectance at the normal incidence is measured within an instrumental acceptance angle $\Delta\Theta$, the complete expression for the measured reflectance R takes the form [7]:

$$R = R_0 \exp\left[-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right] + R_0 \frac{2^5\pi^4}{m^2}\left(\frac{\sigma}{\lambda}\right)^4 (\Delta\Theta)^2, \quad (2)$$

where m is the root mean square slope of the surface profile. The following correlation between the autocovariance length a and m is satisfied [7,8]

$$a = \sqrt{2}\frac{\sigma}{m}. \quad (3)$$

The value of a may be determined by atomic force microscopy (AFM) examination or adopted as a fitting parameter. The second term in Eq. (2) is connected with the scattered reflectance measurement. For a sufficiently long wavelength this term may be neglected. In this case, σ is calculated from the measured reflectance, making use of Eq. (1), which takes the form

$$\ln\left(\frac{R_0}{R_s}\right) = (4\pi\sigma)^2 \frac{1}{\lambda^2}. \quad (4)$$

If ln (R_0/R_s) versus $1/\lambda^2$ is a straight line, its slope makes it possible to determine σ. This is a method for calculation of the root mean square roughness from the measured values of the reflectance at normal incidence (method I).

There is another graphic method for determining of the value σ. For this purpose one can present the plot σ versus λ, making use of Eq. (2). For the appropriate wavelength range, σ is independent of λ. The root mean square roughness may be also determined from this interval, (method II).

The different methods are used for the surface morphology examination. The nanoscale roughnesses of glass induced by fast electron irradiation or oxide glass are studied by AFM and controlled by the surface tension of the melt at the glass transition temperature, respectively [9,10]. Micro-roughnesses arising on the glass surface, for example, during the interaction of femto- and nanosecond laser pulses with glass surface, are examined by scanning electron and optical microscopes [11]. In order to monitor corrosion mechanisms on the glass surface the Fourier transform infrared reflectance spectroscopy is used [12].

In the presented paper a simple and precise method for determination of the rms for the rough surface, when $\sigma \ll \lambda$, is described (nanoscale roughnesses). This method is applied to an examination of porous glass surfaces. The root mean square roughness σ determined from the optical measurements is compared with that obtained from AFM.

2. Experimental

A silica porous layer was formed at one side of the regular wafer of sodium borosilicate glass. The glass surface was polished before the layer fabrication. The porous layer was obtained by etching off sodium borate phase from the two-phase sodium borosilicate glass [13,14]. The phase separation temperature was 490 °C. During the leaching process the soluble sodium and boron oxides of a chemically less durable phase were extracted. The obtained samples were heated at 393 K for 0.5 h. The previous examinations were performed for the samples with geometrical sizes of $10 \times 10 \times 0.5\ \mathrm{mm}^3$, the thickness of porous layer was about 250 μm. Application of the presented optical method for determination of structural parameter σ, requires the surface of porous glass to be flat. However, the surfaces after leaching process usually exhibit deformations. In order to verify the surface after the technological process, the equal thickness fringes obtained from the porous glass surface covered with Al film were observed. Fig. 1(a) presents these fringes from deformed surface. In this case the optical method cannot be used. The fringes are straight and parallel lines when the surface is flat, which is shown in Fig. 1(b). An application of the described optical method is possible for such a surface. It has been found that the samples approximately thick retain flat surface after the technological process. The optimal thickness of the sodium borosilicate glass plate equals 2 mm. The glass surface image is shown in Fig. 2(a) for the sample with $\sigma_{AFM} = 12.4$ nm, the distribution of the heights of the surface irregularities is presented in Fig. 2(b). It is seen that the surface microstructure is homogeneous and the distribution of the heights is close to Gaussian one (conditions 3 and 4). In our examinations $0.01 \leqslant \sigma/\lambda \leqslant 0.05$ (condition 1). The surfaces of the porous layers were overcoated with an opaque Al films, evaporated under appropriate conditions, making possible to reproduce the surfaces examined [15] (condition 2). The conditions required in the Davis model were satisfied. The reflectance at normal incidence was measured as a function of the wavelength in the range from 200 to 2500 nm with the Jasco spectrophotometer.

3. Results

The reflectance spectra for the various surfaces of the porous glasses are shown in Figs. 3(a)–(c). The experimental