

Optical transmission and internal friction in fused quartz melted from natural raw materials

Rudolf Sh. Nasyrov,^a Valery M. Lopatin^b and Boris S. Lunin^{*c}

^a Institute of Mineralogy, Ural Branch of the Russian Academy of Sciences, 456317 Miass, Russian Federation

^b Machine-building Department, South-Ural State University, 456304 Miass, Russian Federation

^c Department of Chemistry, M.V. Lomonosov Moscow State University, 119991 Moscow, Russian Federation.

Fax: +7 495 939 4575; e-mail: lbs@kge.msu.ru

DOI: 10.1016/j.mencom.2012.11.020

It is shown that developed methods of cleaning of low-cost natural quartz raw materials together with modern melting methods make high optical transmission available in wide spectrum range.

Pure fused quartz is widely used in microelectronics, solar energy conversion, fiber optic technology *etc.* New glass technologies make it possible both to improve the characteristics of pure fused quartz and to reduce its manufacturing cost.

Vacuum electric melting, flame melting and vapour-phase method are used in fused quartz industry. High-quality fused quartz can be obtained by the good cleaning of quartz raw materials and using an optimal regime of vacuum melting.

The effectiveness of a combination of high-purity raw material and special vacuum melting technology can be demonstrated using the KS-4V fused quartz as an example. This quartz glass is melted from pre-processed raw materials in a vacuum ampoule in an active gas atmosphere.¹ Synthetic silicon dioxide (SSD) is used as a raw material. KS-4V is the purest fused quartz used to manufacture optical elements, optic fibers and high-*Q* resonators for vibrating gyroscopes. The high cost of KS-4V manufacture connected with the high cost of SSD and labor-intensive production technology is the main barrier against the cost-effective application of this glass.

The aim of this work was to manufacture and characterize pure fused quartz from natural raw materials. It is generally accepted that the melting of fused quartz from natural raw materials leads to the formation of bulk and surface macro- and microdefects arising from mineral and structure impurities contained in the natural quartz. For this reason, the natural raw material is not used directly for the production of high-quality optic glass. Large deposits of pure quartz raw materials occur in the Ural region of Russia. Therefore, the development of new technologies for the production of high-purity melted materials is an important task.

To manufacture a fused quartz prototype, we used high-purity quartz groats produced at the Kyshtym ore-dressing and processing enterprise from the raw material of vein no. 175 of the Kyshtym deposit. Before melting, the groats were additionally purified by a special method.^{2,3} Smelting was performed by the thermal-electric vacuum-compression method. To compare the characteristics of this glass, we melted another block of glass from cristobalite SSD that was used in the production of KS-4B. Disks 12 mm in thickness were cut from these glass blocks for optical characterization. Optically polished cylinders 30 mm in diameter and 90 mm in length were prepared to measure and compare internal friction in these quartz glasses. These samples had high volume/surface ratios, and they were suitable for studying internal friction in the bulk.⁴

The results of the optical characterization showed that the obtained glass samples had almost the same transmission in UV and IR spectrum regions (Figure 1).

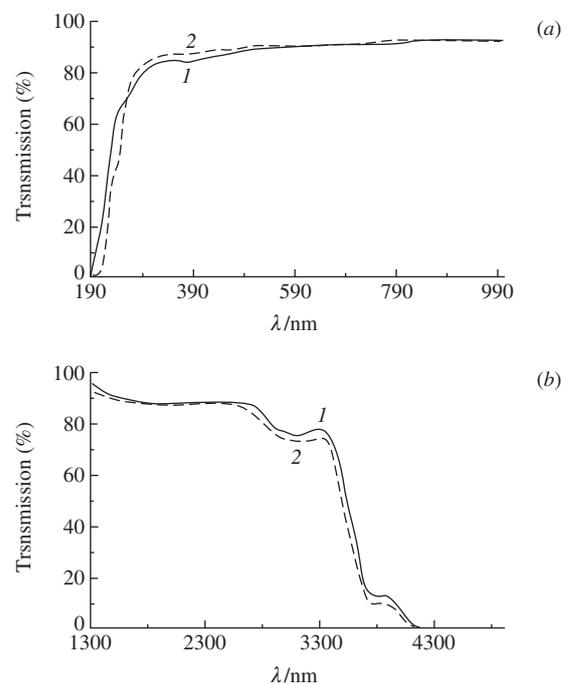


Figure 1 Optical transmission in the (a) UV and (b) IR regions: (1) fused quartz melted from cristobalite SSD and (2) fused quartz melted from a natural raw material.

The high transmission in the UV region points to a small concentration of the impurities causing optical absorption. The IR spectra of these two glass samples are very close to each other. The spectral data obtained allowed us to conclude that the optical characteristics of the fused quartz melted from a natural raw material are not inferior to those of the KS-4V glass.

