

**Effect of heating on dissipation of mechanical energy
in fused silica fibers**

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Principal problem:

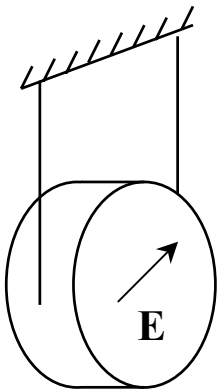
Important role of surface for dissipation in fused silica.

- Losses in fused silica fibers are higher than in a bulk material.

$$Q^{-1} \propto \frac{1}{r_{\text{fiber}}}$$

*A.M. Gretearsson, G.M. Harry
Rev. Sci. Instr. 70 (1999)*

- Losses in the surface layer determine mechanical dissipation for the body oscillating in electric field.



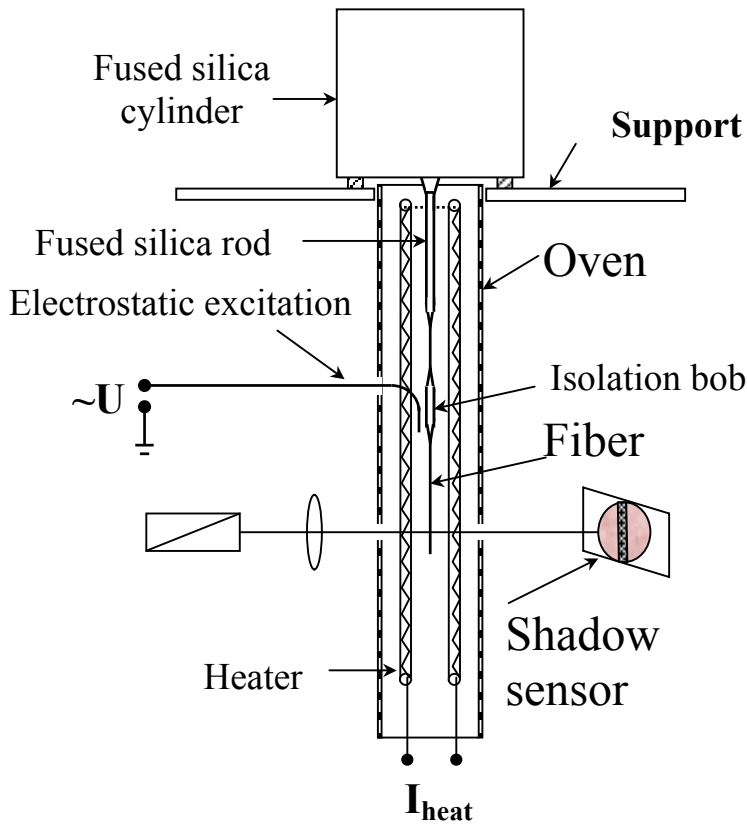
*V.P. Mitrofanov, N.A. Styazhkina,
K.V. Tokmakov
Phys. Lett. A 278 (2000)*

What mechanisms are responsible for the surface losses in well polished samples?

- Adsorbed water.
- ?

The goal: Investigation of effect of heating on Q of fused silica fibers.

