Softening Glass under Acoustic Cavitation

E. A. Chechetkina

Laboratory of Non-Crystalline Materials, Institute of General and Inorganic Chemistry of Russian Academy of Sciences (1980-2011), Moscow 117901, Russia

Abstract: Our previous experiments on ultrasonic treatment of the softening Se-X glasses ($X = \text{Te, S, As, Cl}$) are reconsidered here using a special representation of the optical transmission data with the Se-Te series as an example. The results lead to the conclusion that glass behaves as a self-organizing system of the dissipative type. Bond wave is considered as the dissipative pattern characteristic for glass-forming substances. Above the glass transition temperature, T_g , three-dimensional bond waves provide all-the-volume mobility of atoms, so glass-forming liquid ($T > T_g$) can flow and/or modify its structure under the action of information field that gives the bond wave direction. Thus obtained structure is frozen in a solid glass below T_g , being reflecting in a substantial change in optical transmission after US-treatment including development of optical anisotropy in our case. Finally, a direct observation of internal surfaces of the fractured samples by means of SEM gives additional evidence in favor of the bond wave model and the proposed mechanism by which softening glass interacts with ultrasound.

Key words: Glass, ultrasonic treatment, self-organization, non-crystalline order.

1. Introduction

Everyone knows that glass is a brittle material, and the only one thing that sound can do with glass is to break it into pieces. Ultrasound can be used also for trivial cleaning or polishing of glass surface. It should be noted that this concerns to the state existing below the glass transition temperature T_g , which divides the brittle and softening states [1, 2]. Softening glass can adapt to external influences, e.g., it can flow under loading. Owing to an extra high viscosity (10^{12} - 10^9 poises instead of 10^{-2} - 10^{-3} poises for a “normal” liquid) and the fact that a sample remains its form at rest, softening glass looks rather a solid than a liquid. Just in this solid-like but adaptive state a non-destructive interaction between ultrasound and glass can be expected. This assumption was confirmed by us using Se-X ($X = \text{Te, S, As, Cl}$) glasses and the cavitation regime of US-treatment [3-6]. However, the obtained US-induced effects, being depending on the sample composition, temperature of treatment and history of the series under consideration, create a too

complicated picture for a general understanding of the phenomena. Thus, the goal of this paper is to search for such understanding using a special representation of experimental data and an original vision of glass as a self-organizing system arising owing to characteristic instability of chemical bonding in glass-forming substances.

2. Methods

2.1 The Samples Composition, Form and History

The Se-Te series [3] was chosen as the simplest glass-forming system among the previously investigated four Se-X ($X = \text{Te, S, As, Cl}$) series [3-6]. The Se-Te glasses (0, 1, 2, 5 and 10 at%Te) were obtained by common melting-cooling technology in evacuated quartz ampoules (see Ref. [3] for details); they were XRD-amorphous in the course of experiment, whose design is given in Table 1. Initial samples in the form of tablets of the 15 mm thickness (L_A) and 25 mm diameter with the polished cylinder ends (grains A) were then changed into the blocks having two pairs of perpendicular grains (see grains A and B in Fig. 1) in order to observe a possible

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Corresponding author: Elena A. Chechetkina, Dr., research field: glass physics and chemistry.

development of anisotropy as the result of ultrasonic treatment.

After the last step No. 12 the samples were destroyed mechanically for creating of the differently disposed fractures, which then were investigated by means of optical microscopy and SEM.

2.2 The Sample Control

Structural transformations arising in the course of experiment were detected by optical transmission, which was measured in solid glass at room temperature in the region of $400\text{--}5,000\text{ cm}^{-1}$. The low-frequency part of a typical spectrum is shown in Fig. 2. The frequency $\omega = 1,000\text{ cm}^{-1}$, which divides the “multi-phonon” region ($400 < \omega < 1,000\text{ cm}^{-1}$) and the “transparency window” ($\omega > 1,000\text{ cm}^{-1}$ for selenide glasses) is chosen for determination of transparency, T , which is used as incoming experimental parameter for the following analysis.

