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## Deformation Methods for Investigation of the Deep Level Parameters in Semiconductors

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### Abstract

In this paper deformation methods are offered to investigate deep level parameters in semiconductors. It is based on strain parameters measurements of compensated and overcompensated semiconductors. The dynamic changes of current flow in compensated and overcompensated samples of  $p$ -type  $Si : Ni$  and  $n$ -type  $Si : Mn$  under uniform pulse hydrostatic compression (UHC) was investigated. It was observed that in  $p$ -type  $Si : Ni$  samples ionization energy levels  $Ni$  at UHC increases, on the contrary in samples  $n$ -type  $Si : Mn$  it decreases. The ionization energy and baric coefficient of the shift of  $Ni$  and  $Mn$  levels were bounded.

### 1. Introduction

Over the pulse regime of the action of uniform hydrostatic pressure (UHP) in semiconductors with deep impurities levels, resulting combined strain-thermo-effect causes additional change of conductivity in semiconductors bound with various degrees of filling of the deep levels [1]. Therefore, a deformation technique is proposed allowing investigation of not only the baric changes in semiconductors but also enables to determine ionization energy, concentration and other deep level parameters without using additional techniques such as the temperature dependence of Hall effect capacity spectroscopy, DLTS, etc. [2].

## 2. Samples and Methods of Measurements

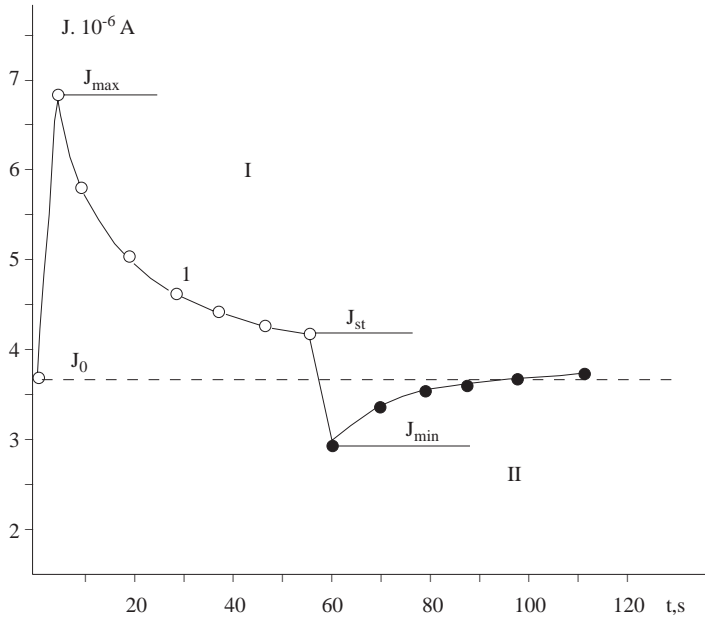
The present method is based on measuring the strain parameters of compensated and overcompensated semiconductors. During the investigation we used samples of  $p$ -type Si:Ni and  $n$ -type Si:Mn silicon with resistivity  $\rho = 10^5 \Omega \times cm$  obtained on a monocrystal silicon base, using KEF-15 and KGD-4 technology as described in [3].

The investigated silicon samples had the shape of a parallelepiped with dimensions  $2 \times 2 \times 4 mm^3$ . To measure the temperature of samples during the process a copper/constantan thermocouple was tightly pressed to the surface of the sample. To prevent thermal scattering and to increase the accuracy of the temperature measurements the samples were wrapped up with a thermocouple in a thermal-insulation envelope formed of epoxy glue. The reference thermocouple was held at  $0^\circ C$ . Control measurements of the electrical conductivity and temperature of a sample-thermocouple system while under application of pressure impulses showed that they are changed simultaneously over the interval  $T = 243 \div 293 K$  and  $P = (0 \div 5) \times 10^8 Pa$ . The required external pressures were produced via installation of a UHP with pneumatic-amplifier [4] which created pressure pulses with slew rate  $\partial P/\partial t = 10^8 Pa/s$  in the temperature interval  $T = 273 \div 293 K$ .