Experimental setup



Fiber

$$l \approx 60 \text{ mm}, d \approx 250 \mu\text{m}$$

Vacuum

$$p \approx 2 \times 10^{-6} \text{ Torr}$$

Temperature

$$20^\circ\text{C} \text{ — } 330^\circ\text{C}$$

Time of cycle of heating and cooling

$$\approx 80 \text{ hours.}$$

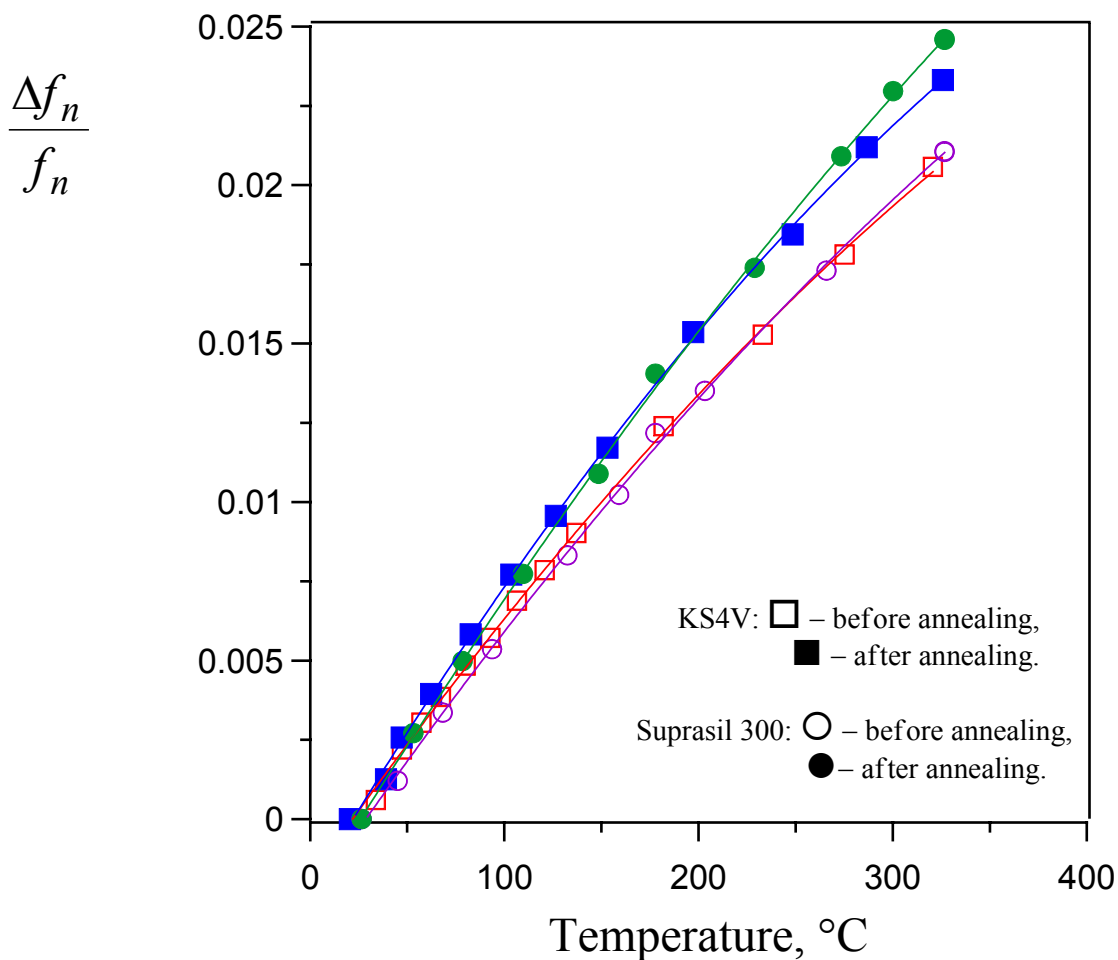
Mode	4	5	6	7	8
Frequency, Hz	1774	3314	4606	5945	7765
$Q \times 10^{-6}$	6.2	8.8	6.6	8.2	8.9
$\frac{1}{f} \frac{df}{dT} \times 10^4, K^{-1}$	1.097	1.007	0.852	1.096	1.094

We could also anneal fibers in air at 1000°C in another oven before the measurement.

Temperature dependence of the Young's modulus of fused silica in fibers

$$f_n \approx \frac{\pi d (2n-1)^2}{32 l^2} \sqrt{\frac{Y}{\rho}}$$

$$\beta = \frac{1}{Y} \frac{d(Y)}{dT} = \frac{2}{f_n} \frac{d(f_n)}{dT}$$



Temperature coefficient of the Young's modulus β in fibers with $d \approx 250 \mu m$

