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Acoustic and Thermal Properties of Stycast 1266 below 100 mK

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We report on the acoustic and thermal behavior of a Stycast 1266 - quartz composite torsional oscillator below 100 mK. The epoxy exhibits heat release manifested by a strong time dependence of the sound velocity below 10 mK. Also, the Stycast sample is sensitive to both γ and μ radiation, displaying transients superposed on the resonant response of the composite oscillator, as well as heating when exposed to a ^{22}Na source. The long thermal relaxation time of the tunneling states together with the high thermal resistance limits the lowest achievable temperature in this insulating amorphous material.

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1. INTRODUCTION

The acoustic and thermal[1] properties of glasses and disordered crystalline materials display a remarkable similarity at temperatures below 100K. Anderson[2] and Phillips[3] developed the Tunneling Model (TM) that attributes the universal behavior to the presence of two-level defects represented by impurity atoms (or groups of atoms) that tunnel between nearly equivalent equilibrium positions. Within this model, the structural relaxation gives rise to the long term heat release from amorphous samples observed experimentally by Schwark *et al.*[4] and Sahling *et al.*[5].

Our recent studies of a-SiO_2 on a composite torsional oscillator[6] show that at low temperatures the passage of γ and μ radiation induces transients in the driven oscillations via a non-equilibrium photo-acoustic effect[7] as well as depositing energy into the oscillator[8]. The results also show that the a-SiO_2 cannot be cooled to below ≈ 4 mK because of heat release. In the present work we show that Stycast 1266 (another amorphous material) is equally sensitive to γ and μ radiation, as well as exhibiting an ultra-long-

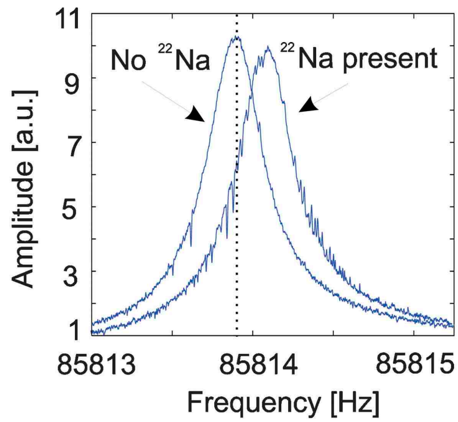

Fig. 1. Two oscillator response curves obtained as the drive frequency was swept through resonance in 2000 s at T=1.16 mK, 550 hours after cooling the cryostat to 4.2 K. The left resonance was taken in the lead-shielded configuration and is almost free of transients ("downticks" below resonance, "upticks" above resonance). The transients in this trace are due to μ since γ do not penetrate through the lead. The resonance shows a positive frequency shift implying an elevated temperature with the oscillator exposed to a 6.1 μCi ^{22}Na γ source, consistent with the increased rate of transients observed.

term heat release. The long thermal relaxation in combination with poor thermal conductivity suggests that Stycast 1266, so commonly used in low temperature physics cannot be cooled below a few mK.

2. EXPERIMENT

The torsional oscillator used in our studies consists of a 2.5 mm diameter, 7.0 mm long Stycast 1266 cylinder, glued to a 2.5 mm diameter, 21.6 mm long X-cut quartz actuator using Stycast 2850GT epoxy. The sample's length was adjusted to set up a 1/2 wavelength of transverse sound in both the Stycast 1266 and quartz[1] with the antinode positioned at the glue joint. The oscillator was attached to a BeCu pedestal using Stycast 2850GT. The oscillator's motion was driven and detected electrostatically using an AC bridge circuit and a lock-in detector via four electrodes evaporated on the quartz crystal. The frequency was swept through resonance in 2000 s, slow enough not to distort the resonant response (Fig. 1) with a drive small enough to preclude self heating or non-linearity. The oscillator was installed on a nuclear demagnetization cryostat whose temperature (cal-

