Inelastic internal friction in nanocomposites of multiwalled carbon nanotubes and polyethylene, polyvinyl chloride, expanded polystyrene

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INTRODUCTION

It is known, that upon annealing of solid-state mixtures, the yield of vacancies V from the material is observed. Defect annealing leads to a change in the shape of the internal friction (IF) temperature spectrum $Q^{-1}(T)$ [1,2]. The non-destructive IF method allows to set the spectrum of structural defects on the analysis of positions of maximums IF, on duration of relaxation time τ and on their deposit in attenuation of elastic vibrations. The criterion of structural relaxation is formed: anelastic structural relaxation can be caused only that structure defect, the system of symmetry of which below the symmetry of crystal. It does not determine the effect value of relaxation [3].

A non-destructive method for the technological control of the structure defects by measuring IF and elastic modulus *E* after laser radiation was developed. The study of influence of structure defects on damping of vibrations in Si/SiO_2 plates by the diameter of D = 100÷60 mm and by the thickness of $h_{SiO2} \approx 600$ nm, $h_{Si} \approx 400\,000$ nm, allows to estimate the degree of perfection of crystalline structure. The measuring of the amplitude dependence of IF allows to set the moment of a separation of dislocation segments from stoppers.

ULTRASONIC METHODS

The experimental methods were used: the metallography optical supervision of microstructure by means of the microscope "LOMO MVT", atomic-force microscopy (AFM) with high resolution. Ultrasonic (US) pulse-phase method for determining the velocities of elastic waves using USMV-LETI, modernized USMV-KNU and computerized "KERN-4" on frequencies $f_{\|} \approx 1$ MHz and $f_{\perp} \approx 0{,}7$ MHz, US invariant-polarization method for determining the effective acoustic μ_{il} and elastic constants C_{ijkl} were used [4,5]. The measured velocity error was equal to $\Delta V/V = 0{,}5÷1{,}5\%$.

EXPERIMENTAL RESULTS AND DISCUSSION

The transversal US velocity $V_{\perp} = 768 \pm 30$ m/sec, shear modulus $G = \rho V_{\perp}^2 = 578$ MPa, the longitudinal US velocity $V_{\|} = 2485 \pm 30$ m/sec, dynamical elastic modulus $E = \rho V_{\|}^2 = 6{,}057$ GPa, Poisson coefficient $\mu = 0{,}44$ nanocomposite polyethylene with low density high pressure $(C_2H_4)_n$ + 3% MWCNT were determined from the oscillogram in fig. 1.

