First publ. in: Physics Letters A 40 (1972), 3, pp. 257-258

THE ELASTIC CONSTANTS OF SOLID ARGON DETERMINED BY STIMULATED BRILLOUIN SCATTERING*

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Received 15 May 1972

The temperature dependence of the longitudinal sound velocities in the [100]- and [110]-directions has been measured in single crystals of argon in a temperature range from 4.2 K to 77 K by stimulated Brillouin scattering. From the data for the sound velocities and previous data for the bulk modulus, the elastic constants C_{11}, C_{12} and C_{44} can be determined in the temperature range from 4.2 to 77 K.

The short range, weak interatomic forces which characterize the atoms of the rare gases and the simple fcc structure of the solids lend themselves the theoretical models.

Working with these crystals involves a not neglectable number of experimental difficulties, due to low melting points, high vapor pressure and very large coefficients of thermal expansion.

Here is reported the first measurement of the temperature dependence of the elastic constants of solid argon by stimulated Brillouin spectroscopy. The temperature dependence was determined in the range from 4.2 K to 77 K. This light scattering technique has several distinct advantages for studies of lattice properties of rare gas solids.

In our experiment we used an optical arrangement as described in [1–3]. The beam of a single mode giant pulse ruby laser with a peak power of 5 MW and a pulse duration of 20 nsec, $\lambda = 6943$Å, beam divergence about 1 mrad, was brought to a focus inside the samples by a lens. The backscattered Brillouin light together with the incident light was recorded photographically by a Fabry-Pérot interferometer. The frequency shift $\Delta\nu$ (Hz) which was determined to an accuracy of about ± 0.3% is related to the hypersonic velocity V by $\Delta\nu = 2nV/\lambda$. The value of the refractive index n was taken from measurements by Smith et al. [3] and Sinnock et al. [4].

The argon samples were grown in a cryostat described by Gsänger et al. [6]. It was possible to show with neutron Bragg scattering and neutron photography at 4K that the measurements of the Brillouin scattering reported here were taken in the [100]-direction and [110]-direction of the single crystals with an error of about ± 1°. Measurements in the [110]-direction were taken on two separate crystals having an estimated volume of approximately 9 and 8 cm^3. The crystal for the [100]-direction had a volume of about 11 cm^3.

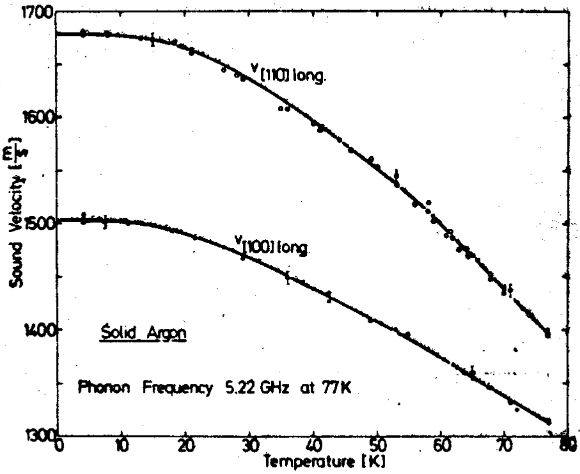

Fig. 1. Sound velocity in single-crystal argon versus temperature. The longitudinal sound wave propagating in the [100]-direction and the [110]-direction was studied. The open and full circles refer to measurements at decreasing and increasing temperature, respectively.

*This work was supported by the Deutsche Forschungsgemeinschaft.

**This work is part of a Ph.D. thesis.

The sound velocity versus temperature are plotted in fig. 1. All data were taken by shooting into the same region of the samples. The laser intensity was low enough so as to not induce dielectric breakdown in the crystals. The values of the elastic constants C_{11}, C_{12} and C_{44} represented in fig. 2 were obtained by using the well-known relations:

$$\rho V^2_{\mathrm{long}[100]} = C_{11}$$

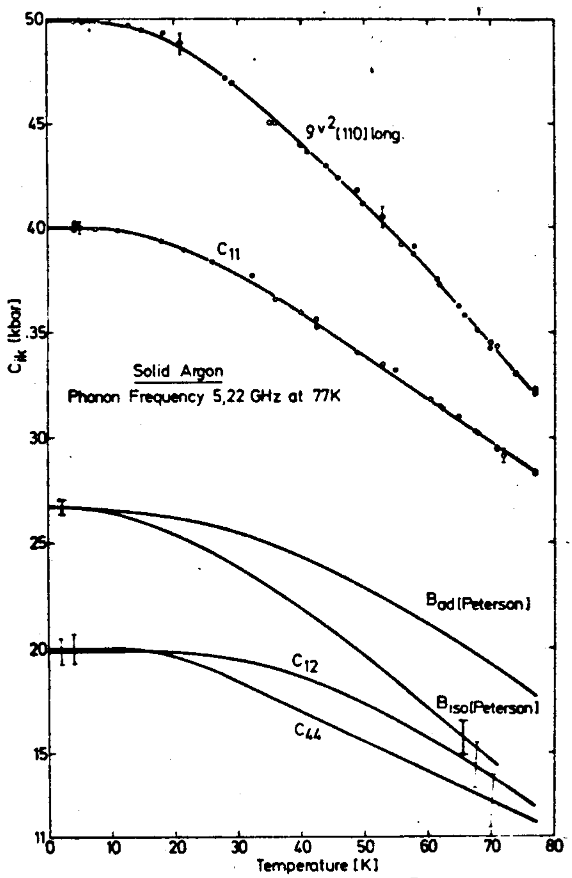

Fig. 2. The elastic constants C_{11}, C_{12} and C_{44} in solid argon versus temperature. We have also plotted $\rho V^2_{\mathrm{long}[110]}$ and the bulk modulus $B^{\mathrm{ad,\,iso}}$ [7] against the temperature. The open and full circles refer to measurements at decreasing and increasing temperature, respectively.

$$\rho V^2_{\mathrm{long}[110]} = \tfrac{1}{2}\,(C_{11} + C_{12} + 2C_{44}).$$

Using the expression for the bulk modulus with the values for B^{ad} from Simmons et al. [7]

$$B^{\mathrm{ad}} = \tfrac{1}{3}\,(C_{11} + 2C_{12})$$

the three elastic constants can be determined. The elastic anisotropy A at $T = 0\mathrm{K}$ is obtained

$$A = 2C_{44}/(C_{11} - C_{12}) = 1.9 \pm 7\%$$

and the deviation δ from the Cauchy relation amount to:

$$\delta = (C_{44} - C_{12})/C_{44} = 0.002 \pm 0.005.$$

With the C_{11}, C_{12} and C_{44} we obtain the Debye temperature θ^D_0 for $T = 0\mathrm{K}$ using a relation given by De Launay [8] and Leibfried [9]

$$\theta^D_0 = 93^\circ \pm 2^\circ\mathrm{K}.$$

We like to thank Professor Dransfeld for his interest in this work, Dipl.-Phys. H.J. Coufal and Dipl.-Phys. H. Peter for experimental assistance.

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