$$\beta \approx 1.7 \times 10^{-4} K^{-1}$$

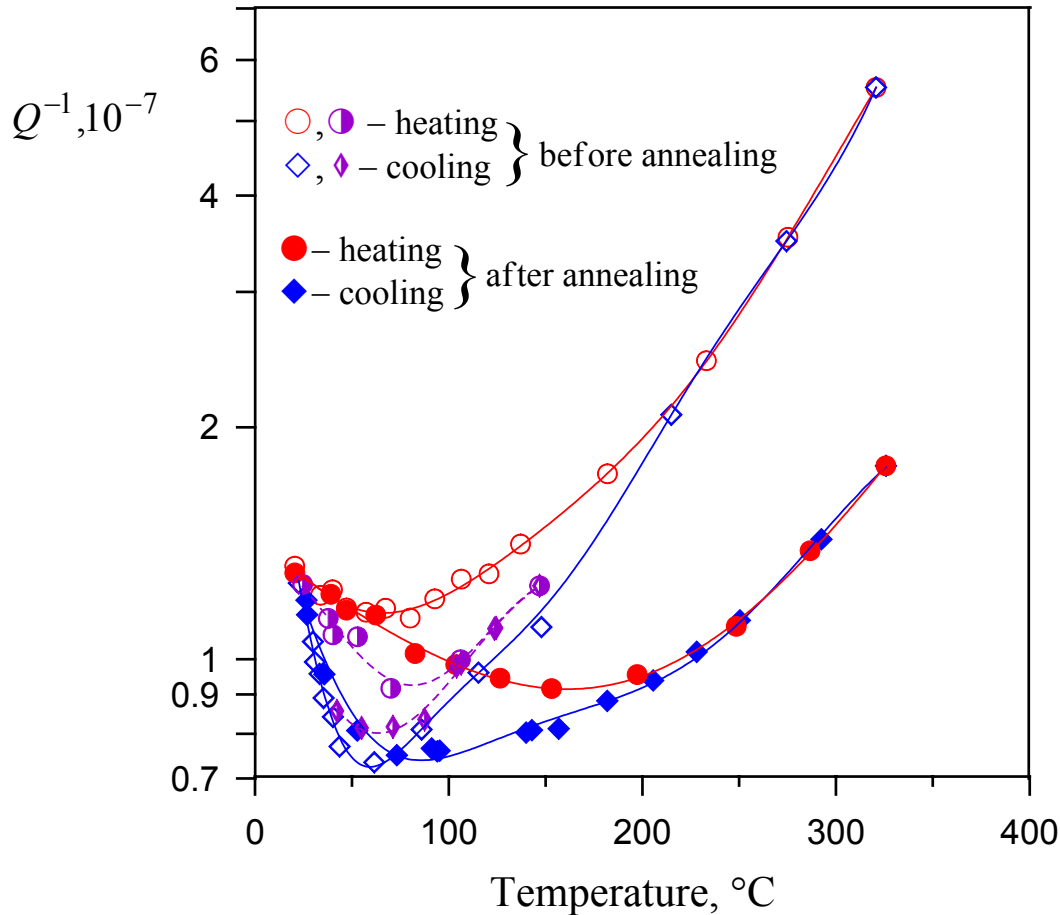
before $1000^\circ C$ annealing,

$$\beta \approx 2.1 \times 10^{-4} K^{-1}$$

after $1000^\circ C$ annealing.

Temperature dependence of losses in fibers

KS4V



The first cycle of measurement:

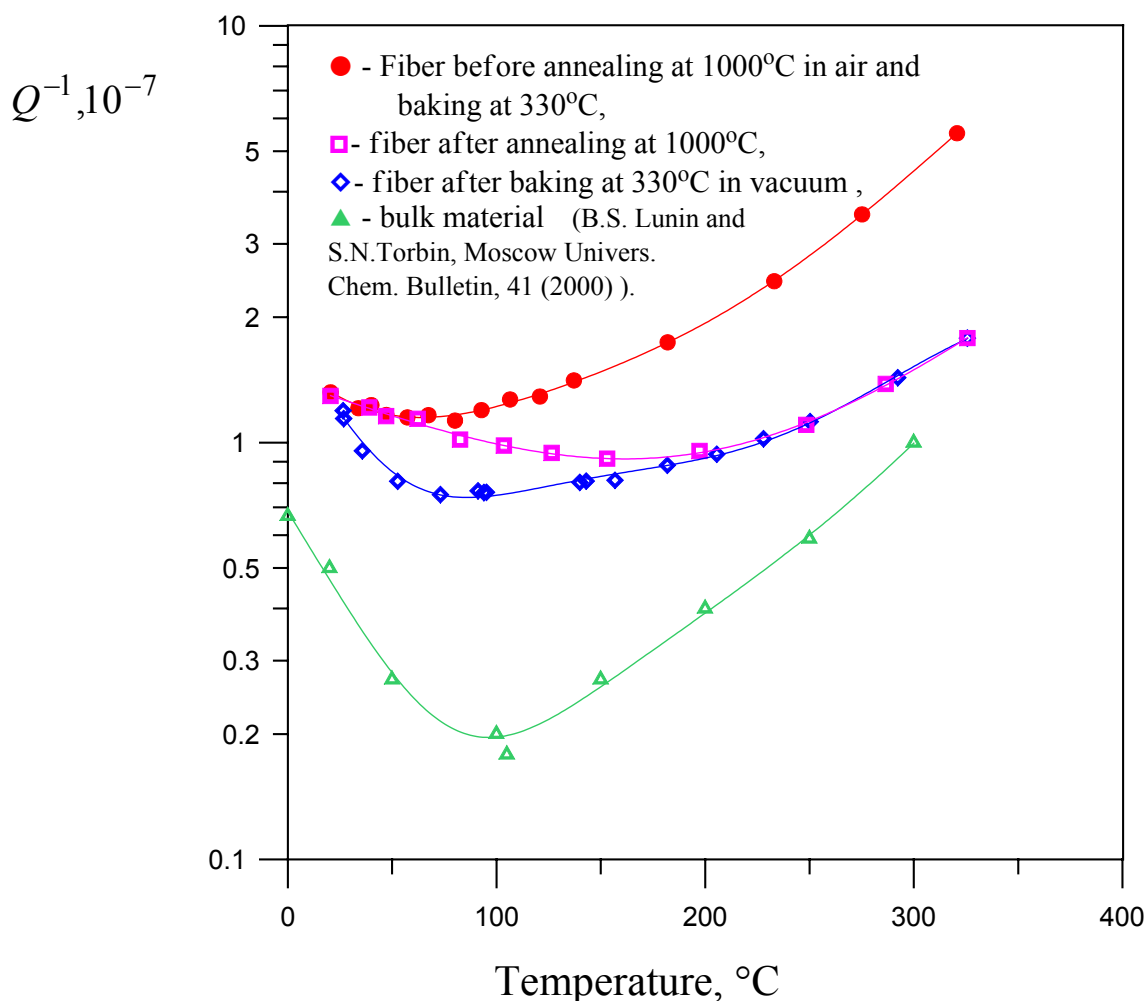
Irreversible temperature dependence of Q in the process of heating and subsequently cooling the fiber.