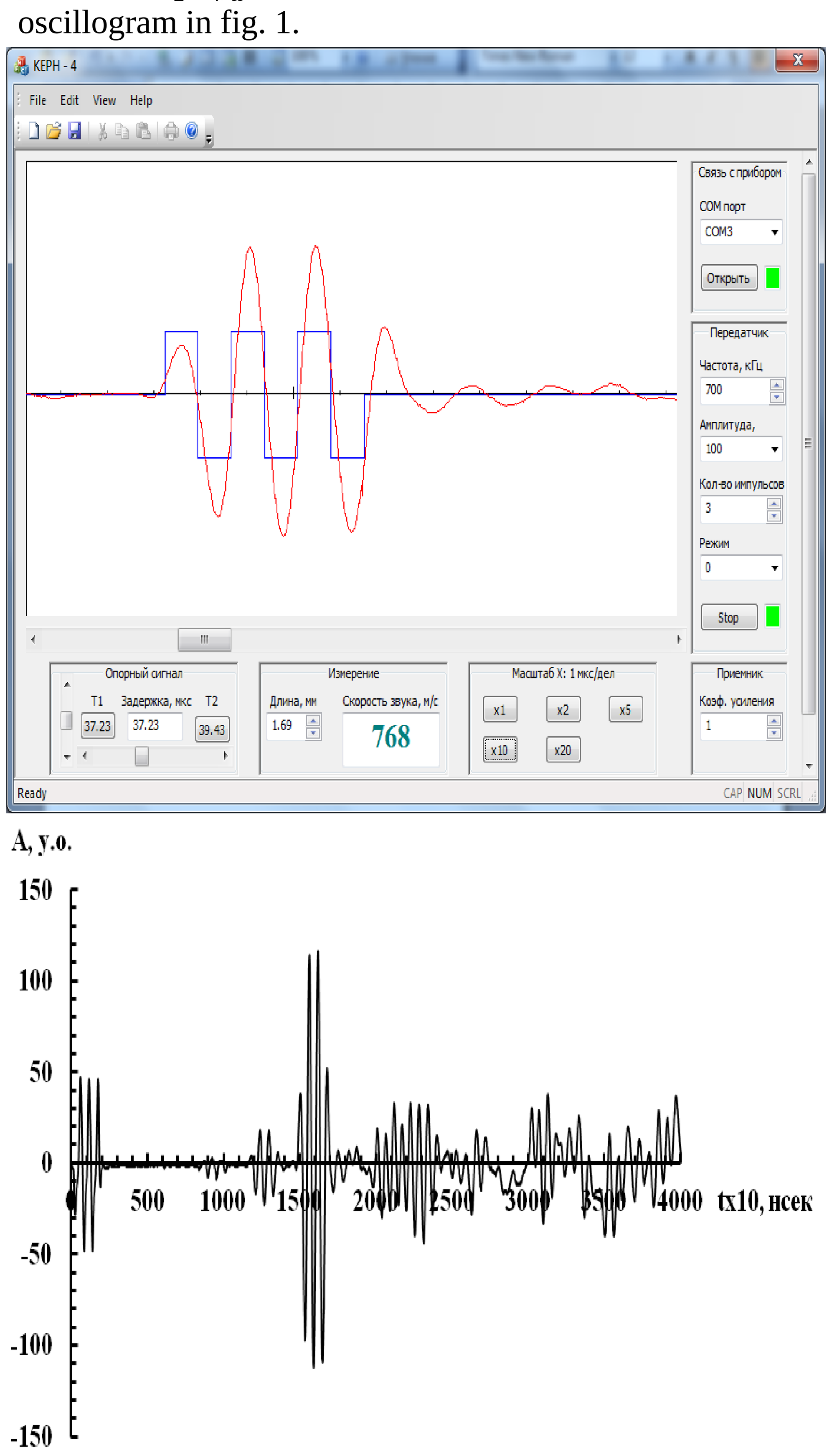

Fig. 1. The illustration of the window for processing data of transversal elastic wave velocity measuring $V_{\perp} = 768$ m/sec in nanocomposite polyethylene + 3% MWCNT by by impulse-phase ultrasonic method on frequence $f_{\perp} \approx 0{,}7$ MHz.

Logarithmic decrement of US attenuation

$$\delta_{\perp} = \ln\left(\frac{A_{n+1}}{A_n}\right) = \ln\left(\frac{113}{48}\right) \approx (8{,}56 \pm 0{,}1) \times 10^{-1}$$

The measurement of internal friction (IF) temperature dependences $Q^{-1}(T)$ was carried out on the identical, passed the same technological route, Si p-type wafer-plates, orientation (100), doped with boron B, with specific resistivity $\rho \approx 7.5$ Ohm·cm, thickness h ≈ 470 000 nm after the application of SiO_2 layer with the thickness h ≈ 600 nm as the result of high-temperature oxidation in dry O_2 at $T_0 \approx 1300$ K. The temperature dependence IF $Q^{-1}(T)$ (fig. 2) and elastic modulus E(T) (fig. 3) (indicatory surface of anelastic-elastic body) of SiO_2/Si wafer-plate is showed in fig. 4.