2.3 The US-Treatment (Cavitation Regime)

Sample is placed in the wire-made holder and then in the cavitation cell shown in Fig. 3 in such a way that one grain A occurs in the front of the horn plate,

and another grain A lies on the teflon support. The cell represents a common chemical glass filled with water, which is a suitable medium for selenium-based glasses having T_g of about $30\text{--}40\text{ }^{\circ}\text{C}$. The horn shifts into the bath until the 10 mm distance between the horn plate and the front grain A of a sample is reached; then the horn is fixed and the US power on.

The US-input frequency and power of 22.4 kHz and about 500 W, respectively, were used. Since cavitation means continuous appearance/disappearance of legion of bubbles of various size and lifetime, the excited

Fig. 1 The form of a sample before US-treatment, and the scheme of optical transmission measurement in two directions relative to A and B grains (I_0 are the incident beams, I_A and I_B are the transmitted beams).

Fig. 2 Example of the optical transmission spectra for the 1%Te sample (here after step 3, $L_A = 14\text{ mm}$). Arrows show evaluation of transparency.

Fig. 3 Cavitation cell with the sample in the process of US-treatment. Red arrow is the US input.

medium generates vibrations in a wide frequency interval, from Hz to GHz. Owing to dissipation of ultrasonic energy by cavitation the “low-temperature” treatments (40 °C or 50 °C) can be done without a special heating: the previously determined value of input power ensure heating to the desired temperature in few minutes with the following saturation for the period indicated in Table 1 as the time of US-treatment. In the case of the “high-temperature”

treatment (72 °C) dissipation due to cavitation was insufficient, therefore we used the initially heated water and, in addition, added some portions of boiling water to compensate the heat loss. After the US-off, the horn is raised, the holder with a sample puts out from the bath and leaves cooling in air. All the samples of a given Se-X series were treated one by one immediately, thus providing the same history for the series.

3. Results

3.1 Change in Transparency during Experiment

The two examples in Fig. 4 show that transparency is a very sensitive parameter for our experiment. It is seen also a remarkable difference between the samples having a very similar chemical composition. The steps are decoded in Table 1; although their sequence looks rather chaotic, it is a normal situation for the pilot experiment, when arising questions are answered successively, one by one. To be more specific, let us consider what happens with the samples transparency, which was measured after each step, from 1 to 12.

Initial 5-year ageing (steps 1→2) leads to expected and a nearly equal darkening of the both samples. The difference becomes much more evident after removing of the surface layer (2→3): Se restores its transparency

Table 1 The history of the Se-Te series.

Step No.	τ months	$\Delta\tau$ months	State of the step		
			Sign	t °C	State/treatment description
1	0			room	Fresh samples; $L_A = 15$ mm
2	60	60	R1	room	Relaxation (ageing for 5 years)
3	60	0	S1	room	Surface removing (A grains); 0.5 mm from each side; $L_A = 14$ mm
4	62	2	S2	room	Surface (A) removing and the new grains (B) creation; $L_A = L_B = 13$ mm
5	70	8	U1	40**	First US-treatment; 40 °C for 5 min (after 8 months relaxation)
6	71,5	0.5	R2	room	Relaxation (for 0.5 month)
7	81	9.5	U2	50	Second US-treatment; 50 °C, 5 min
8	83	2	S3	room	Surface (A and B) removing after the 2 months storage; $L_A = L_B = 12$ mm
9	84	1	U3	40	Third US-treatment; 40 °C for 5 min (after 1 month relaxation)
10	84	0	U4	50	Forth US-treatment; 50 °C for 5 min
11*	132	48	R3	room	Relaxation (ageing for 4 years)
12*	132	48	U5	72	Final US-treatment; 72 °C for 3 min (after 48 months relaxation);

* Additional steps, which were made after the 1-10 steps described earlier [3].

