Phase transition on conductivity in chalcogenide glassy semiconductors in a high electric field

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ABSTRACT

The microscopic mechanism of the phase transition from initial low-conductive state to a highly-conductive one during a switching effect is presented. Its connection with the strong non-linearity of current-voltage characteristics is discussed.

Key words: switching effect in chalcogenides, negative-U centers, multiphonon tunnel ionization, phase transition on conductivity.

At high electric fields chalcogenide glasses have a strongly non-linear current-voltage characteristic and switch from an off-state to on-state with higher conductivity. Therefore memory state or crystallization which occurs after switching arises not from an initial low conducting state but from a highly-conductive one.

In this paper we present the microscopic mechanism of the phase transition from initial low-conductive state to high-conductive one and its connection with the strong non-linearity of current-voltage characteristics.

It is very well known that in chalcogenide glassy semiconductors (CGS) the Fermi energy is tightly pinned by negative-U centers. For these centers the first ionization energy ε_1 is larger than the second ionization energy ε_2 therefore the correlation energy $U = \varepsilon_2 - \varepsilon_1$ is negative. Negative-U centers are charged and pin the Fermi energy.

Ionization energies of the centers depend on the electric field due to a multiphonon tunnel ionization. Therefore the electric field shifts the quasi-Fermi energy which results in a strongly non-linear current-voltage characteristic. Moreover in a high field the effective correlation energy U may change the sign from negative to positive. In this case the centers get neutrally charged and quasi-Fermi energy pinning disappears. Therefore a conductivity phase transition may occur.

To illustrate this, consider equations which govern electron concentration in conduction band and concentrations of negative-U centers in different charged states in the case of multiphonon tunnel ionization of negative-U centers:

$$D^0 + n \leftrightarrow D^- \qquad \text{(1a)}$$

$$D^+ + n \leftrightarrow D^0 \qquad \text{(1b)}$$

$$\frac{[D^0]\,n}{[D^+]} = N_c \exp\left(-\frac{(\varepsilon_1 - KTw_1(T,F)}{KT}\right) \qquad \text{(2a)}$$

$$\frac{[D^-]\,n}{[D^0]} = N_c \exp\left(-\frac{(\varepsilon_2 - KTw_2(T,F)}{KT}\right) \qquad \text{(2b)}$$

Where n and $[D^{+,0,-}]$ are concentrations of free electrons and corresponding states of negative-U centers. In papers [1,2] it has been shown that multiphonon tunnel ionization of negative-U centers (terms $w_{1,2}(T,F)$ in the exponent in the expressions (2a, 2b)), together with Joule heating in the frame of electronic-thermal model of the switching effect shows a good qualitative and quantitative agreement with experimental data and supplies an explanation for an exponential region of the CGS current-voltage characteristic.

In the high electric field U may be defined also as difference between the first and second thermal ionization energies. But now one has to take into account, that these values are decreased due to multiphonon tunnel ionization according to expression (2a, 2b)

$$U(F) = (\varepsilon_2-\varepsilon_1) - KT(w_2(T,F) - w_1(T,F)) = U(F=0) - KT(w_2(T,F) - w_1(T,F)). \qquad (3)$$

Approximation values of $w_{1,2}(T,F)$ are equal to $w_{1,2}(T,F) = F^2 q^2 \tau^3_{21,22}(T) / 3\hbar m$. Here q and m are electron charge and mass, and $\tau_{21,22}$ are tunneling times between adiabatic potentials for first τ_{21} and second τ_{22} ionization of negative-U centers [3].

Solving equation U(F)=0 one obtains value of field $F_0(T)$, which separate the situation with negative and positive value of the U(F). Our calculation has shown that $F_0(T)$ really exists for the case when centers have negative U for weak field: U(F=0) <0.

So for fields $F>F_0(T)$ quasi-Fermi level may be shifted. In this case one has final on-state which is governed by new quasi-Fermi level position, i.e. abrupt changing of conductivity occurs which may be considered as phase transition on conductivity.

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Biographies

Tsendin Konstantin was born in 1942 in Ulan-Bator, Mongolia. In 1965 he graduated the Physical department of the Leningrad State University. Since 1968 he works in the Ioffe Physical-Technical Institute. He obtained his Ph.D. degree in 1978. Since 1998 he is a full professor of the solid-state chair of the Saint-Petersburg State Polytechnical University. The scope of the main interest is the kinetic phenomena in disordered semiconductors.