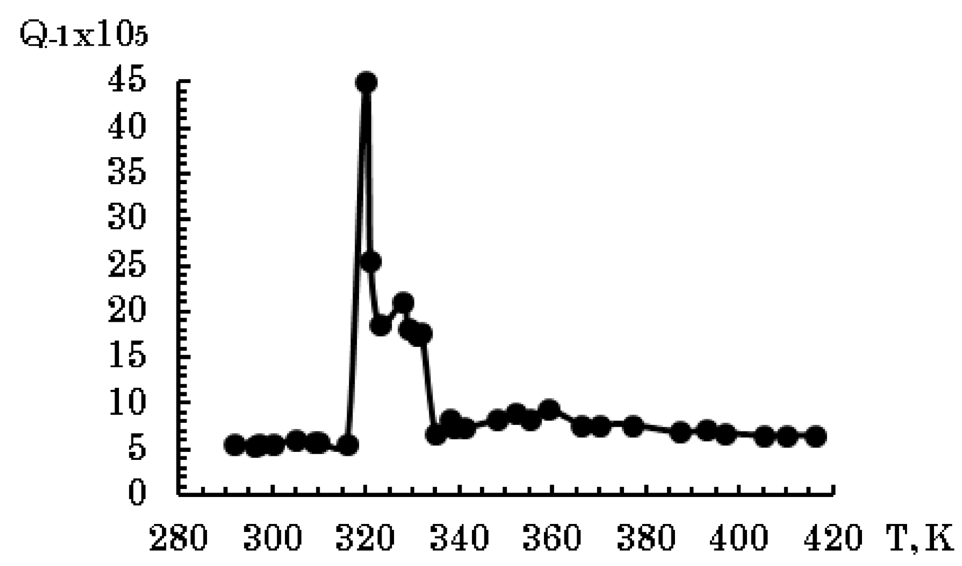

Fig. 2. Temperature dependence of internal friction $Q^{-1}(T)^{-1}$ in SiO_2/Si wafer-plate

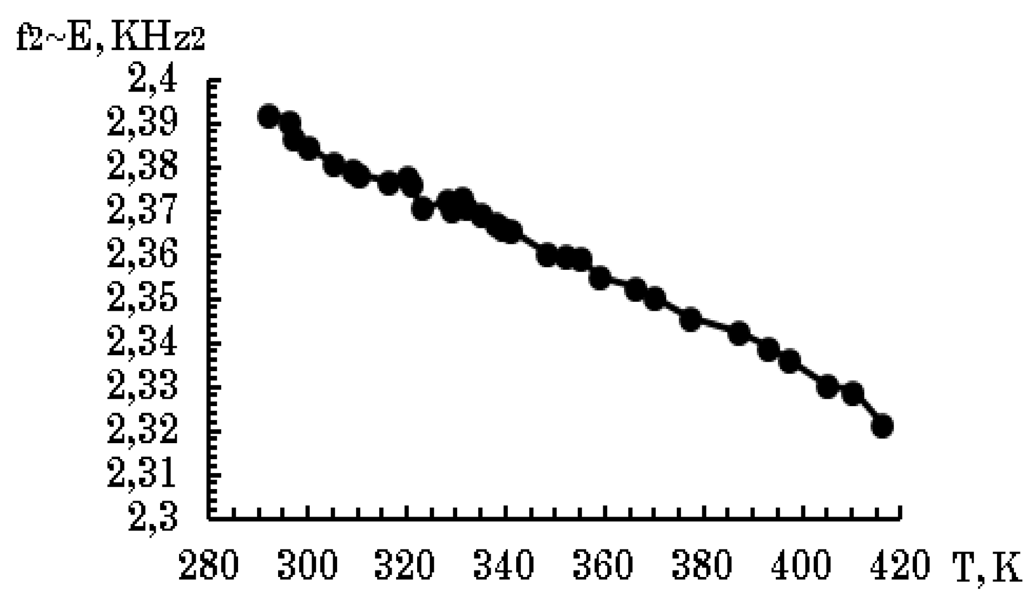

Fig. 3. Temperature dependence of SiO_2/Si wafer-plate the square of the resonant frequency f^2~E