** Note that glass transition temperature of Se is about 35 °C.

Fig. 4 Change of transparency for pure Se (0%Te) and Se-1%Te (1%Te) glasses. The transmission was measured in the A direction (see Fig. 1); the steps 1-12 are commented in Table 1 and in the text.

almost completely while the 1%Te sample restores only partially. One can connect this with a different distribution of the scattering agents (e.g., crystalline nuclei), which are concentrated on the surface of Se sample, but both on the surface and in the volume of the 1%Te sample. This explanation, however, becomes doubtful after the next surface removing (S2, 3→4), which leads to unexpected *decrease* of transparency for the both samples. Really, the thinning of the samples (from 14 mm to 13 mm) should give the opposite and very slight effect, and the method of mechanical treatment (grinding, polishing) was the same.

The following low-temperature US-treatments (4→5 at 40 °C and 6→7 at 50 °C) leads to the expected decrease of transparency, however, the samples react quite differently: Se (0%Te) becomes almost dark ($T_{5-7} \rightarrow 0$) and 1%Te remains partially transparent (from $T_5 = 0.4$ for U1 to $T_7 = 0.2$ for U2). The next surface removing (S3, 7→8) restores transparency, as it is expected, and again Se restores more effectively (from $T_7 = 0.02$ to $T_8 = 0.55$) than 1%Te (from $T_7 = 0.2$ to $T_8 = 0.41$).

The second pair of low-temperature treatments, U3 (8→9, 40 °C) and U4 (9→10, 50 °C), differ drastically from the first one (U1 and U2): now selenium actually indifferent to US-treatments, and 1% Te unexpectedly *increase* its transparency after U3 (from $T_8 = 0.41$ to $T_9 = 0.54$). Final high-temperature US-treatment U5 (72 °C) bring no surprises: the both samples become dark ($T_{12} < 0.1$). At this point experiment was finished because of a critically thinning samples for our standard 9 mm diameter measuring beam (next surface removing would lead to the 11 mm thickness) and because of the developed inclination for cracking, especially for high-Te (5% and 10%) samples.

The cases of a strange behavior of transparency multiply when considering all the samples (0%, 1%, 2%, 5% and 10%Te) and the both directions (A and B). In order to systemize all the results, at least for the US-treatments, let us consider the transparency data in special coordinates of “effect” and “anisotropy”.

3.2 Effect of Ultrasonic Treatment

The effect of US-treatment can be evaluated using

the transparency change as

$$E_i = (T_{i-1} - T_i)/T_{i-1}$$

where T_{i-1} is the transparency before the treatment (e.g., $T_{i-1} = T_4$ for the U1 treatment, which corresponds to step $i = 5$), and T_i is that after the treatment (T_5).

Maximum effect $E_i = 1$ means formation of an absolutely dark sample: $T_i = 0$. Minimum effect $E_i = 0$ indicates that no change in transparency has been detected after the treatment: $T_{i-1} = T_i$. Really, the most results/points in Fig. 5 are within these limits. However, the region of $E_i < 0$, which corresponds to unexpected *enlightenment* of a sample after US-treatment is also in action. One of these points, 1%Te (U3, A) was emphasized above, when considering Fig. 4. Taking into account all the samples and the both direction, we observe this anomaly also in the 2% Te sample (U3, for both A and B directions) and in pure selenium (U2, 0%Te, B).

The second anomaly seen in Fig. 5 is the *nonlinear* behavior of the effect depending on glass composition. This feature was revealed by us on the fresh glasses Se-X ($X = \text{Te, S, As, Ge, Cl}$) for a set of properties (ultrasound velocity, relative intensity of emission line from valence band, intensity of vibration bands) [7]. Interestingly, that non-linear extremum was observed in the low-concentration region, namely, at the 1-2%Te in the Se-Te case. The same region in Fig. 5 seems most non-linear also.

In order to extract non-linearity in a more obvious way, let us summarize in Fig. 6 the absolute values of the effects for each composition in the both directions—separately (A or B) and summary (A+B). In the last case the non-linearity maximum located at 1%Te is most prominent. On the other hand, when considering A and B separately, another effect of *anisotropy* emerges.

