Spectral Dependence of the Kapitza Resistance Between 0.5K and 2.3K

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The frequency dependence of the thermal boundary resistance between a solid and helium has been tested in earlier experiments [1] indicating a smooth and structureless transition between regular und anomalous Kapitza resistance. In our experiments, carried out with tunable monochromatic phonons, we find a sharp threshold in the decrease of reflectivity at about 85 GHz with additional structures at higher frequencies for a solid surface in contact with liquid or gaseous ^{4}He.

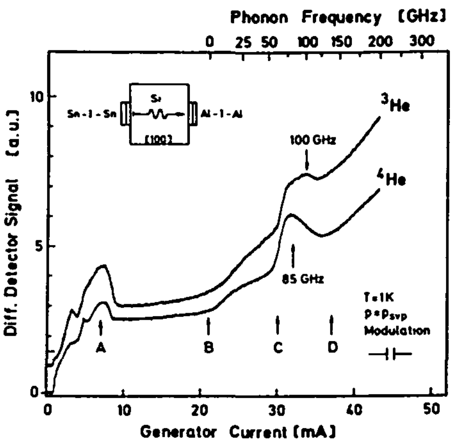

Figure 1: Detector signal of an Al detector vs.the current of a Sn generator. The sample is in contact with ^{3}He or ^{4}He gas respectively

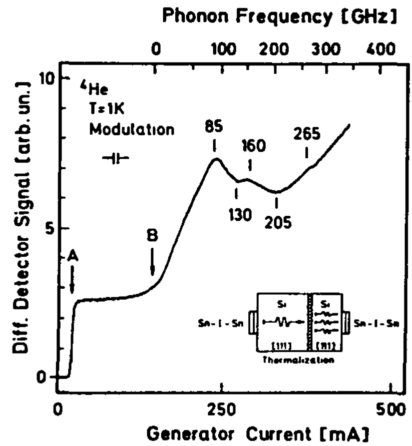

Figure 2: Bolometer signal vs. the current of a Sn generator obtained by the thermalizing arrangement which was immersed into liquid ^{4}He

Our experimental arrangements are shown as insets in Fig. 1 - 3. The Sn generator emits monochromatic phonons [2,3] both into the substrate and into helium. Phonons radiated into the substrate propagate ballistically to an Al junction working as a quantum detector [Fig. 1]. The sample is in contact with ^{3}He or ^{4}He gas respectively ($p = p_{svp}$, $T = 1.0$ K). It is important to realize that phonons which are reflected at the generator/helium interface also contribute to the detector signal. At small currents some peaks (A) due to nonlinearities in the I-V characteristics of the generator are observed. The following plateau is caused by a constant number of recombination phonons. Begin-

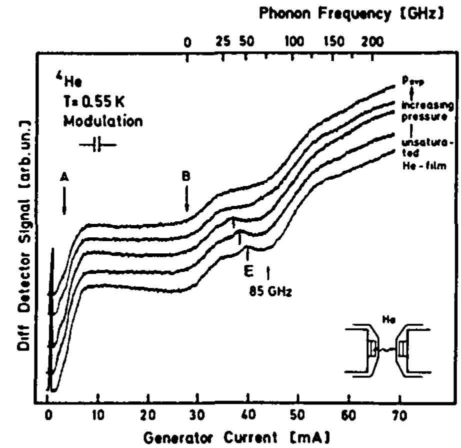

Figure 3: Differential detector signal vs. the current of a Sn generator obtained by gas sound experiments in a volume between two tunnel junctions

ning with 0 GHz (B) monochromatic phonons are generated. If the phonon energy exceeds $2\Delta_{Det}$ (C) pairbreaking in the Al junction leads to a steplike sensitivity increase. At higher frequencies a significant difference in the detected phonon signal between ^{3}He and ^{4}He occurs. If ^{4}He gas is in contact with the sample a strong decrease of the phonon signal starting at 85 GHz is observed. After reaching a minimum at about 130 GHz the signal increases again, obviously at frequencies lower than $4\Delta_{Det}$ (D). If the sample was in contact with ^{3}He gas a small decrease of the phonon signal at about 100 GHz is followed by a minimum at about 120 GHz. In contrast we observed a complete disappearance of the frequency threshold phenomena when the generator first was covered with condensed nitrogen or a thin oil film and then was immersed into liquid ^{4}He or by keeping the sample under vacuum [4].