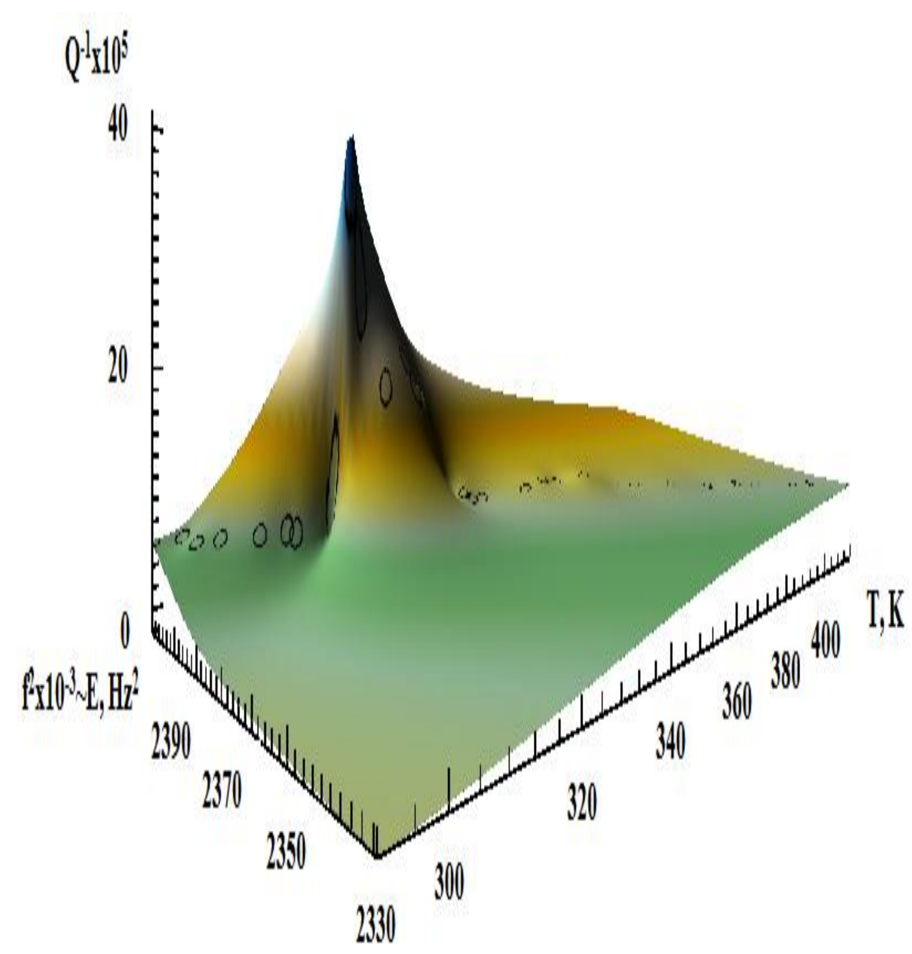

Fig. 4. Temperature dependence of internal friction $Q^{-1}(T)$ and elastic modulus *E*(*T*) (indicatory surface of anelastic-elastic body) of SiO_2/Si wafer-plate

The dependence of the height of the maximum IF on the radiation dose also indicates the relaxation process of reorientation IF $Q^{-1}(T)$ and and elastic modulus E(T) (indicatory surface of anelastic-elastic body) of SiO_2 after of radiation defect complexes. On the temperature dependence mechanical treatment in the initial state and annealing at $T_{an} \approx 670$ K for $t_{an} \approx 2100$ s in fig. 4 the small background value of IF $Q_0^{-1} \approx 2{\cdot}10^{-6}$ to T ≈ 385 K was observed.

Internal friction $Q^{-1} = \ln(A_1/A_2)/\pi$, IF defect $\Delta Q^{-1}/Q^{-1} = Q^{-1}_{sat}-Q^{-1}_{sk}/Q^{-1}_{sk}$ and US attenuation coefficient $\alpha = Q^{-1}/\lambda = Q^{-1}/V/f = \lg(A_0/A_1)/h$ were determined from the oscillogram of pulses with the corresponding polarization $V_{\|[001]}$ in the "dry" SiO_2 skeleton before and after saturation $V_{\|[001]}^S$ from the ln amplitude ratios A_1, A_2, (A_0 - no sample).

Complex elastic modulus E* is equal to the sum of the dynamic elastic modulus $E' = \rho V^2$ and the loss modulus $E'' = E'\delta$ [3]:

$$E^* = E'(1 + \delta) = \rho V^2(1 + \delta) = \rho V^2(1 + \pi Q^{-1}), \qquad (1)$$

where δ is the logarithmic decrement of the US attenuation, ρ is the specimen density, $V_{\|}$ is the quasilongitudinal US wave velocity, and internal friction is equal $Q^{-1} = \delta/\pi$.