The second anomaly emphasized when considering Fig. 7, namely, a different reaction of the samples on the first and second low-temperature (40-50 °C)

treatments. Using the “effect” values and the summary procedure, one can observe the *memory* of glass, which appears in the fact that the secondary US-treatments (2) are much less effective than the initial ones (1).

3.3 The US-Induced Anisotropy

Optical anisotropy that has been emerged in Figs. 6 and 7 can be presented in a direct form as $A = T_B/T_A$. As a rule, $A > 1$ because a sample after US-treatment usually becomes more transparent in the lateral direction B than in the front direction A. However, the cases of $A < 1$ are seen in Fig. 8 too. In contrast to the above described *anomalous effect* $E < 0$ around 1%Te composition (see Fig. 5), this anomalous anisotropy can be observed everywhere except the boundary compositions of 0%Te (Se) and 10%Te, the first one being demonstrating the largest “normal” anisotropy (up to $A = 3.3$) and the second one being actually isotropic ($A \approx 1$).

The final high-temperature treatment (72 °C, red points) is of a special interest not only because of a large deviations from isotropic case ($A = 1$) but also for the inversion of anisotropy ($A > 0 \rightarrow A < 0$), which happens between 1%Te and 2%Te compositions. Namely, although the 1%Te sample is almost 3 times darker in the front direction A than in the lateral direction B ($A = T_B/T_A = 3$) the following 2%Te sample is 4 times *lighter* ($A = 0.25$ means $T_A/T_B = 1/0.25 = 4$). The next 5%Te sample is even more inversed ($T_A/T_B = 1/0.20 = 5$). The last 10%Te sample is actually isotropic for all the US-treatments. The fact that 10%Te lies on the boundary of conventional glass-forming region for the Se-Te system (conventional GFR corresponds to the critical cooling rates not more than 10^2 K/s, a condition that ensures obtaining of *bulk* glasses having macroscopic dimensions) indicates that the development of the US-induced anisotropy is just the glass feature but not the GFR boundary effect.

Fig. 5 Effect of US-treatments of the Se-Te samples measured in the front side A (top graph) and in the lateral side B (bottom graph).

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Fig. 6 The summary effect of US-treatments, $\Sigma E = \Sigma |E(U_i)|$ with $i = 1, 2 \dots 5$, depending on composition (%Te) and/or the direction (A and/or B).

Fig. 7 The summary effect in dependence on the treatment temperature, the direction of measurement (A or B) and the sequence of the treatment (1 or 2).

Fig. 8 Optical anisotropy in the US-treated samples of the Se-Te series. Five successive US-treatments (40 °C-1, 50 °C-1, 40 °C-2, 50 °C-2, and 72 °C) are shown by light-blue, light-green, blue, green and red, respectively.

4. Discussion

Optical transmission gives indirect and average information concerning structural change due to development of some SAs (scattering agents) in glassy matrix, but no information about these SAs nature and location. To increase informability of the method we have used a periodical removal of the surface layer (steps “S” in Table 1) and, besides this, a special representation of the transparency data (Figs. 5-8). New features that have emerged in this study forward additional themes for consideration. (i) What is the nature of the *scattering agents* which develops in glass during its ageing and/or US-treatment; (ii) Where are these SAs located—on the surface or/and in the volume of a sample; (iii) What is the nature of *nonlinearity* in the property-concentration curves (Figs. 5, 6, and 8) and of the samples’ *memory* to the previous US-treatments at the same temperature (Fig. 7); (iv) Finally, what is the *mechanism* by which ultrasound can interact with softening glass. Below these themes are considered successively.

