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Study of Electron-Phonon Interactions in III-V Semiconductors

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Experimental Investigation of the Electron-Phonon

Interaction in III-V Semiconductors

Introduction

This quarterly report presents the final measurements of the attenuation of 9.3 kmc phonons in Tourmaline as a function of temperature. The temperature dependence of attenuation in quartz was also measured. Both materials showed an approximate T^7 dependence at low attenuation levels. The Tourmaline leveled off to $T^{0.8 \pm 0.1}$ at 95°K and the quartz gradually changed to $T^{4.0 \pm 0.5}$ at 41°K. Below 35°K the quartz attenuation was lower than Tourmaline but above this temperature the Tourmaline attenuation was lower.

Progress is reported on InSb preparation with a rod from InSb crystal C now ready for 9.3 kmc acoustic measurements. Report is also made of an unsuccessful attempt to detect microwave phonon propagation in a rod from InSb crystal A with higher sensitivity than used previously. This set a lower limit to the attenuation at 10 db/cm.

Attenuation measurements of 10 mc acoustic waves are reported down to 77°K for InSb and down to 4°K for GaAs.

1. 9.3 Kmc Phonons

Temperature Variation of Attenuation in Tourmaline and Quartz

Preliminary measurements of the temperature dependence of phonon attenuation in Tourmaline crystals were presented in the previous quarterly report.

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These data showed a tendency for a decrease in slope of the attenuation curve as the temperature increased. There also appeared to be a difference in the attenuation/cm when looking at the first echo as compared with the second echo. This seemed to imply a change in transducer loss with temperature.

A considerable improvement, in this period, was made in the sensitivity of the equipment and in the accuracy of the measurements. The decrease in slope with increasing temperature was indeed confirmed and the measurements extended to higher temperatures as shown in Fig. 1. The apparent change in transducer loss with temperature was shown to be an effect, as postulated in the last report, of the interference of the receiver saturation with the first echo.

The interference of receiver saturation with the first echo was reduced considerably by setting up the equipment for more precise tuning. The rf coupling into the cavity was adjusted by a fine adjustment to get exact critical coupling. This meant less reflection of the main pulse back into the receiver. The critical coupling also required maintaining the magnetron frequency exactly at the cavity resonant frequency . This was done by continuously monitoring the reflected pulse from the cavity and tuning to keep it minimized. A microwave diode switch was also added in the receiver line to provide an additional 20 db attenuation of the main pulse into the receiver. Thus the receiver saturation was reduced considerably such that there was no interference with the first echo.

Once the first echo was cleaned up in this way it became clear that the values of attenuation in db/cm were the same within experimental errors for the first echo as for the other echos. It was also possible to extend the measurements to higher temperatures going all the way to $94^{\circ}K$ before the first echo became too small to measure.

Attenuation measurements were also made on quartz* for the sake of comparison. The results, shown in Fig. 1, which we obtained for quartz were consistent with those of Pomerantz[1] which were shown in the previous report. However, Pomerantz's data covered a range from 1 db/cm to 8.5 db/cm whereas our measurements extend from 0.03 db/cm to 20 db/cm. The slope starts out at $T^{7.1 \pm 1.2}$ near 0.6 db/cm and gradually goes down to $T^{4.0 \pm 0.5}$ in the region between 10 and 20 db/cm.

It is worthwhile at this point to discuss the way in which these measurements of attenuation were made. Starting at the boiling temperature of helium, 4.2°K, the amplitudes of various echoes as seen on an oscilloscope display of the detected output of a superheterodyne receiver were compared with the amplitudes of pulses sent thru the same receiver by a standard signal generator. Thus, a reading in dbm was obtained for each of a selected number of echoes at 4.2°K. Then as the temperature was increased the loss for each echo was recorded as the difference between the reading in dbm for that temperature and the reading at 4.2°K. These measurements thus represent the attenuation relative to that at 4.2°K. For the green tourmaline, the first, second, third, seventh and eleventh echoes were recorded. The eleventh echo was followed up to 8.7°K, the seventh up to 12.8°K, the third up to 21.3°K, the second up to 35.0°K, and the first up to 94°K. Thus it was possible to get reasonably accurate attenuation values over

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*obtained from Industrial Optics Co., Bloomfield, N. J.

