PHONON DAMPING IN CRYSTALLINE AND AMORPHOUS SOLIDS AT HYPERSONIC FREQUENCIES

Article *in* Le Journal de Physique Colloques · December 1981

DOI: 10.1051/jphyscol:1981637

2 authors:

René Vacher
Université de Montpellier
208 PUBLICATIONS **5,170** CITATIONS
SEE PROFILE

Jacques Pelous
Université de Montpellier
128 PUBLICATIONS **2,961** CITATIONS
SEE PROFILE

JOURNAL DE PHYSIQUE
Colloque C6, supplément au n°12, Tome 42, décembre 1981

PHONON DAMPING IN CRYSTALLINE AND AMORPHOUS SOLIDS AT HYPERSONIC FREQUENCIES

R. Vacher and J. Pelous

Laboratoire de Spectrométrie Rayleigh Brillouin (ERA 460), Université des Sciences et Techniques du Languedoc, Place E. Bataillon, 34060 Montpellier Cedex, France

Abstract.- We present new Brillouin scattering measurements, for temperature ranging from 1 K to room temperature in a broad range of insulating solids (crystalline and amorphous solids). We analyse the temperature dependence of the attenuation of longitudinal phonons (frequency higher than 15 GHz) on the basis of the physical processes responsible for the phonon damping.

Measurements of acoustic attenuation in solids for frequencies higher than 10 GHz are scarce, because the large attenuation at these frequencies makes the ultrasonic experiments difficult, excepted at low temperatures. Brillouin scattering, which is the appropriate tool for such measurements, has been used in a broad range of insulating solids for temperatures ranging from 1 K to 300 K. We have studied ionic and molecular crystals, inorganic glasses and amorphous polymers. Our purpose is to bring out the laws for the temperature variation of the damping, to compare them with those observed at lower frequencies, and to analyse these results on the basis of the theoretical models describing the physical processes responsible for the attenuation.

(i) Ionic crystals. In such materials, the acoustic damping α is known to originate from anharmonic phonon-phonon interaction. Sodium Chloride is used here as an example. In this crystal, previous ultrasonic measurements[1] have demonstrated the existence of two well-defined limiting regimes. At low temperatures (below 20 K) the condition $\omega\tau >> 1$ was fulfilled (ω is the frequency of the acoustic wave and τ the lifetime of thermal phonons). The experiment gave $\alpha \sim T^4$ in agreement with the theory in the Landau-Rumer regime.[2] At higher temperatures, the Akhieser regime ($\omega\tau<<1$) was reached : the ultrasonic attenuation α was then found proportional to T° which also agrees with theory. In contrast, Brillouin experiments around 30 GHz indicates $\alpha \sim T^n$, with $n \simeq 2.5$ below 60 K. At higher temperatures, the T° law is not observed. A satisfying explanation of this surprising behaviour can be found extending the current theories of the attenuation due to phonon-phonon interactions, to the unusual temperature-frequency regime reached in our experiments.[3]

(ii) Molecular crystals. Our experiments in succinonitrile[4] and α-sulfur[5] have demonstrated that a dispersion and attenuation of elastic waves can be observed by Brillouin scattering in molecular crystals. Such experiments at hypersonic frequencies show that relaxation processes with characteristic times of the order of 10^{-11} s.

are present in these crystals, in addition to anharmonic phonon-phonon processes. For more details on the molecular relaxation observed in α-sulfur, the reader is referred to the paper presented separately at the same Conference.[6]

(iii) Inorganic glasses. Above 1 K, two striking features are observed in most of the inorganic glasses. For temperatures around 1 K, the ultrasonic attenuation is proportional to T^3 (frequencies lower than 1 GHz). In this temperature range the dominant process is the relaxational absorption via phonon-assisted tunnelling. At higher temperatures, a - more or less pronounced - absorption peak is often observed, which is assigned to thermally activated relaxation processes. Such a behaviour has been observed in glasses of very different chemical composition as, for instance, vitreous SiO_2 and $LaSF_7$, a metallic oxyde glass, for frequencies of about 100 MHz.[7] Our Brillouin scattering experiments in $LaSF_7$, plotted in Fig.1, exhibit a completely different behaviour (the frequency is about 40 GHz) : α is found nearly proportional to T in the whole temperature range studied.