(1) The first candidate for SAs, is of course, crystalline inclusions that develop in glassy matrix in the process of its devitrification. Although we have not observed crystals in our samples by means of ordinary XRD, a low sensitivity of the method (say, 1-5% of crystallinity) gives opportunity to propose the existence of tiny nuclei, which are “invisible” by XRD but can scatter the probing beam (see I_0 in Fig. 1) very effectively, thus providing the observed jumps in transparency (Fig. 4). This *nucleation hypothesis* is hardly applicable, however, in the cases when transparency *increases* after the US-treatment (see the negative- E points in Fig. 5). One can explain this anomaly as the cavitation-induced dissolution of the previously formed nuclei—however, this assumption contradicts with the well-known fact that sonification always *intensifies* nucleation. Then one can object that it is true for the investigated cases of saturated solutions and melts [8-10], while glass is a new object

for sonochemistry and, what is more, it may be a principally different object because of significant deviations from classical theory of crystallization [11]. In summary, the nature of SAs remains unclear, and the nucleation hypothesis can be used only as the first approximation.

(2) Glass is inclinable to heterogeneous nucleation, although in a wide limits as concern distribution of nuclei between surface and volume. In order to evaluate this property using the transparency data, let us introduce the *extent of heterogeneity* in the form of

$$G = (T_{i+1} - T_i) / (T_{i-1} - T_i)$$

where T_{i-1} is the transparency before the treatment (ageing or US-treatment), T_i is that after the treatment at the “ i ” step, and T_{i+1} is that after the following removal of the surface layer.

The G value can change from the *heterogeneous limit* $G = 1$ ($T_{i+1} = T_{i-1}$), which corresponds to the state when all the nuclei are concentrated at the surface, and the *homogeneous limit* $G = 0$ ($T_{i+1} = T_i$) corresponding to the uniformly distributed nuclei. This is actually true for the *spontaneous nucleation* presented in Fig. 9, although a strong non-linearity along the concentration axis is observed. Remember that the non-linearity was seen also in Figs. 5, 6 and 8, however, in this case this feature is expressed most glaringly, changing from an almost heterogeneous ($G \rightarrow 1$) aged Se to actually homogeneous ($G \rightarrow 0$) aged Se-Te sample in which only 2%Te is added.

The situation for US-induced heterogeneity is less obvious. First of all, the design of experiment that provides the needful steps are absent and the most suitable combination we have is the double (U1+U2) treatment with the following surface removing. For this case the extent of heterogeneity can be written as

$$G^*_{A,B} = (T_8 - T_7) / (T_4 - T_7)$$

where the transparencies are T_4 for the state before US-treatment (U1+U2), T_7 for the state after the treatment and T_8 for the following surface-removed state (see Table 1 and Fig. 4). The calculation results presented in Fig. 10 look reasonable only for 0%Te

Fig. 9 Extent of nucleation heterogeneity after initial 5-year ageing of Se-Te glasses calculated as $G = (T_3 - T_2)/(T_1 - T_2)$. In the insertion a probable arrangement of nuclei (red regions) are shown for the Se (0%Te) case.

Fig. 10 Extent of heterogeneity after the first low-temperature US-treatment ($i = 5-7$, for both A and B directions). Insertion is commented in the text.

(Se) and 1%Te, and when increasing of Te content the heterogeneous limit $G = 1$ is overcome, up to $G^* = 1.7$ for 5%Te (A). One can say that except the 1%Te sample with $G^* = 0.4-0.7$ other Se-Te samples are completely heterogeneous or even

“superheterogeneous”. This result makes doubtful a simple nucleation hypothesis.

Really, if one explains “superheterogeneity” ($G^* > 1$) in the assumption that the sample before US-treatment was just populated with nuclei (see left

state with arrow “4” of the probing beam in the Insertion), and the following treatments (steps 5 and/or 7 in Table 1) forces these nuclei to move into the surface layer, as it is shown in the right part in the Insertion with the probing beams before (arrow 7) and after (arrow 8) the surface removal. This means that after removing of the layer (step 8 in Table 1) the sample becomes more transparent than it was initially (step 4), and because of $T_8 > T_4$ one obtains formally $G^* > 1$. However, the question is *how* can crystalline nuclei *move* through the glassy matrix, and (if they can) *why* the nuclei go to the surface.

