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Report:

Abstract

The dynamic structure factor of a sodium silicate glass sample has been measured by inelastic X-rays scattering (IXS) as a function of the exchanged wave-vector Q at a fixed temperature T = 100 K.

The sample was prepared with a 40% sodium concentration. A detailed line-shape analysis confirms the presence of a negative dispersion of the apparent speed of sound in the low wave-vector range, already observed at T=600 K (see the previous report of experiment HD181).

The speed of sound is temperature independent between 100 and 600 K while the sound damping shows a small but measurable variation between the two temperatures, in the Q region corresponding to energies smaller than the Boson Peak energy (E_{BP}). Moreover the Q dependence of the damping (Γ), for $E<E_{BP}$, is approximately $\Gamma \sim Q^4$.

Experiment and results

The dynamic structure factor has been measured for five Q-sets of the nine analyzer spectrometer arm. The Q-sets were chosen so as to span with great detail (about 15 points in Q) the low wave-vector ($Q < 5$ nm^{-1}) range.

The chosen temperature, T=100 K, strongly reduces the inelastic signal, compared to the previous experiment at 600 K. This is, to our knowledge, the first experiment at such a low temperature in an oxide glass. The marked elastic line, associated to the frozen density fluctuations, and the low inelastic signal make it necessary the use of long integration times.

An integration time of around 10 minutes/point, corresponding to a total time of 30 hours/spectrum was chosen. The measured spectra, see figure 1, are characterized by a signal to noise ratio which is sufficient to determine the speed of sound with a 1% accuracy.

The spectra have been fitted to a damped harmonic oscillator (DHO) function convoluted to the instrumental resolution plus an elastic line whose shape is given by the resolution itself. The effect of the analyzers slits

finite aperture on the line shape has been carefully taken into account in the analysis of the spectra. The analyzer collects the intensity in a range of wave-vectors corresponding to its horizontal slit aperture and this contribution is non-negligible for wave-vectors $Q < 2\ nm^{-1}$.