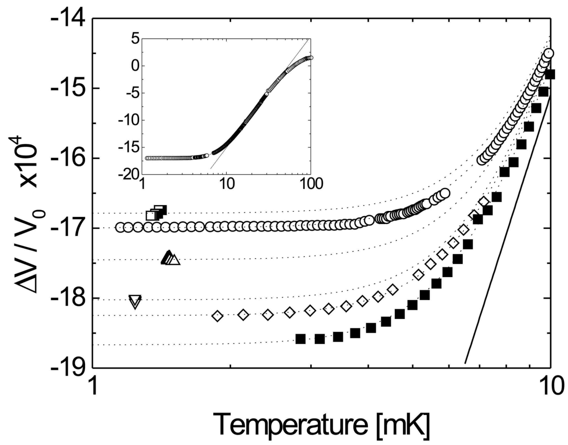

Fig. 2. The sound velocity shift (computed from the resonant frequency) vs temperature taken at (from top to bottom) 552(open squares), 648(circles), 816(triangles), 1152(inverted triangles), 1725(diamonds), 1800 (filled squares) hours after the initial transfer of liquid helium. The inset shows the temperature dependence obtained near 648 hours over the whole temperature range. Data at 1725 hours were obtained with the cryostat shielded by a 5 cm thick lead brick wall together with exposure to a 6.1 μCi ^{22}Na γ source. Data at 1800 hours was taken with the lead shielding in place but without the source present (see Fig. 1). The dotted lines through the data were fits obtained by modelling the thermal resistance (see text). The solid lines in the main figure and inset represent the limiting expression (using the tunneling model) for the low temperature behavior, $\Delta V/V_0 = 2.054{\times}10^{-3}\log_{10}(T/0.0543)$.

ibrated against the melting curve of ^{3}He) was varied between 1 and 100 mK. The sample's temperature did not rise above 100 mK, to avoid reactivation of relaxed tunneling sites. A 5 cm thick lead wall around the cryostat served to reduce the flux of ambient γ radiation.

In Fig. 1 we show spectra taken with the cryostat held at 1.16 mK as the frequency was swept through resonance. In the shielded configuration (left trace), the resonance is almost free of transients that we have modelled as due to a nearly instantaneous change in the spring constant (with rise and fall time less than the characteristic relaxation time of the oscillator) induced by a rapid elevation of phonon temperature due to the passage of energetic particles[7]. The resonance that is shifted to higher frequency was observed with the oscillator exposed to a 6.1 μCi ^{22}Na source. The rate of transients increased substantially showing the sensitivity of Stycast 1266 to 0.511 MeV and 1.27 MeV photons emitted by the ^{22}Na source which we calculate[9] will deposit ≈3.2 fW to the epoxy and ≈20 fW to the quartz driver. In contrast to the a-SiO_2 sample[7,10], in Stycast no ringing was observed following a transient, presumably because of the lower Q of the epoxy. The transients' amplitudes are at least an order of magnitude smaller than the on-resonance amplitude at f_0.

In Fig. 2 we show the sound velocity shift, $\Delta V/V_0$ (V_0 measured at 63 mK) for a series of temperature sweeps (not all data sets were taken over the entire range of temperature), where the sound velocity is calculated from the resonant frequency[11]. The plot shows two prominent features. The sound velocity has a pronounced "flattening" at low temperatures, and when measured over a period of many weeks, this flattening occurs at a progressively lower sound velocity with increasing time. We attribute the time dependence of the sound velocity to a diminishing heat release from the epoxy. The inset shows the behavior of the sound velocity over the whole temperature range.