The temperature dependence of IF $Q^{-1}(T)$ (fig. 5) and the elastic module E (T) (fig. 6) (pointing surface of inelastic-elastic properties) of SiO_2 is showed in fig. 7.

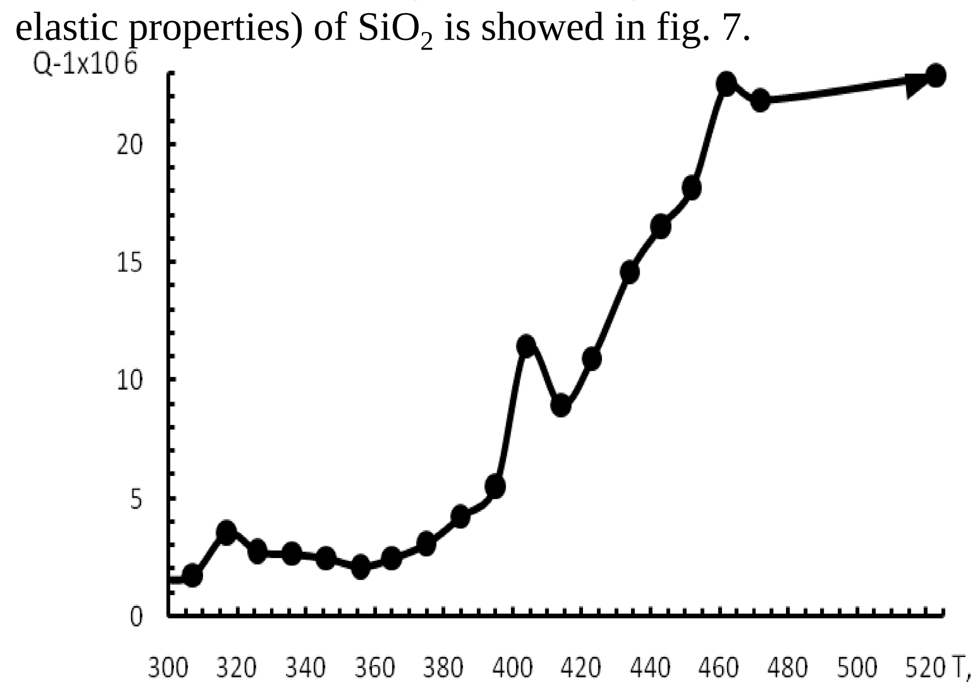

Fig. 5. The temperature dependence of IF $Q^{-1}(T)$ in SiO_2

The small background IF value $Q_0^{-1} \approx 2.10^{-6}$ to $T_0 \approx 385$ K was observed.

