Ultrasonic Attenuation in Quasi-one-Dimensional $(\text{TaSe}_4)_2\text{I}$ Compound

M. Saint-Paul, P. Monceau and F. Levy*

Centre de Recherches sur les Très Basses Températures, Associé à l'Université Joseph Fourier, CNRS, BP. 166, 38042 Grenoble cedex 9, France

** Institut de Physique Appliquée, Ecole Polytechnique de Lausanne, 1015 Lausanne, Switzerland*

Abstract The quasi-one-dimensional compound $(\text{TaSe}_4)_2\text{I}$ is characterized by a very small shear elastic constant C_{44} corresponding to a sound velocity of 450 m/s. A large peak in the ultrasonic attenuation of the C_{44} mode is observed around the Peierls transition $T_P = 263$ K. This transition involves the formation of a charge density wave with an associated lattice distortion. The anelastic relaxation process is discussed.

INTRODUCTION

$(\text{TaSe}_4)_2\text{I}$ is a quasi-one-dimensional conductor which undergoes a Peierls transition at $T_P = 263$ K [1]. Phonon softening at $2k_F$ (Fermi momentum) induces lattice modulations associated with an electron charge density wave. Elastic singularities at the Peierls transition are not yet understood [1]. We present ultrasound attenuation measurements of the slow shear mode C_{44} and longitudinal mode C_{33} in the temperature range between 200 and 300 K.

EXPERIMENTAL RESULTS

Crystals with typical dimensions $3 \times 2 \times 2$ mm³ were used. The longitudinal (C_{33}) and shear (C_{44}) modes were generated with the wave vector q along the [001] direction (c axis). Standard pulse echo technique was used in the frequency range 10-100 MHz with LiNbO_3 transducers. Because of the high attenuation at room temperature only one echo is obtained and the inverse of the amplitude of the echo was measured in decibels and taken as a measure of attenuation. The length of the samples was fixed at 3 mm. The elastic constant C_{44} is very small $C_{44} = 1.3 \times 10^9$ N/m², it corresponds to a sound velocity of 450 m/s. The longitudinal mode C_{33} is equal to 1.2×10^{11} N/m², it corresponds to a sound velocity of 4250 m/s. The sharp peak in the attenuation of the C_{44} mode at T_P is related to the structural transition which occurs at this temperature and is associated to a sharp decrease of the elastic constant C_{44} [2]. The peak in attenuation is very sensitive to the Niobium content: Attenuation of the $(\text{Ta}_{1-x}\text{Nb}_x\text{Se}_4)_2\text{I}$ with $x = 1.2\%$ does not show a sharp peak at 263 K, doping smears out the Peierls transition [1]. It should be also noted that the attenuation at around 270 K for the doped sample is smaller than the attenuation for the pure sample. Attenuation can be analyzed by

$$A/A_{\max} = \omega^2 \tau / (1 + (\omega \tau)^2) \quad (1)$$

where ω is the measuring frequency and τ is the time constant of the relaxation process. The experimental results are well described using the power law $\tau = \tau_0 [T_0 / (T - T_0)]^{1.5}$ with $\tau_0 = 5.7 \times 10^{-9}$ s and $T_0 = 242$ K. The measurements show that around the Peierls transition there is a critical slowing down of the relaxing entities which are coupled to the elastic wave. The relaxation time τ of this process diverges at the temperature T_0 roughly 20 K smaller than T_P (Fig 1a).

The attenuation of the mode C_{33} for the Nb doped sample the maximum of the attenuation is shifted to a lower temperature (Fig 1b), and the data can be analyzed using equation (1) with $T_0=180$ K and $\tau_0=1.8 \times 10^{-8}$ s.

CONCLUSION

The microscopic nature of the relaxing entities cannot be deduced from the ultrasonic measurements alone. Nevertheless the anelastic relaxation process can be related to structural instabilities which happen around the Peierls transition. Strongly correlated fluctuations have been observed around T_p in neutron scattering experiments [3]. The CDW modulated structure at the Peierls transition implies several Q -states belonging to distinct domains (Q is the superstructure wave vector[3]). We believe that the lattice distortions with various effective orientations are responsible for the relaxation behaviour observed around T_p . The one dimensional structural fluctuations can also give a large contribution to the attenuation measured above T_p . The physical meaning of the temperature T_0 cannot be given but it could correspond to the fluctuation freezing in the spin Peierls state.

Figure 1. Relative change in attenuation in dB of the shear mode C_{44} (a) and of the longitudinal mode C_{33} measured at 15 MHz for $(\text{TaSe}_4)_2\text{I}$ and $(\text{Ta}_{1-x}\text{Nb}_x\text{Se}_4)_2\text{I}$ with $x=1.2\%$. The full curves have been calculated using equation (1) with $T_0=242$, 180 K and $\tau_0=5.7 \times 10^{-9}$ and 1.8×10^{-8} s respectively.

REFERENCES

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