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TEMPERATURE - WAVE EFFECTS OCCURRING IN SEMICONDUCTORS WITH DEEP IMPURITY CENTERS UNDER PULSED HYDROSTATIC COMPRESSION**R. Khamidov¹, O. Mamatkarimov²**

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Abstract. *In this work are considered for the first time thermal vibrational and wave processes occurring in a silicon crystal lattice with nickel impurities that create deep energy levels in its band gap under pulsed hydrostatic compression. Theoretical calculations showed that the increase in temperature of the samples under dynamic compression is mainly associated with a change in the temperature of the surrounding fluid. The derived differential equation shows that at dynamic pressure (at high rates of rise of hydrostatic pressure), wave thermodynamic processes occur.*

Keywords: *Semiconductors, deep levels, nickel impurities, hydrostatic pressure, hydrostatic compression, pulsed pressure, relaxation effect, strain effect, oscillatory processes.*

It is known [1-5] that in semiconductor materials with impurities that create deep energy centers in its volume, even at room temperatures, deep-lying centers can be in an incompletely ionized state. This is what makes such materials sensitive to external influences. They, when exposed to pulsed hydrostatic pressure to this kind of semiconductor materials, are subjected to two external influences at once. This is the effect of hydrostatic deformation and temperature stimulated by impulse pressure.

Let's try to understand what happens in the volume of a semiconductor material with deep impurity levels under pulsed hydrostatic pressure. In the process of exposure to hydrostatic pressure, the semiconductor material is in a liquid environment. Under the impulse action of external deformation, the volume of the semiconductor and the liquid decreases adiabatically and this leads to different energy and thermodynamic effects.

The formula for changing the temperature of the liquid can be written according to [6] as follows:

$$dT(P) = \frac{\alpha v T}{c_p} dP \quad (1)$$

Here $dT(P)$ is the temperature increment at an adiabatic pressure increment dP , α is the expansion coefficient at constant pressure, v is the specific volume of the liquid ($v = \frac{1}{\rho}$), T is the initial temperature, and c_p is the specific heat capacity at constant pressure.

If we do not take into account the dependence of the specific volume on pressure, formula (1) can be rewritten as follows:

$$\Delta T(P) = \frac{\alpha v T}{c_p} \Delta P \quad (2)$$

Here ΔT is the change in temperature at the amplitude of pressure rise.

Using this formula, you can roughly calculate how many degrees the liquid will heat up at different amplitudes of dynamic pressure. It can be seen from the formula that the temperature change values do not depend on the pressure change rate. If the process of liquid compression is carried out in a thermally insulated system without heat exchange with the external environment, then the temperature change depends only on the amplitude of the pressure rise. At lower rates of pressure rise, heat exchange of fluid with the external environment occurs.

At lower rates of pressure rise, it is necessary to take into account the process of heat exchange with the external environment. To do this, we write the non-stationary heat conduction equation for a liquid [7].

$$\frac{\partial T}{\partial \tau} = \frac{\chi}{\rho c_p} \frac{\partial^2 T}{\partial x^2} + Q \quad (3)$$

In this formula, Q is the heat of internal sources, ρ - is the density of the liquid and χ is its thermal conductivity. In our case, there are no internal heat sources in the liquid ($Q = 0$). We write the left side of the formula in the following form

$$\frac{\partial T}{\partial \tau} = \frac{\partial T}{\partial P} \frac{\partial P}{\partial \tau} \quad (4)$$

Let's rewrite the formula

$$\frac{dT(P)}{dP} = \frac{\alpha v T}{c_p} \quad (5)$$

In our case, temperature is only a function of pressure. Therefore, we rewrite the last formula

$$\frac{\partial T}{\partial P} = \frac{\alpha v T}{c_p} = \frac{\alpha T}{\rho c_p} \quad (6)$$

We rewrite formula (3) taking into account (4) and (6)

$$\frac{\partial T}{\partial P} \frac{\partial P}{\partial \tau} = \frac{\chi}{\rho c_p} \frac{\partial^2 T}{\partial x^2} \quad (7)$$

Here $\frac{\partial P}{\partial \tau} = v_p$ is the rate of pressure rise.

Thus, we can write the equation of thermal conductivity taking into account the rate of pressure rise.

$$v_p \frac{\partial T}{\partial P} = \frac{\chi}{\rho c_p} \frac{\partial^2 T}{\partial x^2} \quad (8)$$

If we put (6) in (8), then the heat conduction equation for the process of fluid compression comes to equilibrium at constant α , v_p , and χ

$$v_p \alpha T = \chi \frac{\partial^2 T}{\partial x^2} \text{ or } \frac{\partial^2 T}{\partial x^2} - \frac{\alpha v_p}{\chi} T = 0 \quad (9)$$

Denoting the constants in this formula, we bring the equation to the standard form.

$$\sqrt{\frac{\alpha v_p}{\chi}} = k \frac{\partial^2 T}{\partial x^2} - k^2 T = 0 \quad (10)$$

The coefficient k by its nature is the wave vector of elastic waves, which depend on the rate of pressure rise. At high rates of rise, the impact pressure propagates as elastic waves. And with a very slow change in external pressure ($v_p \approx 0$), elastic waves are insignificant or absent altogether. In this case, the thermodynamic process occurring during static compression of a liquid can be considered equilibrium and equations (10) take the form:

$$\frac{\partial^2 T}{\partial x^2} = 0 \quad (11)$$

Thus, differential equation (10) is the heat conduction equation for dynamic (adiabatic) and (11) for static (isothermal) compression of a liquid.

The change in the temperature of a semiconductor during dynamic compression in a liquid medium consists of two parts. This is due to the adiabatic decrease in its volume and due to the ambient temperature, which can be approximately calculated using formula (2).

$$\Delta T = \Delta T_L + \Delta T_C \quad (12)$$

Here ΔT is the total change in the temperature of the semiconductor material, ΔT_L is the change in temperature due to a change in the temperature of the liquid, ΔT_C is the change in temperature due to a decrease in the volume of the semiconductor crystal. A change in the crystal temperature due to a decrease in its volume can be neglected, since at an external hydrostatic pressure the decrease in volume is insignificant.

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