According to the tunneling model, in the limit of low temperatures the sound velocity should display a logarithmic temperature dependence. From the data shown in the inset to Fig. 2, we find the low temperature sound velocity to be $\Delta V/V_0 = 2.054\times10^{-3}\log_{10}(T/0.0543)$, where T is the temperature in K. This expression is plotted as the solid line in Fig. 2. We used the calculated thermal resistances $R_{Bd1} = 210T^{-3}[K^4W^{-1}]$ (the boundary resistance at the Be-Cu-2850-quartz joint[12]), $R_{Casimir} = 463T^{-3}[K^4W^{-1}]$ (the thermal resistance of the quartz[12]), $R_{Bd2} = 268T^{-3}[K^4W^{-1}]$ (the boundary resistance of the quartz-2850-Stycast 1266 joint[13]) and $R_{ep} = 3.2\times10^4T^{-2}[K^3W^{-1}]$ (the thermal resistance of the epoxy[14]) in series with one another to calculate the heat release from the epoxy. This is done by using the sound velocity as a thermometer and determining the heat release necessary to raise the temperature of the epoxy to a value consistent with the observed $\Delta V/V_0$. The heat deposited by the passage of γ from building materials and by cosmic-ray μ is negligible (≈5 fW)[15]. We obtain values of heat release and time after cooldown to 4.2K($\dot{Q}[pWg^{-1}], t[hours]$) as being (26.5, 552), (24.2, 648), (19.7, 816), (15.3, 1152) (11.5, 1800). The resulting temperature dependent behaviors are plotted as the dotted lines in Fig. 2. From these data we infer that even after the passage of ≈2000h, the epoxy never cools below 6.5 mK. However, there is a puzzling discrepancy: with the ^{22}Na source in place, the amount of heat deposited is ≈23 fW, whereas the heat input required to cause the observed offset in sound velocity between the 1725 hour and 1800 hour runs is ≈200 fW, with only ∼10 fW attributable

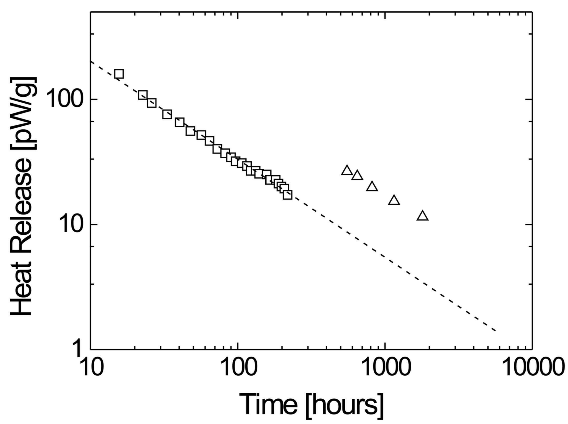

Fig. 3. The evolution of the calculated heat release (open triangles) in pWg^{-1} vs the elapsed time since helium transfer in hours. The results of Schwark *et al.*[4] (open squares) and an extrapolation for comparison are also shown. The identical time dependence of both data sets is slower than t^{-1}.

to the relaxation between data sets. It is possible that the distribution of two level systems is altered by the bombardment with γ, affecting our thermometry. However, the role of the thin 2850GT epoxy may be poorly accounted for. In general, the thermal resistances of insulating solids are not well documented in the mK regime. Consequently, the actual time-dependent heat leaks may be considerably smaller than our inferred results.

In Fig. 3, we plot the time dependence of the inferred heat release, together with the results of Schwark *et al.*[4], who obtained data on Stycast 1266 over a shorter time interval. Our inferred heat leaks follow a similar time dependence, though they are higher in magnitude. Again this difference may possibly be attributed to errors in the thermal resistances, or may be a consequence of the procedure used in cooling down the cryostat, since the heat release depends on the starting (high) temperature as well as the time spent below that temperature[5].

3. SUMMARY

We have measured the acoustical and thermal properties of Stycast 1266 at low temperatures. We also see the incidence of transients that we attribute to the interactions with γ and μ particles. We see prominent effects of heat release from which (in this geometry) we infer that the Stycast never cools below $\approx$ 6.5 mK. These effects should be manifested in a number of different experiments. For example, long-term heat release from epoxy-coated walls was invoked to explain the residual heat leaks in the Lancaster-style demagnetization cells[16].

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