(3) An alternative hypothesis to the nucleation one is based on the two above emphasized features: *non-linearity* (in respect to glass composition—see Figs. 5, 6, 8-10) and *memory* (to the previous US-treatments—Fig. 7). The same features are known to be characteristic for classical *self-organizing* systems of the *dissipation* type [12-14]. It should be noted that not every system can be the self-organizing one: it must be complex enough and exist far from equilibrium.

Complexity means that the system consists of many-state elements (at least, two-stable ones), and all the elements are interconnected by a *feedback* that

ensures their collective behavior. Self-organization means *evolution* of the system by organization of the elements into *dissipative patterns* which reorganize the incoming energy and/or information flows [15] in a special way characteristic for the system under consideration.

The question is what dissipative patterns can generate glass-forming substance? If chemical bond is the element of the non-crystalline network, the two-state element is alternating bond. It should be noted that the idea of alternating bonding in the form of reversible transformation of ordinary covalent bond (CB), the same that in related crystal, into HVB (hypervalent bond) characteristic for non-crystalline state ($CB \leftrightarrow HVB$), was firstly forward and developed by Dembovsky [16, 17] in his theory of glass formation (see Ref. [18] for review). Then I have understood that alternative bond is not necessary HVB and, what is principal, the acts of bond exchange $CB \leftrightarrow AB$ are correlated in time and space, thus forming the bond wave like that shown in Fig. 11, on the left. Among the known dissipative patterns, bond wave is most close to the BZh (Belousov-Zhabotinsky) chemical waves spreading in a liquid containing definite set of chemical reagents [20]. Like BZh chemical

Fig. 11 Three-dimensional bond wave after [19]: snapshot of the bond wave element containing two wavefronts of the d thickness populated with alternative bonds indicated by black springs (a) and the solitonic behavior of three intersected bond waves of the Λ wavelength (b).

waves, bond wave is “chemical” in its nature, but unlike *BZh* reaction, which needs a set of reagents with alternating oxidation-reduction states, bond wave is a simple pattern that can realize even in elementary substance like Se.

The bond wave model was born in 1987 [21] during my attempts to understand our experiment on magneto-viscous resonance [22]. Then the model was tested by understanding of general features of glass-forming substances: thermodynamic (the lowering melting and boiling points) [23], structural (the first sharp diffraction peak, FSDP) [24] and dynamic (non-Arrhenius viscosity temperature dependence and a partial reproducibility of the $\eta(T)$ data) [25]. The present-date state of the bond wave model is given in Ref. [26], where the temperature dependence of the bond wave parameters (wavelength and velocity—see Λ and V in Fig. 11) is considered with the conclusion of a possible (co)existence of bond waves of different dimensionality (1D, 2D and 3D). In particular, the glass transition phenomenon is considered as the 3D→2D transition which takes place at cooling when the distance between wavefronts becomes so large that correlation between the *d*-layers becomes impossible, so their collective movement is arrested, therefore they stop/freeze in the network thus forming a static substructure of the $\Lambda(T_g)$ period in solid glass.

(4) In order to understand how US field can interact with softening glass, let us use the information aspect of bond wave. It was emphasized by the author earlier [27] that observation of glass fractures from the eyes of the bond wave model leads to the conclusion that several bond wave can coexist and, in doing so, they intersect each other without distortion, like solitons—see Fig. 11, on the right. Bond wave needs information for the direction of its spreading. One information field giving direction V_1 forms a highly anisotropic layer structure; two fields (V_1+V_2) form the columnar structure, and three fields ($V_1+V_2+V_3$) create the cellular structure, which is isotropic

macroscopically. Since the latter is usual for glass, one can propose that common glass is formed in a complex information field, e.g., in random temperature-pressure gradients. When information field is introduced specially (e.g., ultrasonic field in our experiments) unusual structures with a possible anisotropy can appear. Now let us consider what we saw in the process of US-treatment and after it.