(1) M. Pomerantz, Temperature Dependence of Microwave Phonon Attenuation, Phys. Rev. 139, A501 (1965)

a wide dynamic range. With the quartz the fifteenth echo was followed up to 24.9°K, the sixth up to 28.6°K, the third up to 33.8°K, the second up to 36.9°K and the first up to 44.1°K.

It is interesting to compare our results for tourmaline and quartz with some of the generalizations deduced by Pomerantz [(1)] from his measurements of attenuation as a function of temperature in a variety of materials. For longitudinal waves in various materials Pomerantz quoted attenuations all proportional to T^n with an average value $\bar{n} = 4.8 \pm 1.4$. His data for quartz e.g. involves four points. The straight line which he draws thru these appears to have a slope of $T^{4.4}$. However, as was noted earlier, these points cover a rather limited dynamic range. Therefore, it is clear from examining Fig. 1 that his data is quite consistent with ours although we can definitely see a change of slope in our data while this is not obvious in his.

In our tourmaline measurements the change of slope is, of course, very obvious. The basic theory for scattering of acoustic phonons by thermal phonons of Landau and Rumer[(2)] predicts a T^4 dependence for three phonon scattering. (a thermal phonon and acoustic phonon scatter to produce a second thermal phonon.) However, they show that this theory applies only to transverse acoustic phonons. In order to get scattering of longitudinal acoustic phonons according to Pomeranchuk[(3)] one must have a four phonon process which leads to a T^7 dependence.

[(2)] L. Landau and G. Rumer, Sound Absorption in Solid Bodies, Phys. Z. Sowjetunion, 11, 18 (1937)

[(3)] I. J. Pomeranchuk, J. Phys. (USSR) 4, 259, 529 (1941); 6 237 (1942)

It is very suggestive that our data show a dependence near T^7 for both quartz and tourmaline at the lower temperature. However, it must be pointed out that several authors[4] have discounted the necessity of invoking a four phonon process for scattering of longitudinal acoustic waves, due to the finite life-times of the thermal phonons and the resulting quantum mechanical uncertainty in their energy.

The Landau and Rumer theory applies only well below the Debeye temperature where dispersion effects are not important. They point out that in the high temperature limit the attenuation should approach a slope of T to the first power. It is also suggestive that our tourmaline data reach a slope of $T^{0.8 \pm 0.1}$ at $\sim 90^{\circ}$K. This would imply a Debeye temperature of 10-15°K for tourmaline - considerably lower than the value of 860°K obtained from the Lindeman melting temperature formula[5]. Incidentally, Pomerantz's prescription that the Debeye temperature is about 10 times the 3 db/cm temperature leads for tourmaline to $\Theta_D = 190^{\circ}$K and for quartz $\Theta_D = 290^{\circ}$K.

Preparation of InSb for 9.3 Kmc Phonon Propagation

A significant improvement was accomplished in the polishing of a rod from InSb crystal C. The difficulty discussed previously in development of a concave surface was eliminated by replacing the pyrex glass mounting blank with a lead

(4) I. S. Ciccarello and K. Dransfeld, Ultrasonic Absorption at Microwave Frequencies and at Low Temperatures in MgO and Al_2O_3, Phys. Rev. 134, A1517 (1964)

(5) J. M. Ziman, Electrons and Phonons. Oxford at the Clarendon Press (1960)

glass blank as suggested in the previous report. Thus an InSb crystal 0.25 cm long with surfaces flat to $\sim$500 Å and parallel to 0.3 minutes of arc was obtained and will be tested for acoustic propagation.

Another attempt was made at propagating 9.3 Kmc phonons thru an InSb rod from crystal A. An input pulse 20 db larger than used in the previous attempt was applied to the quartz transducer crystal. The quartz transducer was significantly better than the one used in the previous attempt having an overall loss of 62 db as opposed to 76 db for the previous test. (This transducer was similar to the quartz rod which was used for the temperature dependence discussed above). The total loss in the transducer plus 2.80 cm long InSb crystal for the expected first echo was greater than 117 db which represented the limit of sensitivity of the system. Thus the attenuation in InSb was greater than 10 db/cm.