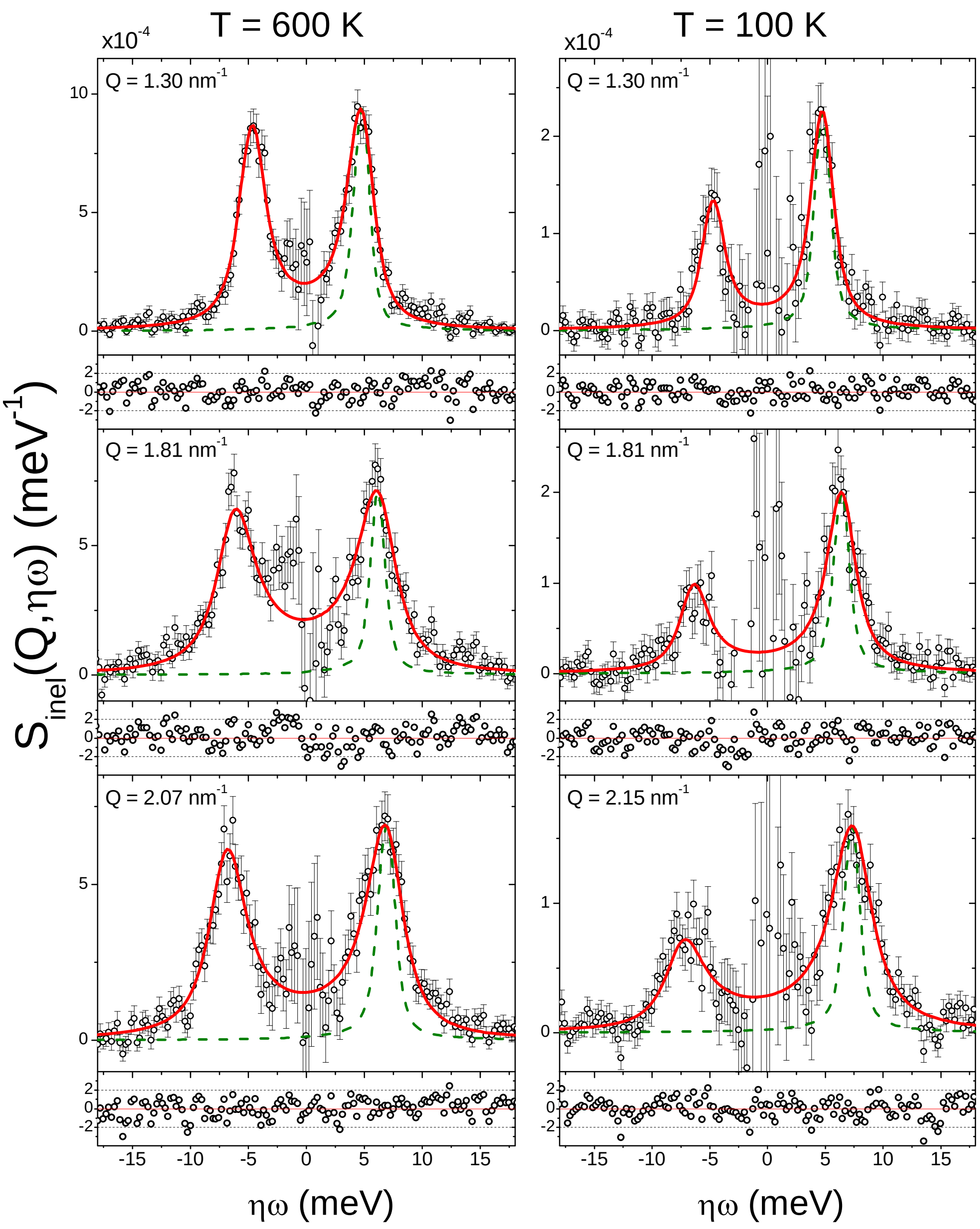

Figure 1. Inelastic part of the dynamic structure factor as a function of the energy at the indicated wave-vectors Q. The plotted quantity is obtained as difference between the measured intensity and the elastic line, plus a baseline. It is thus convoluted to the instrumental response function, which is plotted as a dashed line for reference. The left column shows data from a previous experiment (see report HD181) at a temperature T=600 K. The right column presents the new data, collected at T=100 K. The red lines are the best fitted DHO profiles convoluted to the instrument resolution. The error bars take into account both the uncertainties on the spectrum, on the resolution and on the intensity of the subtracted elastic line. The asymmetry in the peaks intensity is a manifestation of the principle of detailed balance and is more pronounced at lower temperature. The low temperature data are more noisy even if counted longer, being the intensity roughly proportional to temperature because of the Bose population factor. However the line shape analysis is very accurate as shown by the small residues (plotted below each figure in standard deviation units).

The figure shows the comparison between the inelastic part of the dynamic structure factor at the two temperatures T=600 K and T=100 K. At a wave-vector $Q = 1.3\ nm^{-1}$ (upper part of the figure) the broadening (Γ) of the peaks with respect to the resolution (dashed green) is smaller at T=100 K than at 600 K. At the lowest temperature Γ is also very small compared to the resolution. The difference in width between the two

temperatures is reduced as the wave-vector is increased, and for $Q > 2\ nm^{-1}$ the damping Γ becomes temperature independent, as visible also directly from the spectra.

This observation is quite unexpected since, up to now, it was believed that anharmonic effects cannot affect the sound propagation at the very high frequencies ($\nu > 1$ THz) probed with IXS.

This result suggests that for energies lower than the boson peak energy, the dynamics in the glassy states is affected by anharmonic processes. Further investigations in this direction are required to better understand this novel phenomenon.

References

G. Baldi, A. Fontana, G. Monaco, L. Orsingher, S. Rols, F. Rossi, and B. Ruta, submitted to Phys. Rev. Lett.