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ELECTRON EMISSION FROM EXTENDED DEFECTS IN DLTS EXPERIMENT*

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Dislocations parallel to a Schottky junction are considered as an example of well defined extended defects, and their behaviour in DLTS experiment is examined. A possibility of electron hopping between different traps of the defect, and inter-electronic Coulomb interaction are taken into account. Thermal electron emission from the considered defects is no longer exponential with time and consequences of this fact are discussed.

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Deep Level Transient Spectroscopy (DLTS) is now a widely used method for studying point defects (traps) in semiconductors. It is based on examination of the thermal emission of electrons from the traps to the conduction band (or holes to the valence band) and exploits the Schottky junction capacitance as a measure of the number of charges trapped within the space charge region of a junction. The standard DLTS procedure assumes that the capacitance transient connected with the electron emission from the traps obeys the exponential decay law. When the transient is nonexponential, the DLTS linewidth is anomalously broadened, and the physical meaning of an activation energy determined from the Arrhenius plot is not defined. That is just the case of so-called extended defects, i.e. the defects composed of a number of traps so closely spaced that interaction between them cannot be neglected. Well defined extended defects are dislocations and they are the object of the present considerations.

According to Read [1], a dislocation in n-type semiconductor is treated as a linear arrangement of evenly spaced traps. Those traps accept electrons from the conduction band, so that the dislocation becomes negatively charged line and is surrounded by a positive space charge cylinder of ionized donors. At T=0 K the trapped electrons are evenly spaced, and if c is the spacing between adjacent

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electrons on the line, and a the spacing between adjacent traps, the occupation fraction is $f = a/c$.

A change in the electrostatic energy of a charged dislocation caused by increase of the number of trapped electrons by one, assuming equidistant charge distribution, can be expressed as the sum of two components

$$q\phi(f) + (q^2/\varepsilon a)f,$$

where q is the electronic charge, and ε the dielectric constant, ϕ is the potential at a trapped electron caused by the other electrons on the line and the positive space charge, and $(q^2/\varepsilon a)$ is the energy of electrostatic interaction of two adjacent charges on the line. It is important that the latter energy will be regained when an electron is emitted from the line - on the cost of a work done by the system which relaxes toward uniform charge distribution.

A uniform distribution of electrons on the line is realized only in equilibrium at T=0 K. As the temperature increases, electrons can move from equidistant positions, and additional energy of nonuniformity will appear, which can be expressed through the deviation of the spacing between adjacent electrons from its equidistant value $\Delta c_{i,i+1} = c_{i+1} - c_i$, as

$$U_n = N(q^2/\varepsilon a)f^2\sigma^2,$$

where σ stands here for the mean squared value of $\Delta c_{i,i+1}/c$, and N is the number of traps in the defect.

This nonuniform distribution is assumed to be the equilibrium distribution. Then, one can exploit the fact that for a given mean squared value, the Gaussian distribution is the most random at all, for which the configurational entropy is a maximum and equals [2]

$$S_n = Nfk\ln(\sigma\sqrt{2\pi e}),$$

where σ has now the meaning of the standard deviation of the distribution, k is the Boltzmann constant, and $e = 2.71\ldots$.

It is assumed further that the electrons rearrange themselves among different traps of a dislocation segment, during the emission process, so as to keep always an equilibrium distribution. It means that free energy of the electron system should be a minimum with respect to σ, which determines a relation between σ and f. Having U_n and S_n, the free energy of nonuniformity, G_n, is also known.

Consider now a dislocation in equilibrium with the matrix. Then, for a process in which an electron is transferred from the matrix to the dislocation, under constant temperature and pressure, the corresponding change in Gibbs free energy has to be zero

$$\zeta + q\phi(f) + (q^2/\epsilon a)f - \Delta H + T\Delta S + \Delta G_n(f) = 0$$

which determines the equilibrium occupation fraction f_o. Here ΔS is the ionization entropy, and ΔG_n is the change in Gibbs free energy of nonuniformity due to increase of the number of trapped electrons by one.

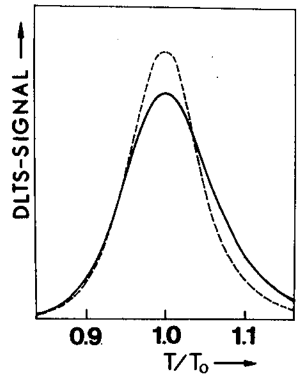

Fig.1. The DLTS line shape of an extended defect according to the present theory (solid line) in comparison with the line shape expected for isolated traps under the same experimental conditions (dashed line).

Making use of the derived relations, one can construct the rate equation for the capture-emission process at a dislocation segment and therefrom the equation describing emission of electrons

$$\mathrm{d}f/\mathrm{d}t = -2e_n^* f^{3/2}\exp[(q^2/\varepsilon a)f/kT],$$

where $e_n^* \sim \exp(\Delta S/k)\exp\{-[\Delta H + (q^2/\varepsilon a)f_o]kT\}$.

This nonlinear equation can often be simplified by neglecting $(q^2/\varepsilon a)f/kT$ compared with unity. But even then, the entropy factor which enters into it makes that the kinetics of electron emission is no longer exponential with time. The solution of the simplified equation is

$$f(t) = [e_n^* t + f(0)^{-1/2}]^{-2}.$$

One can examine now the impact of this type transient on the DLTS signal. The conclusions are following. The position of the DLTS-peak depends slightly on the initial occupation fraction. The DLTS peak is broadened and its shape is shown in Fig. 1. The activation energy determined from the Arrhenius plot corresponds to $\Delta H + (q^2/\varepsilon a)f_o$ instead of ΔH as in the case of simple point defects.

Actually, there are observed two electron traps in plastically deformed Si [3], and two traps in plastically deformed GaAs [4,5], which display the logarithmic filling law (characteristic of extende d defects) and moderate line broadening. These traps can be classified into the category of defects considered here. There is also observed a DLTS peak in deformed Si which has very unusual shape [3, 6]. As argued in [7], that peak corresponds to dislocations threading the space charge region of a diode and its shape is determined mainly by electron tunneling.

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