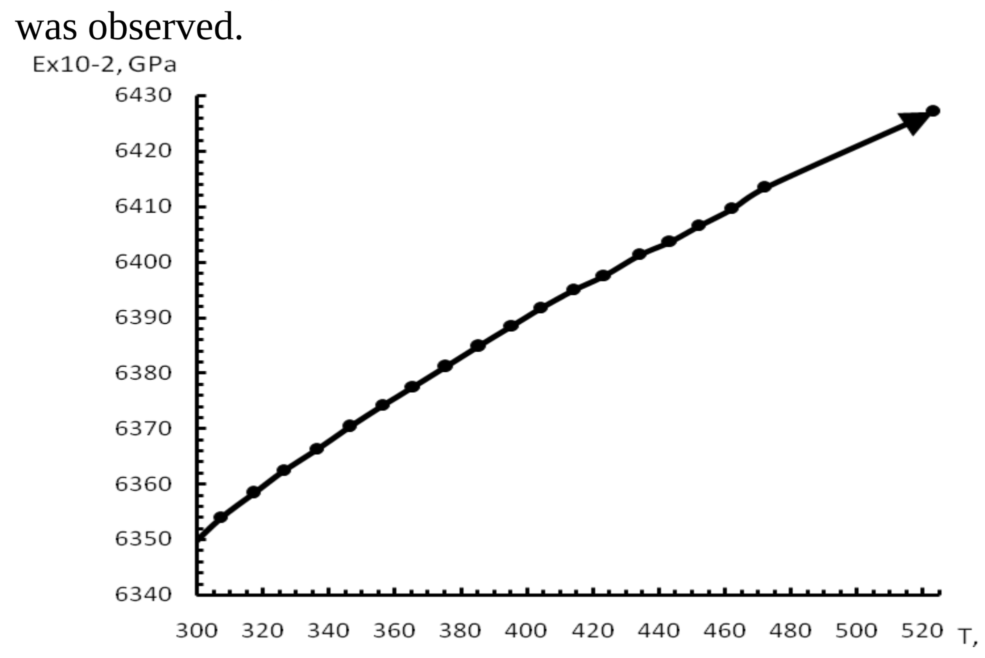

Fig. 6. The temperature dependence of elastic modulus E(T) of SiO2

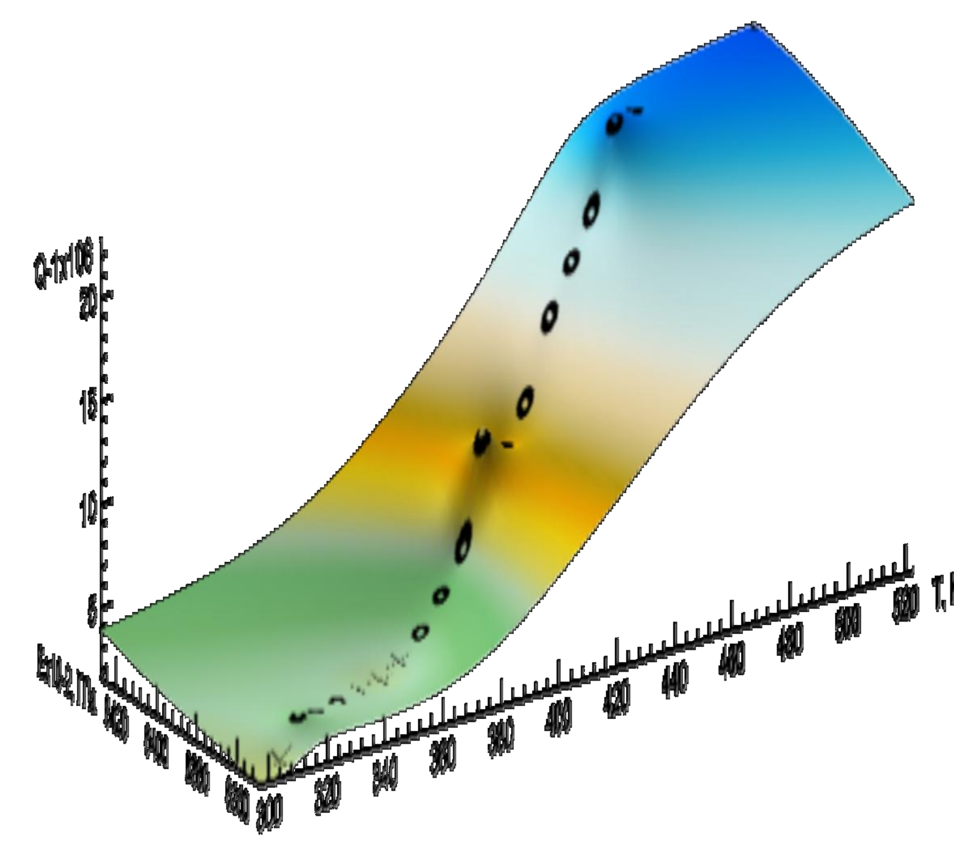

Fig. 7. The temperature dependence of IF Q-1(T) and elastic module E(T) (indicatory surface of inelastic-elastic properties) of SiO_2

CONCLUSIONS

1. The value of internal friction background Q^{-1}_0 after temperature, mechanical treatments describes the changes of the elastic stress σ_i fields in nanocomposite.
2. The increase of the nanocomposite crystallinity degree at growth of multiwalled carbon nanotubes concentration filling with the nanotubes of matrix results in the decline of content of organized phase.
3. The polarization angle ϕ – the deflection of elastic displacements vector U from wave normal direction n and elastic anisotropy integral coefficient A_{μ} are the most universal characteristics of anisotropy and testify about anisotropic deformation ε.

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