## 3. Experimental Results

$I = f(t)$  kinetics for a  $p$ -type Si:Ni sample over the range of impulse action (region 1) and while under UHP (region 2) at the initial operating temperature of  $T_0 = 273 K$  is shown in Figure 1. Measurements showed that when the pressure increases in the interval  $P = (0 \div 5) \times 10^8 Pa$  the temperature of samples abruptly increase to  $T_{max}$ , a value ranging from 243 K to 293 K and depending on pressure and  $\partial P/\partial t$ . The value of current in samples increases from  $I_0 = 3,7 \times 10^{-6} A$  to  $I_{max} = 6,8 \times 10^{-6} A$  according to the temperature of samples (Fig. 1 region 1). After removal of pressure the temperature of a sample relaxed to its static values over during  $50 \div 60 s$  at  $P = (0 \div 5) \times 10^8 Pa$ .

Unlike the influence of UHP, when reducing pulsed pressure the value of temperatures and current of samples are first lower to values  $T_{min}$  and  $I_{min}$ , respectively, from which they relax to their initial values, i.e. to  $T_0$  and  $I_0$  (Fig. 1, region 2). Similar dependence of  $I = f(t)$  under similar conditions under UHP were obtained for  $n$ -type Si : Mn samples. Measurements of the Hall effect in  $p$ -type Si : Ni and  $n$ -type Si : Mn samples under UHP impulse action at temperatures  $T_0, T_{max}$  and  $T_{min}$ , i.e. at the extreme point changes of  $I_{max}$  and  $I_{min}$ , showed that the change of current in the samples is essentially due to the change of carriers current concentration ( $\approx 96\%$ ), since under these experimental conditions their mobility changes slightly ( $\approx 4\%$ ).



**Figure 1.** Kinetics of current flow in the  $p$ -type  $Si : Ni$  samples under pulse action (1) and removal of UHP with  $\partial P/\partial t = 10^8 Pa/s$  velocity at initial operating temperature  $T_0 = 273K$

#### 4. Experimental Result Processing

The dynamical changes of conductivity of current in overcompensated samples of  $p$ -type  $Si : Ni$  and  $n$ -type  $Si : Mn$  for impulse UHP can be presented in the form [6]:

$$I = Ue\mu n(P, T) \times S/L = Ue\mu n_0[\exp(-E_i - \alpha_i P)/kT] \times S/L, \quad (1)$$

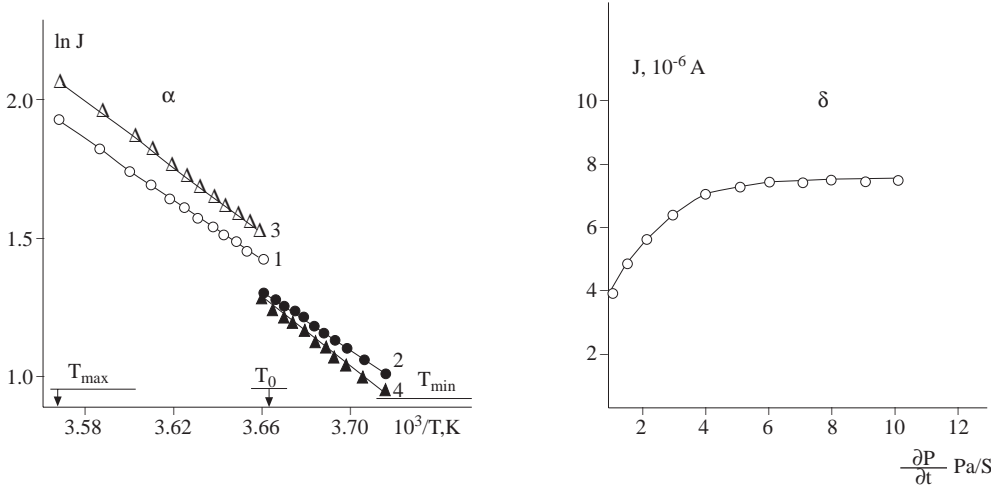
where  $U$  is the voltage applied to sample;  $S$  and  $L$  are cross-section and length of sample;  $e, \mu, n$  are charge, mobility and concentration, respectively, of carriers of current,  $E_i$  and  $\alpha_i$  are values of the energy of an impurity level and pressure of this level, respectively;  $P$  is the value of UHP;  $T$  is the temperature of a sample; and  $K$  is Boltzmann constant. By taking the logarithm and differentiating with respect to temperature expression (1) can be rewritten as:

