Review Report for the PhD thesis

"Enhanced charge carrier thermo-emission from the dislocation-related electronic states in silicon"

submitted by Maxim V. Trushin

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This work is devoted to the study of the dislocations in silicon that are not only extended defects, but also represent model quasi-one-dimensional systems. These defects are well-known to introduce both shallow and deep level states in silicon band-gap which are responsible for the luminescence and electronic properties that are of interest to create new devices such as the infrared sources and field-effect transistors. Recently, the well-controlled dislocation networks (DNW) with various filling with electrons and holes appear to be reproduced by the silicon direct bonding method. Owing to the development of the DNW method the author of this thesis could realize the goal of this work that was to investigate the enhancement of carrier thermo-emission from the sub-bands induced by dislocation deformation potential near both the conduction and valence bands in the silicon band-gap.

The thesis of Maxim Trushin consists of an Introduction, theoretical and experimental chapters and Conclusions.

The previous studies of the dislocation-related electronic states in the band-gap of silicon are discussed in an Introduction. Specifically, the review of the results obtained by the DLTS method for a row of shallow and deep traps that was detected in n- and p-type Si samples with dislocations introduced by macroscopic plastic deformation is presented. So far, the theoretical description of the field enhanced emission from the dislocation-related states is noticed to be practically absent. Besides, the author makes a remark that the only experimental observation of 1D shallow states that was carried out by A. Castaldini and his colleagues by means of DLTS method is followed to be taken into account. Then, the goal of this work is formulated that is to develop a comprehensive theoretical model describing the emission of carriers from the dislocation-related levels towards the valence and conduction bands of silicon and to verify the main provisions of the suggested models by extensive experimental investigations using the n- and p-type Si samples with regular DNW.

The theoretical part concentrates on the exact numerical calculations of the influence of dislocation deformation potential on the carrier thermo-emission from the core states of screw and 60° dislocation towards the valence and conduction bands of silicon. The role of the Poole-Frenkel effect for charged Coulomb centers in the barrier lowering for carrier thermo-emission has been established, with the interaction between the dislocation deformation potential and the external electric field.

The experimental part contains the description of the p- and n-type silicon samples with DNW. These samples were studied by various methods of junction spectroscopy such as DLTS, isothermal DLTS (ITS) and by capacitance-voltage and current-voltage (CV/IV) characterization. The results of structural analysis of DNW by transmission electron microscopy were also taken into account. The CV/IV measurements have revealed neutral charge in empty state of shallow traps that are in a good agreement with the theory of 1D deformation induced dislocation states. The observed emission enhancement from the shallow traps is noted to be not ascribed to the classical Poole-Frenkel phenomenon due to attractive Coulomb potential. These data are evidence of the „band-like" behavior of shallow trap peaks and their broadened shape can be a result of continuous lowering of the potential barrier for carrier thermo-emission with increase of the occupation rate of dislocation core states.

The main results of the thesis are summarized in Conclusions from which it is necessary to distinguish the impact of the external electric field on the carrier thermo-emission from shallow states in both p- and n-type silicon samples using the capacitance techniques. The values of the Poole-Frenkel coefficient have been shown to exceed the value predicted for singly charged Coulomb center that appears to be due to the interaction between the dislocation deformation potential and the external electric field. These principal provisions are reflected by the publications in high-level peer-reviewed journals and presented at six international conferences.

Finally, new theoretical and experimental results presented in the PhD thesis by Maxim Trushin are evidence of a high qualification of the author in the field of the condense matter physics and of physics of semiconductors. I evaluate the thesis submitted by Maxim Trushin with the grade very good and being guided told above I note that he deserves award of doctoral degree after successful defense.

Reviewer

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Questions to the candidate

Q1

You have shown that the emission enhancement observed from the shallow traps cannot be described within frameworks of the classical Poole-Frenkel phenomenon due to attractive Coulomb potential. Specifically, the nonlinearity in the dependences of the kT- corrected logarithms of emission rate on square root of electric field appears to verify this conclusion.

Would it be possible to detail more a conclusion that this effect is caused by with the interaction between the dislocation deformation potential and the external electric field?

Maybe, the involvement of the linear and quadratic Stark effect that is caused by the interplay between the electron-vibration interaction and charge/spin correlations at the point and extended defects is needed to account for this influence of the external electric field?

Q2

The electrons and holes captured at both deep and shallow sub-bands introduced by the deformed potential in Si band-gap are well-known to transfer along dislocations thereby forming their electrical and optical characteristics.

Do you consider the possibility of this transfer on the shape of the DLTS spectra?

The variable-range hopping transport appears to dominate during DLTS filling pulses specifically at low temperatures.

Did you try to vary the duration of DLTS filling pulses over a wide range to exclude a possible contribution of this effect that seems to be revealed as the distortions of DLTS spectral shape?