Classical and fractal models of chalcogenide glasses viscoelasticity

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Although chalcogenide glasses have been extensively studied using various methods, the long-term mechanical relaxation processes in these glasses have not yet been investigated. This study therefore focuses on analyzing mechanical stress and strain relaxation, as well as creep by observing the time-dependent behavior of torque or torsion on a torsion pendulum in response to step deformation or stress.

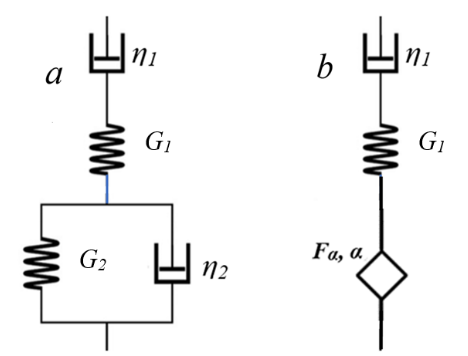

Fig. 1. Classical Burgers (*a*) and partially fractal (*b*) viscoelastic models.

First, we considered the four-element Burgers model (Fig. 1*a*), consisting of Maxwell and Kelvin bodies connected in series. The temperature dependence of this model parameters η_1, G_1 and η_2, G_2 for As-Se glass (T_g≈435K) was determined from experimental data on the relaxation of mechanical stress over time and is presented on Fig.2. As can be seen, in the temperature range of 370K to 430K, G_2 decreases drastically from 150 GPa by more than a hundred times, while G_1 changes only from 6.0 GPa to 3.5 GPa. Classical rheological models are based on a simple combination of Hooke's and Newton's bodies, resulting in exponential stress and strain time dependencies. However, a significant number of materials with complex microstructures, such as glasses, are characterised by a power-law dependence of their creep and stress with time.

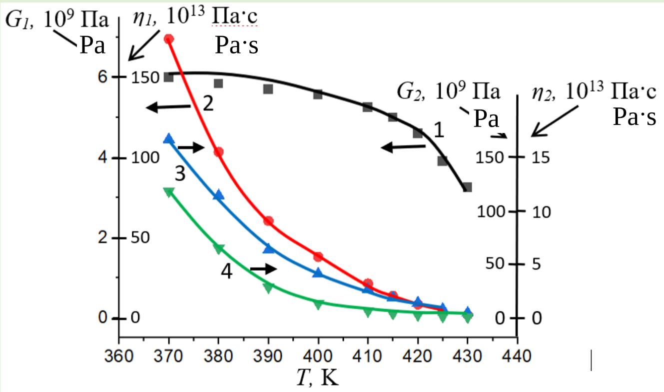

Fig. 2. Temperature dependence of the Burgers model parameters: 1 – G_1, 2 – η_1; 3 – G_2, 4 – η_2.

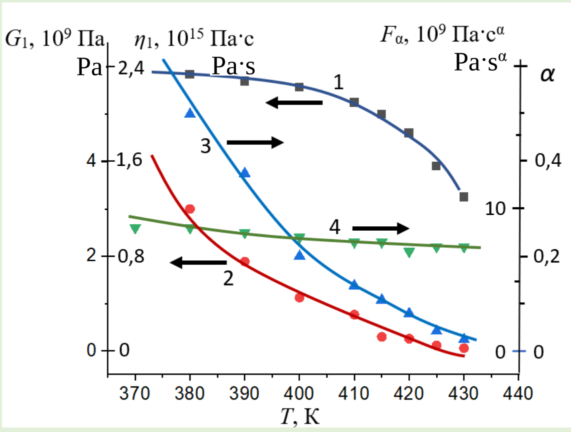

Fig. 3. Temperature dependences of the fractal model parameters: 1 – G_1, 2 – η_1, 3 – F_α, 4 – α.

The power-law behaviour can be explained by generalising the classical models by introducing of different orders fractional derivatives, which leads to the creation of fractal viscoelastic models. In order to reflect the diversity of viscoelastic behaviour, it is advisable to use a combination of classical and fractal models; in particular, we have proposed to replace the Kelvin-Voigt element by a fractal element in the Burgers model (Fig. 1*b*). In this way, purely elastic and plastic properties are reproduced, and the fractal element provides a power law for the behaviour of the mechanical parameters, in particular, the strain for considered model: $\varepsilon(t)=\sigma_0\left(\frac{1}{G}+\frac{t}{\eta}+\frac{t^\alpha}{F_\alpha \Gamma(1+\alpha)}\right)$. Temperature dependence of the partially fractal model parameters shown on Fig. 3. The parameter α of the fractal model varies within a small range: 0.25 ≤ α ≤ 0.20, while, as expected, F_α decreases sharply when the glass softening point is approached. It should also be noted that the introduction of fractality leads to an increase in the parameter η_1 of 20-25% with an unchanged value of G_1 compared to the classical model.

Conclusion: The partially fractal model provides a better correlation between experimental and calculated data than the classical one. It can be assumed that the physical meaning of the fractional derivative order in the description of viscoelasticity is determined by the fractal dimension of the relaxation times set.