2. <u>10 mc Phonons</u>

The holder for making 10 mc phonon attenuation measurements discussed in the previous report was used successfully for measurements on GaAs down to 4.2°K. The 3/8" diameter 10 mc quartz transducer was bonded onto the crystal with Dow Corning's DC-200 fluid having a viscosity of 30,000 cs. No difficulty occurred with transducer ringing as experienced previously with DC-200. However, with Nonaq Stopcock grease this occurred repeatedly in the region near 120°K.

The attenuation data for GaAs and InSb are shown in Fig. 2 and, as expected at this frequency, shows no appreciable change with temperature. Measurements down to 4°K were made only with the GaAs by this writing, but they will be completed for InSb and InAs shortly.

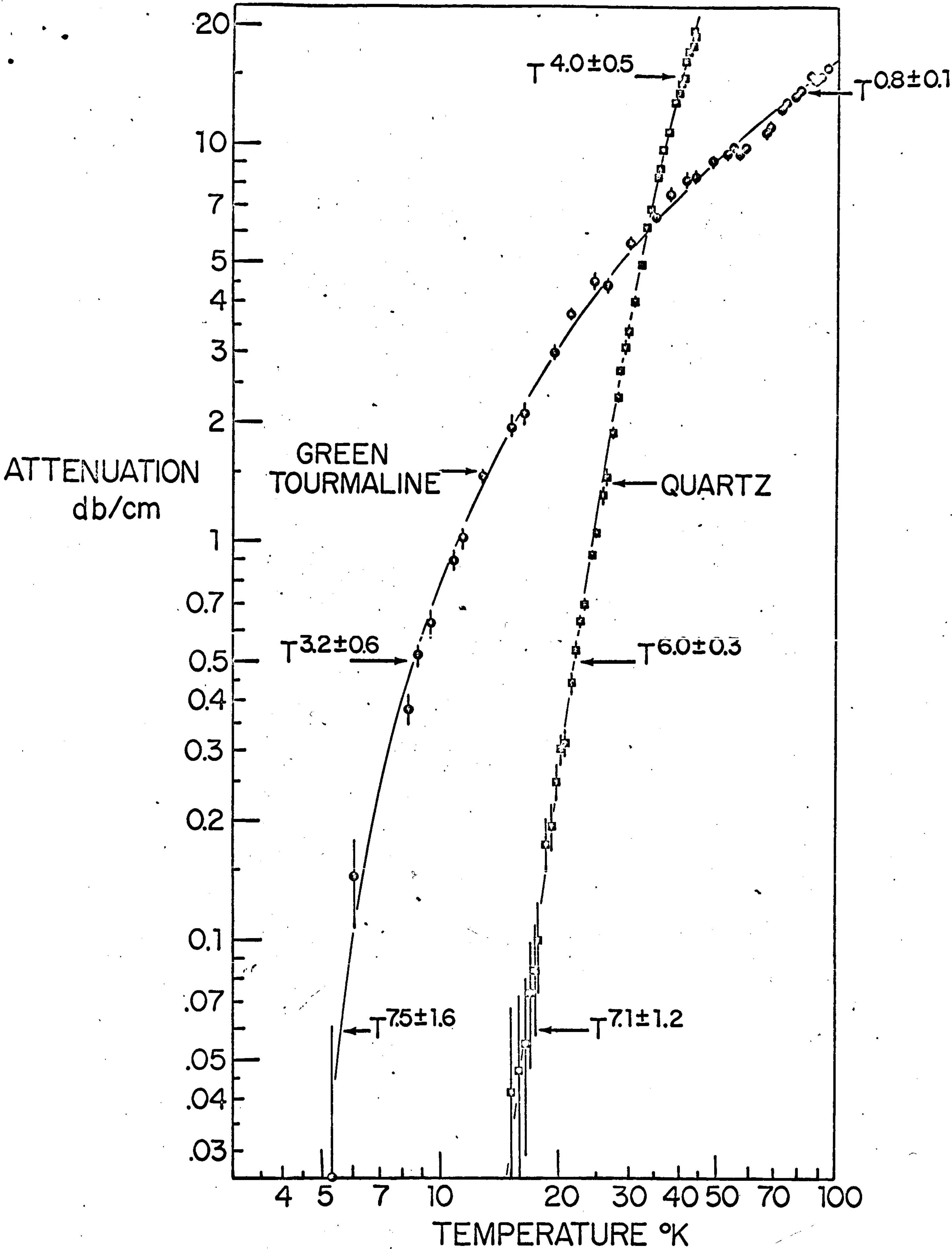

Fig. 1. 9.3 Kmc phonon attenuation in tourmaline and quartz.