$$\partial(\ln J)/\partial E = \partial(\ln Ue\mu n_0 S/L)/\partial E - k^{-1}(E_i - \alpha_i P)(\partial(1/T)/\partial T). \quad (2)$$

Taking into account  $\partial(\ln Ue\mu n_0 S/L)/\partial T \approx 0$  for ionization energy of impurity levels  $E_i$  we have:

$$E_i = -k[\partial(\ln I)/(\partial T)(\partial(1/T)/\partial T)] + \alpha_i P. \quad (3)$$

From this one can see that  $E$  depends on the velocity change of  $I$  and  $T$ . Temperature dependencies of current in the samples  $p$ -type  $Si : Ni$  (curve 1 and 2) and  $n$ -type  $Si : Mn$  (curve 3 and 4) are given in Fig. 2(a). They correspond to the experimental results of relaxed regions 1 and 2 in Fig. 1. Ionization energy levels for  $Ni$  and  $Mn$  as a function of their baric shift coefficient are defined according to expression (3) and the experimental results are given in Fig. 2. Energy levels  $E_{Ni} = 0.42eV$  and  $E_{Mn} = 0.52eV$  were composed using  $\alpha_{Ni} = 1.2 \times 10^{-11} eV/Pa$  and  $\alpha_{Mn} = 1.8 \times 10^{-11} eV/Pa$  respectively. These results confirm those of the authors in [3, 4].



**Figure 2.** a) Temperature dependence of current in  $p$ -type  $Si : Ni$  samples (1, 2) and  $n$ -type  $Si : Mn$ (3,4) under UHP (1, 3) action and absence of pressure (2, 4) at  $T_0 = 273K$ . b) Dependence of amplitude values on current in  $p$ -type  $Si : Ni$  samples on the velocity of UHP pressure change with an amplitude of  $P = 5 \times 10^8 Pa$  at  $T_0 = 273K$

The maximum current as a function of pressure change velocity at UHP  $I_{max} = f(\partial P/\partial t)$  with amplitude  $P = 5 \times 10^8 Pa$  in  $p$ -type  $Si : Ni$  samples with initial operating temperature  $T = 293K$  is plotted in Fig. 2(b). One can see that the current amplitude maximum values monotonically increases with velocity and, at certain values, the change of current depends on velocity ( $\partial P/\partial t = 10^8 Pa/s$ ), resulting in the plateau observed in  $I(P)$ . Analysis of experimental data shows the plateau appears to be independent for  $I_{max} = f(\partial P/\partial t)$  and linked with full atom ionization in the  $Ni$  impurity levels in  $Si$ .

In the studied system, i.e.  $p$ -type  $Si : Ni$ , the electrical neutrality equation of carrier current in the region full of "feeble"  $Ni$  levels may be written [5]:

$$p = N_A - N_D,$$

where  $N_A = N_D + p$  and where  $N_D$  is small donors concentration, and  $N_A$  is the compensated acceptors of impurities concentration. In investigated samples of  $p$ -type

$S_i : N_i$  the full concentration of electrically active atoms proves to be equal to  $3,47 \times 10^{14} \text{cm}^{-3}$ , and is in good agreement with the data in [6].

## 5. Conclusion

The studied method of the pulse action UHP may be used successfully to determine some baric deep level parameters via baric measurements in semiconductors.

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