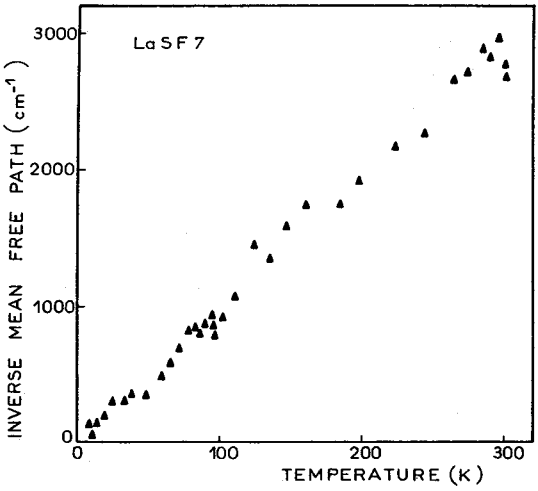

Fig. 1 - Hypersonic attenuation of longitudinal waves (42 GHz) in metallic oxyde glass $LaSF_7$.

In vitreous SiO_2, we have already shown[8] that the relaxation process which accounts for all of the ultrasonic attenuation can only explain one part of the hypersonic values. Phonon-phonon interactions have been suggested to explain this excess. A similar explanation can be proposed for $LaSF_7$ results.

(iv) Amorphous polymers. At ultrasonic frequencies, the peak due to thermally activated relaxations is also observed in polymers. However, at low temperatures, α appears here proportional to ωT. Our results in polystyrene (Fig.2 - the frequency is about 18 GHz) exhibit a T-dependence in a large temperature range, and agree approximately with an ω-law where compared to the ultrasonic values below 10 K. The best candidate for explaining a ωT law is a distribution of thermally activated relaxation processes, with a nearly constant density of activation energies.[9]

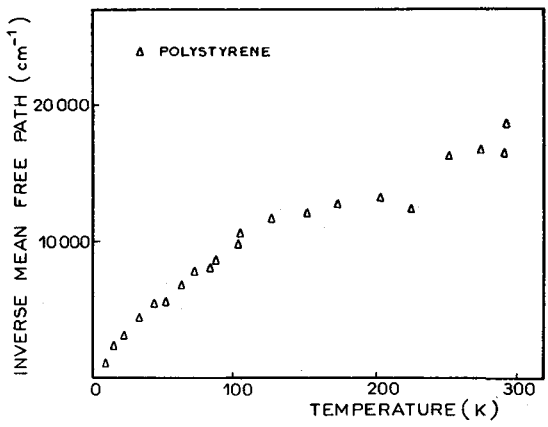

Fig. 2 - Hypersonic attenuation of longitudinal waves (18 GHz) in amorphous polystyrene.

However, as for inorganic glasses, the hypersonic results cannot be described as a whole on the basis of the ultrasonic values of the relaxation parameters.

The above results show that, for all of the insulating solids studied, the temperature dependence of acoustic damping is very different for ultrasonic and hypersonic frequencies. In amorphous materials, the thermally activated relaxations appear to be insufficient for explaining the hypersonic results above 20 K. Phonon-phonon interactions seem to contribute appreciable to the acoustic damping.

1 | *L.G. Merkulov, R.V. Kovalenok and E.V. Konovodchenko, Sov. Phys. Solid State 13 (1971) 968.*

2 | *H.J. Maris in "Physical Acoustics" Vol.8, W.P. Mason, Ed. (Academic, N.Y. 1974) p. 279.*

3 | *J.P. Bonnet, M. Boissier, R. Vacher, (to be published).*

4 | *H. Fontaine, R. Fouret, L. Boyer and R. Vacher, J. Physique, 33 (1972) 1115.*

5 | *R. Vacher, J. Sapriel and M. Boissier, J. Appl. Phys. 45 (1974) 2855.*

6 | *M. Boissier, R. Vacher and B. Perrin, this conference.*

7 | *A. Raychaudhuri, private communication.*

8 | *R. Vacher, J. Pelous, F. Plicque and A. Zarembowitch, J. Non-Cryst. Solids, to be published.*

9 | *J.Y. Duquesne and G. Bellessa, J. Physique (France), to be published.*