The samples before US-treatment have a standard surface shown in Fig. 1, however, after the treatment the surface changed depending on the treatment temperature and the sample composition. The most intriguing surface was formed after the highest-temperature (72 °C) treatment—see Fig. 12a. This is the last treatment, after which the glasses were destroyed, denuding a usual “glassy” fracture like that shown in Fig. 12b. It seems that the “crumpled” surface and smooth internal surfaces have developed independently. This may be a consequence of a *complex US-field* realizing in our experiments: the US-input (red arrow in Fig. 12c) gives a general direction, and cavitation medium (brown tails) generates the lateral waves of two types. The waves of the first type are exited by the babbles explosion at the sample surface; the multiple and random local temperature-pressure shock gives intersected surface waves. The waves of the second type originate from the exited medium and move from the lateral grains into the volume of the sample. Thus, there is a competition between the US-income direction, which creates wavefronts parallel to the A grain, and perpendicular wavefronts from the lateral grains B; the both are shown by red lines in Fig. 12c.

The competition of the differently directed bond waves can create a strongly anisotropic structure, when one direction prevails. Nevertheless, even in the highly anisotropic samples (in accord with Fig. 8) one cannot see a difference between the fractures parallel to A or B grains. Therefore, some fractures were also investigated by means of electron microscopy. The most interesting results are presented in Fig. 13. The

Fig. 12 (a) The 5%Te sample after last 72 °C US-treatment; (b) the fracture surface obtained after the sample destruction; (c) The scheme for the cavitation treatment with red arrow is the US input—see text for other details.

Fig. 13 SEM images of two fractured Se-Te samples (0%Te and 2%Te) previously subjected to the 72 °C US-treatment. The fractures are parallel to the A grain or the B grain of the samples before their destruction.

observed differences correlate well with the *inversion* of anisotropy seen in Fig. 8 for 72 °C. Really, in pure Se (0%Te) the “A” fracture, which is perpendicular to the US-input and also to the I_A measuring beam (Fig. 1), is populated with the scattering agents, while the “B” fracture is completely free from them. Correspondingly, the transparency in the “B” direction is in three times higher than in the “A” direction. The “inversed” sample of 2%Te ($A < 1$ in Fig. 8) gives the opposite “A” and “B” images in Fig. 13. The problem is how the scattering agents look like. In the “A” fracture of Se (0%Te) we see a mass of tiny needles—but it is known that selenium is inclined to the spherulitic crystallization. In the “B” fracture of the 2%Te sample, there are no potential crystals at all: we see a continuous rough surface without crystalline features.

For explanation of this puzzle it should be remember that *in situ* measurements of the samples in the process of US-treatment are absent. All the transparency data and the images considered above correspond to the state obtained *after* the treatments. Although the 3D waves are stopped/freeze below T_g , the solid glass is not “dead” completely, as it is justified by its ability for plastic flow and the so called “secondary relaxation” processes. From the eyes of the bond wave model, the processes below T_g are stipulated by the 2D bond waves existing in the limits of the stopped d -layers. Such processes may be a simple nucleation with the following crystal growth, or development of unusual scattering agents like those shown in Fig. 13. Then the role of the US-treatments of softening glass is to prepare of a specific substructure of d -layers, as the active zone for the following development of unusual formations of both crystalline and non-crystalline type.

5. Conclusions

Ultrasound can actively interact with glass in the case when glass is in the softening state ($T > T_g$) and ultrasound is applied in the cavitation regime.

Results of this interaction, which were observed in solid glass by means of optical transmission, point to a deep transformation of glass structure including development of anisotropy.

The nucleation hypothesis is hardly applicable for explanation of the observed effects, a conclusion that was made after consideration of the transparency data presented in special coordinates.

An alternative explanation is proposed, which is based on classical notions about self-organization and original bond wave model. Then ultrasonic field acts as information field that gives the direction of bond wave spreading within the sample. Complex ultrasonic field, which realizes in the process of cavitation, creates a set of competing bond waves whose wavefronts, being freezing below T_g , form a specific substructure in the solid glass. Just this substructure and/or its following evolution we have observed change in optical transmission and in SEM images.

The cavitation treatment of glass is of a great potential significance for glass practice; however, to realize this possibility the following investigations, both experimental and theoretical, need. I hope that this work will open an entrance into the empty region of glass sonochemistry.

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