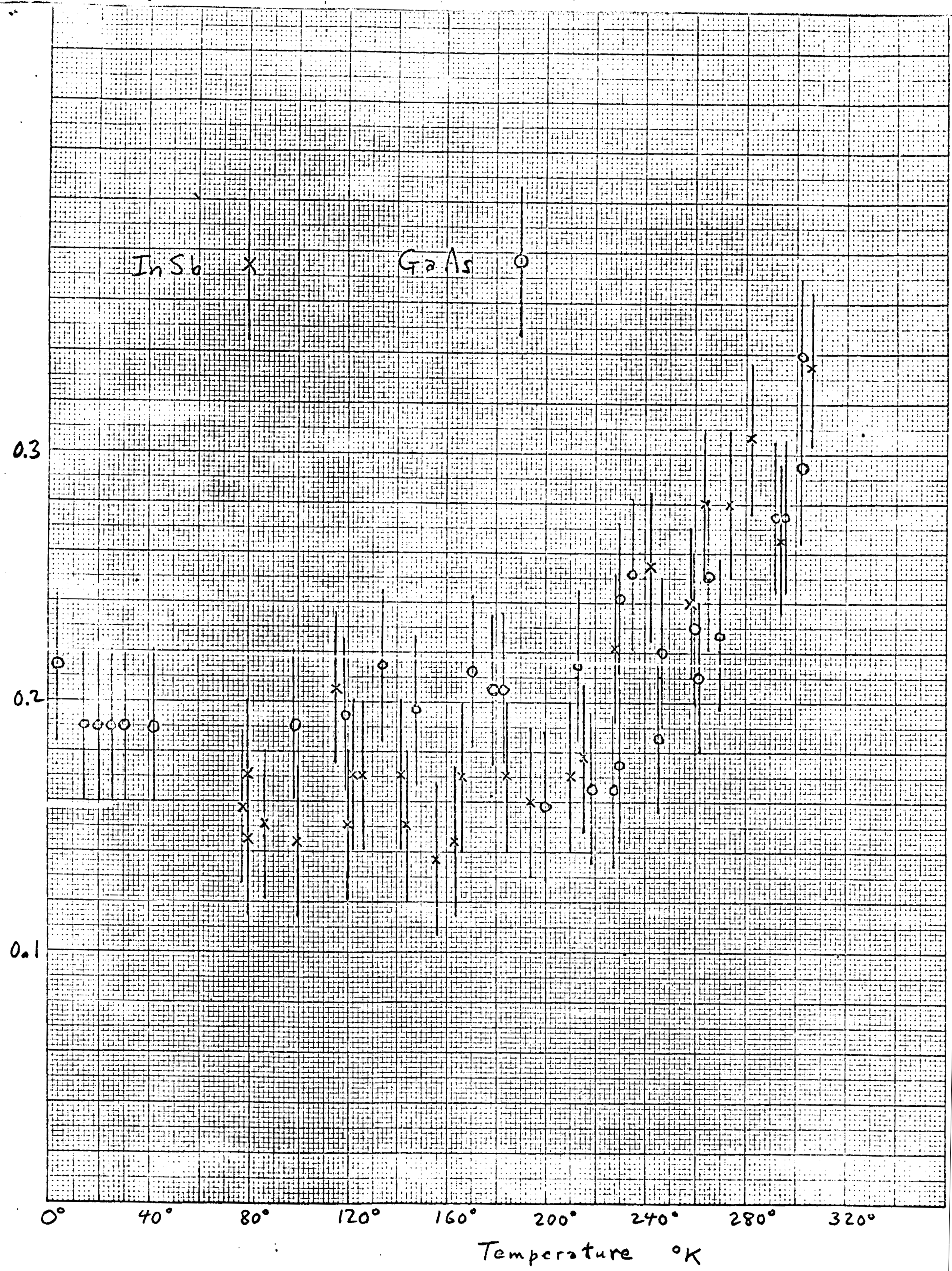

Fig. 2. Temperature dependence of attenuation of 10 mc phonons in InSb and GaAs.