

REFLECTION OF HIGH FREQUENCY PHONONS AT FREE SILICON SURFACES

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Résumé.- Nous avons fait des expériences de réflexion des phonons par des surfaces libres de Si $[100]$ dans lesquelles on pouvait distinguer phonons réfléchis et phonons diffusés, les réfléchis se propageant selon $\langle 110 \rangle$. La proportion phonons diffusés sur phonons spéculairement réfléchis est une fonction croissante de la fréquence.

Abstract.- In reflection experiments at free silicon $[100]$ - surfaces we could distinguish between specularly and diffusely reflected transverse phonons propagated along $\langle 100 \rangle$ - directions. With increasing phonon frequency the number of diffusely scattered phonons increase relative to that of specularly reflected phonons.

Our experiments are motivated by two problems connected with the passage of high frequency phonons through boundaries: The Kapitza resistance /1/ between solids and helium and also the large phonon losses at the interfaces between substrate and evaporated metal films found by Trümpf /2/ in phonon generation and detection experiments with superconducting tunnelling junctions as phonon generators and detectors.

The geometry of our reflection experiment (see inset of figure 1) differs from that of experiments carried out by other authors /3-6/, giving some more specific conditions: 1) The angle of incidence is oblique for specularly reflected phonons so that incident and reflected phonons propagate in $\langle 110 \rangle$ directions which are pure mode directions for all phonon polarizations (Path 1 of the inset). 2) By a slight misalignment of the generator-detector direction from $[100]$ (about 4°) fast transverse phonons propagating along Path 3 (in $[010]$ and $[2\bar{1}0]$, see inset of Figure 1) are strongly focused resulting in a large signal of these diffusely scattered phonons. 3) The polarization vector of the fast transverse phonons lies in the scattering plane.

As with the earlier experiments the scattering surface was part of a vacuum chamber allowing changing surface conditions (vacuum or helium coverage), whilst all other surfaces have been in contact with liquid helium. The high purity Si-crystals (25 mm diameter, 5 mm thick) were mechanically polished. Constantan heaters (0.4 x 0.4 mm²) and superconducting Sn-tunnelling junc-

tions have been used.

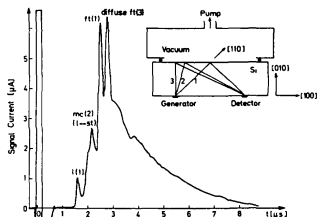


Fig. 1 : Typical detector signal for a scattering surface in vacuum. Heater power : 3.6 W/mm², pulse duration : 50 ns, bath temperature : 1.8 K. The inset shows the experimental set-up and the propagation paths of the phonons of the individual pulses.

A typical detector signal is shown in figure 1. Duration of the generator pulse was about 50 ns. The crystal was misaligned, as mentioned above. The detector signal consists mainly of four pulses. The propagation paths of the phonons of the individual pulses are indicated in the inset of figure 1. Due to their propagation time the first three pulses can be ascribed to specularly reflected phonons: longitudinal (l), mode converted (mc), and fast transverse (ft) phonons. The specularly reflected slow transverse phonons were defocused and could not be detected.

As a consequence of its propagation time the fourth pulse cannot be ascribed to specularly

reflected phonons. Its width is not considerably greater than that of the other pulses. If the phonons of the fourth pulse are diffusely scattered, they must propagate in a narrow "channel" formed by phonon focusing. As mentioned above, such a "channel" exists in fact for the chosen orientation (Path 3 in figure 1). The propagation time of the fast transverse phonons on this path agrees well with the delay time of the fourth pulse.

This interpretation of the fourth pulse could be verified by evaporating selectively indium onto the surface showing that it originates from phonons diffusely scattered from spots directly opposite to the detector and to the generator.

Since the diffuse scattering is probably due to the roughness of the scattering surface, one expects that the ratio of the diffusely and specularly reflected parts of the detector signal depends on the wavelength of the phonons.

Due to the fact that with increasing heater power the maximum energy density of the phonon spectrum shifts to higher frequencies, one can qualitatively test the detector signal in dependence on the phonon frequency by using a heater as phonon generator and varying the heater power. Figure 2 shows the relative amplitudes, i.e. the amplitudes of the individual pulses divided by the amplitude of the third (ft) pulse versus the heater power.

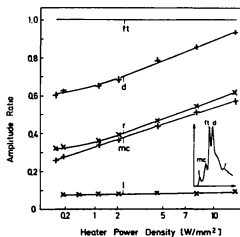


Fig. 2 : Amplitudes of the different pulses divided by the amplitude of the ft-pulse versus the heater power.

It shows that the longitudinal (l) pulse has the same frequency dependence as the fast transverse (ft) whilst the fourth (d) pulse, the second pulse (mc) and the tail (r) of the signal increase with

increasing heater power stronger than the ft-pulse. This confirms our interpretation that the ft and the l pulses originate from the same scattering mechanism (mainly specular) in contrast to the diffuse scattering of the d, r, and mc pulses.

Another interesting result which so far we do not understand, is the fact that the ft and the d pulses are reduced differently by helium coverage of the surface: the ft-pulse is reduced by approximately 45 %, the d-pulse by more than 85 %. In both cases the incident phonons are transverse, polarized in the boundary.

Using superconducting Sn-tunnelling junctions as generators we can compare the yield of specularly reflected pulses to that of ballistic experiments ^{2/}. We find that at least 60 % of the phonons are specularly reflected. Furthermore, we did not get an indication that either the ft or the d-pulse is scattered inelastically by the free, mechanically polished surface.

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