# The Effect of Temperature Gradient on Ultrasonic Attenuation

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## Synopsis

The effect of temperature gradient on ultrasonic attenuation is estimated based upon the simple phenomenological theory, and it being found that the attenuation coefficient for a CdS crystal is 0.76 dB/cm at temperature gradient 100 K/cm.

It is quite well known that an injected ultrasonic wave attenuates in propagating in solids,[1] which is for example due to the electron= phonon interaction through the deformation potential, piezoelectric potential, impurity scattering and so forth.  On the other hand, the amplification of ultrasonic wave was found in semiconductors and semi- metals as functions of the velocity of sound and the velocity of electrons driven by an external electric field or an electric and magnetic field.

Here in this report we examine the effects of temperature gradient on the ultrasonic attenuation under an external electric field in the x-direction, using the phenomenological method,[2,3] so that $\omega$ , the angular frequency of ultrasonic wave, is limitted to rather the low frequency.  The attenuation of ultrasonic wave by temperature gradient may be figured out at a physical consideration more or less.  It means the energy loss of ultrasonic wave by the diffusion due to the temper-

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ature gradient.  A certain merit in finding the temperature gradient
will be promised under a condition $v_s = v_d$, where $v_s$ is the sound velocity
and $v_d$ is the electron drift velocity.

The force by a temperature gradient is simply expressed through a
pressure gradient, therefore the linearized force is written down as,
for N-electron system,[3]

$$F = - \nabla_x p/m^* = - (k_B n/m^*)[ iqT + \partial T/\partial x ],\qquad\qquad (1)$$

where $p = n k_B T$ [perturbed electron density n varies as $\exp[i(qx - \omega t)]$] is
the pressure, T is the lattice temperature and $\partial T/\partial x$ is a x-component
of temperature gradient.  Then one can easily obtain the amplification
coefficient of ultrasonic wave in the fashion similar to Ref.(3):

$$\alpha = \frac{\omega^2 K^2}{v_s} \omega_p^2 \tau_{eff} \sqrt{[ \{\omega_p^2 \tau_{eff} + \frac{k_B T}{m^*} \tau_{eff} \frac{\omega^2}{v_s^2} \}^2 + \omega^2 \gamma^2 ]},$$

$$\tau_{eff}^{-1} = \tau^{-1} + \frac{k_B}{m^* v_s \gamma} \frac{\partial T}{\partial x} , \qquad \gamma = 1 - v_d/v_s \; . \qquad\qquad (2)$$

The symbols K and $\omega_p$ are the electromechanical coupling constant and
the plasma frequency, respectively.  The others are the usuals.
Accordingly the temperature gradient results in the ultrasonic wave
attenuation.  We study the temperature gradient explicitly in eq.(2) by
putting $v_d = v_s$.  Then the more inspectional relation is obtained:

$$\alpha = K^2 ( \omega/\omega_p v_s )^2 \frac{\partial}{\partial x} [k_B T/m^*] ,\qquad\qquad (3)$$

when     $(\frac{\omega_p v_s}{\omega})^2 > k_B T/m^*$ ,     $\frac{v_s}{\omega} \frac{\partial}{\partial x} [k_B T/m^*]$ ,

which is quite independent of the electronic loss in the absence of the temperature gradient. By the inspection of eq.(3) the electromechanical coupling constant K must be large for the observation of ultrasonic attenuation. $\alpha$ will be calculated for InSb and CdS as examples. Let us take the physical constants as the following,

|  | InSb | CdS |
|---|---|---|
| elastic constant $c_1$ (N/m$^2$) | $3.07 \times 10^{10}$ | $e_1{}^2/c_1 =$ |
| piezoelectric constant $e_1$ (C/m$^2$) | 0.144 | $1.99 \times 10^{-12}$ |
| sound velocity $v_s$ (m/sec) | $2.28 \times 10^3$ | $1.75 \times 10^3$ |
| carrier density N(/m$^3$) | $1 \times 10^{19}$ | $1 \times 10^{19}$ |
| angular frequency $\omega$(rad/sec) | $5 \times 10^9$ | $5 \times 10^9$ |

The results of eq.(3) is, at temperature gradient 100 K/cm :

$\alpha$[InSb] = 0.15 dB/cm,          $\alpha$[CdS] = 0.76 dB/cm,

and at 500 K/cm:

$\alpha$[InSb] = 0.76 dB/cm,          $\alpha$[CdS] = 3.80 dB/cm.

In general, the effects of temperature gradient on ultrasonic attenuation is very small. However, for a sample which has the large electromechanical coupling constant such as CdS, one can investigate the interaction of electron diffusion and ultrasonic attenuation. The author is very grateful to Professor Y.Inuishi and Dr.F.Hashimoto for their encouragement. This work was partly supported by "THE SAKKOKAI FOUNDATION".

References
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