We therefore conclude that enhanced phonon transport from the generator into ^{4}He starts at 85 GHz. A corresponding threshold of increased phonon transport into ^{3}He is found at 100 GHz.

With a new kind of bolometer [5] we could extend both the observable frequency range from 0 GHz to 285 GHz and the temperature range from 1.0 to 2.3 K [inset of Fig. 2]. Between 0 GHz (B) and 85 GHz the detector signal increases with increasing phonon frequency and is almost structureless, whereas at 85 GHz a breakdown in the reflectivity is observed followed by additional structures at about 130, 160, 205 and 265 GHz. No significant influence of the helium temperature on the threshold frequency was observed in the temperature range from 0.95 K to the λ point of ^{4}He, whereas at higher temperatures (normal fluid ^{4}He) only a small change in the signal slope at about 85 GHz occurs.

To study the phonon transport into helium we used two tunnel junctions which are mounted opposite each other [inset of Fig. 3]. The volume inbetween can be filled with gaseous or liquid helium respectively [6]. The He temperature is adjustable between 0.5 K and 2.3 K. Fig. 3 shows the detector signal vs. generator current for different ^{4}He pressure. Considering only the upper curve of Fig. 3. ($p = p_{svp}$, $T = 0.55$ K) at small currents (A) a plateau occurs. With increasing current (B) monochromatic phonons are generated. At 85 GHz a strong increase of the detector singal is observed reaching its maximum at about 130 GHz. At higher frequencies the signal increases again at 160 GHz and 265 GHz. The onset freqency of 85 GHz for enhanced phonon transport into helium did not depend on the pressure of the ^{4}He gas in the range of 10^{-4} Torr up to liquid helium. With ^{3}He gas between the junctions the threshold frequency shifts to 100 GHz. Both thresholds show a small temperature shift (roughly 20 % from 2.3 K to 0.5 K) to lower frequencies with decreasing temperature.

Below 1.0 K we observe at reduced ^{4}He gas pressure an additional structure (E) at frequencies below 85 GHz [lower traces of Fig. 3.]. With increasing He pressure the structure shifts to lower frequencies and disappears before reaching saturated vapour pressure. The additional structure might result from film thickness resonances in the helium film above the generator surface, whose thickness increases with increasing pressure [7]. The threshold at 85 GHz is not affected by the observed film thickness resonances. With ^{3}He we have not observed similar structures as yet.

Summarizing, we observed strongly enhanced phonon transport from a real solid into ^{4}He starting at about 85 GHz which is independent of the He gas pressure up to liquid helium. With the isotope ^{3}He the onset frequency for enhanced phonon transport shifts to 100 GHz. The threshold frequencies are almost independent of the He temperature in the range between 0.5 K and 2.3 K. Only slight shifts to lower frequencies with decreasing He temperature have been observed. No significant influence of the generator material (Sn, Al, SiO) or the generator preparation on the onset frequency has been observed. Moreover at low temperatures and thin He films we observed an additional structure which might be interpreted as film thickness resonances in the He film layer on the generator.

Our results may be interpreted in terms of strong phonon coupling by resonant excitations [8] or two-level transitions [9] of adatoms or surface imperfection in the van der Waals potential of the surface. This is also indicated by the strong influence of the atomic weight of the helium isotope ^{3}He and ^{4}He on the Kapitza threshold frequency. One finds that the ratio of the onset frequencies is about the square root of the mass ratio. Our results may also be compared with those of inelastic neutron scattering on grafoil with ^{4}He layers revealing dispersionless surface excitations, roughly at the same frequencies as we observed [10].

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