The second cycle:

- a) immediately after the first cycle, $p \approx 2 \times 10^{-6} \text{ Torr}$ $Q_{heating}^{-1} \rightarrow Q_{cooling}^{-1}$
- b) intercycle time – 24 hours,
 $p \approx 10^{-4} \text{ Torr}$ $\left\{ \begin{array}{l} \text{heating:} \quad Q_2^{-1} < Q_1^{-1}, \\ \text{cooling:} \quad Q_2^{-1} > Q_1^{-1} \end{array} \right.$

The preliminary annealing at $T \approx 1000^{\circ}C$ in air reduced losses at high temperature range.

Comparison of the temperature dependence of losses in fibers and in bulk material.



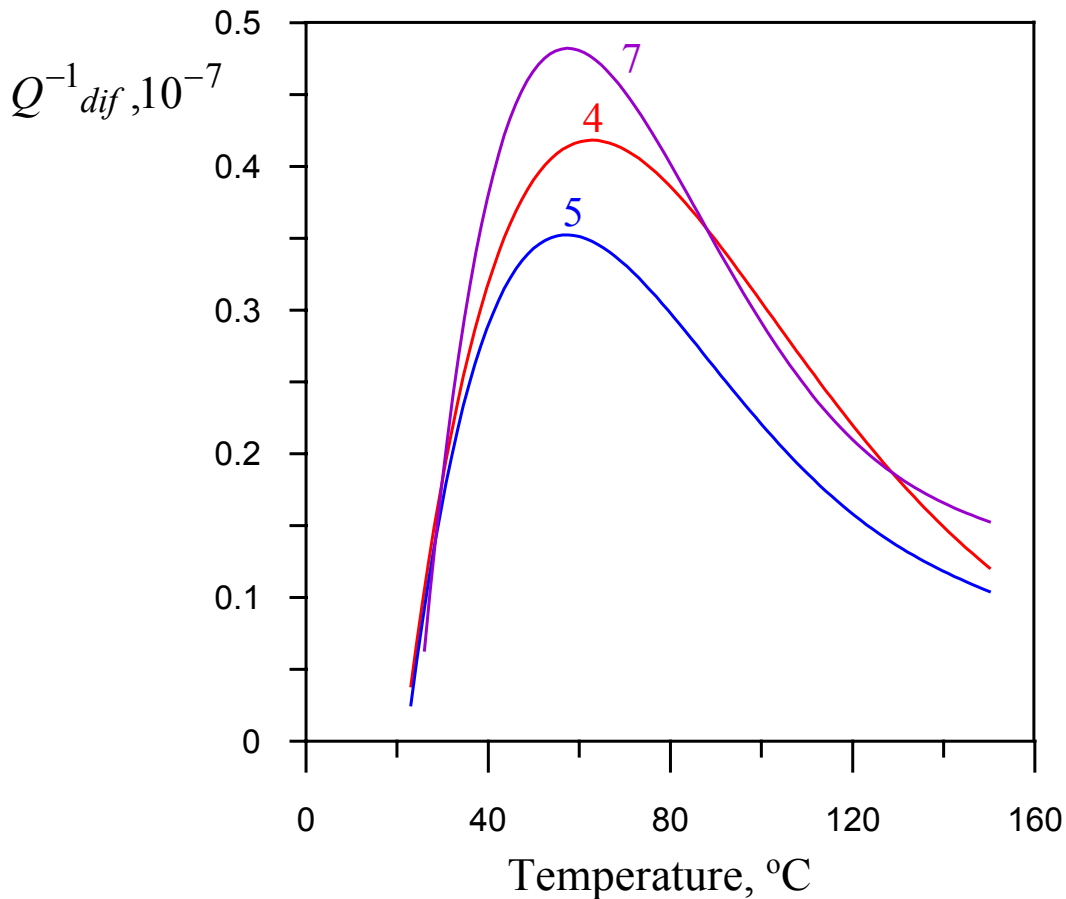
- The room temperature Q does not change after these procedures