However, the internal friction in these glass samples is very different. The internal friction characterizes the dissipation of oscillation energy in materials. In fused quartz, it depends on structural defects, internal stress and impurity content. The most frequently used *Q*-factor is proportional to the relative energy of oscillator *W* to the energy dissipated in this oscillator during one period (ΔW):

$$Q = 2\pi W / \Delta W = \pi \tau f, \quad (1)$$

where τ is the damping time of free oscillations, and f is the frequency.

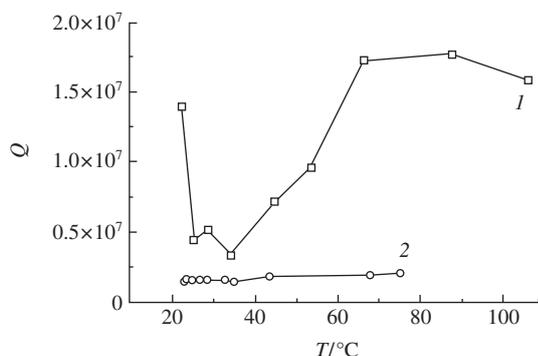


Figure 2 Q-factor vs. temperature: (1) fused quartz melted from cristobalite SSD and (2) fused quartz melted from a natural raw material.

We measured the damping time of free oscillations at a frequency of ~ 30 kHz and then calculated the Q -factor from equation (1).⁵ The measurements were carried out *in vacuo* at 20–100 °C. The accuracy of the Q -measurements was ~ 4 –5%. Figure 2 shows the Q -factor of the cylindrical samples as a function of temperature. One can assume that structure impurities are the principal cause of the growth of internal friction. These structural impurities strongly distort the random silicon–oxygen network of the fused quartz and lead to formation stress siloxane bonds, which effectively disperse the energy of oscillations.

This assumption is confirmed by a comparison of the temperature dependences of the speed of sound for both of the glass samples (Figure 3). It is known that the speed of sound (c) in fused quartz depends linearly on applied stress (σ):⁶

$$c = c_0 - k\sigma, \quad (2)$$

where c_0 is the speed of sound in relaxed glass, and k is a coefficient.

We calculated the speed of sound from the experimental data using equation (3):

$$c = 2Lf, \quad (3)$$

where L is the length of the cylindrical resonator.

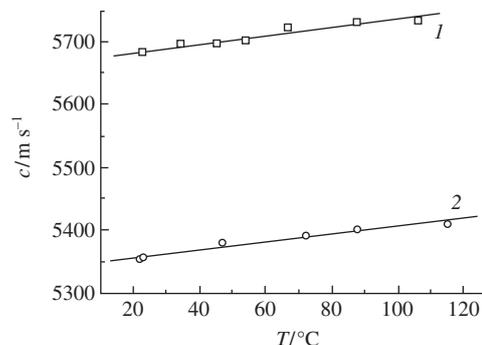


Figure 3 The speed of sound in the fused quartz vs. temperature: (1) fused quartz melted from cristobalite SSD and (2) fused quartz melted from a natural raw material.

These functions have almost the same slope and differ from each other by 320 m s^{-1} in this temperature range. This difference in the speed of sound confirms the existence of the high internal stress in the fused quartz melted from natural raw materials. Therefore, to increase the Q -factor of such fused quartz one should improve the purity of the raw material and choose optimal regime of melting.

In general, these results allow us to conclude that the developed methods of cleaning provide high-quality fused quartz for optical instrument making.

References

- 1 I. I. Cheremisin, V. S. Rudenko, A. Z. Bazurin, V. S. Doladugina and S. A. Popov, *Abstracts of the 7th Science-Technical Conference on Silica Glass*, St. Petersburg, 1991, p. 49.
- 2 R. Sh. Nasyrov, *Obogashchenie Rud*, 2009, no. 6, 14 (in Russian).
- 3 R. Sh. Nasyrov, *RF Patent 2431601*, C01B33/00, 2011.
- 4 S. D. Penn, A. Ageev, D. Busby, P. Willems, G. M. Harry, A. M. Gretersson and K. Numata, *Phys. Lett. A*, 2006, **352**, 3.
- 5 B. S. Lunin, S. N. Torbin, M. N. Danchevskaya and I. V. Batov, *Vestn. Mosk. Univ., Ser. 2: Khim*, 1994, **35**, 24 (*Moscow Univ. Chem. Bull.*, 1994, **49**, 19).
- 6 R. E. Strakna, A. E. Clark, D. L. Bradley and W. M. Slie, *J. Appl. Phys.*, 1963, **34**, 1439.

Received: 23rd May 2012; Com. 12/3930