We suppose:

- Internal stresses are responsible for losses in fiber at high temperature range.
- Some relaxation process associated with adsorbed water produces losses above the room temperature.

Such a behavior of $Q^{-1}(T)$ can be explained by effect of adsorbed water.

$$\Delta Q^{-1}_{dif} = Q^{-1}_{heating} - Q^{-1}_{cooling}$$

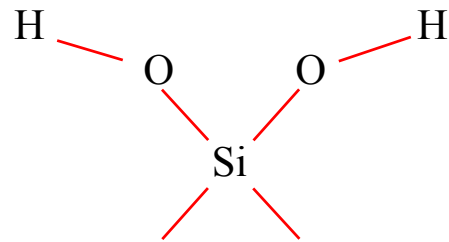
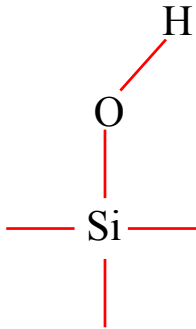


- Adsorbed water manifests itself as a relaxation peak of losses. It is wider than “Debye peak” $Q^{-1} = \Delta \frac{\omega\tau}{1 + \omega^2\tau^2}$.
- Number of relaxing units changes in the process of variations of temperature.
- Estimate of the activation energy:

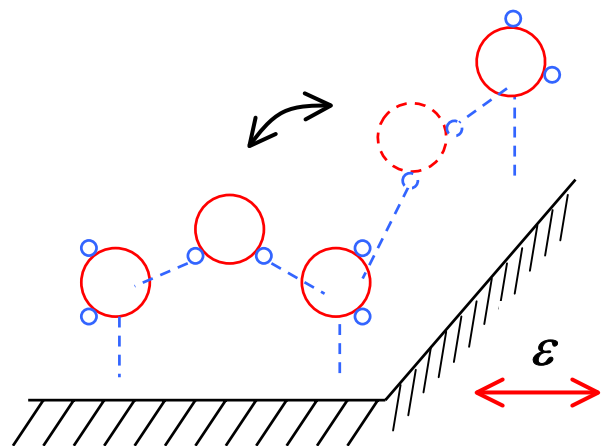
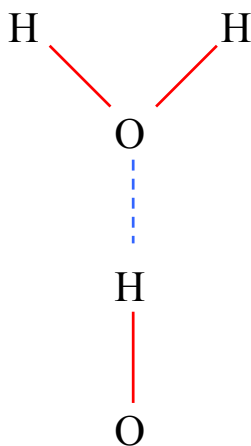
$$\omega\tau = 1, \quad \tau = \tau_0 e^{\frac{E_a}{kT}}, \quad \tau_0 \approx 3 \times 10^{-14} \text{ c}, \quad E_a = 0.65 \text{ eV}.$$

For example, it is possible to suppose the following model of dissipation in fused silica fibers which is associated with adsorbed water.

Water molecules can form extremely strong bonds to the surface of fused silica-silanol groups ($-\text{Si}-\text{OH}$).



Other water molecules are held via more weaker hydrogen bonds to the first layer molecules forming clusters on the surface.



Upper adsorbed molecules can have various orientation.

Bending of the fibers results in expansion and contraction of its surface layers. If hydrogen-bonded molecules oriented along and across the fiber's length have slightly different binding energy they will change their orientation in accordance with a new equilibrium distribution of orientations \Rightarrow This is the thermally activated relaxation process.

Conclusion

We investigated one possible mechanism of dissipation in fused silica fibers which is likely associated with weakly bonded water molecules.

Evidently, there are other mechanisms which are responsible for excess surface losses in fused silica fibers.