Electronic-thermal switching in amorphous chalcogenides

Nikita Bogoslovskiy
Ioffe Physical-Technical Institute, Russian Academy of Sciences,
Politekhnicheskaya 26, St. Petersburg 194021, Russia; e-mail nikitabogoslovskiy@gmail.com

ABSTRACT

We show that multiphonon tunnel ionization of negative-U centers is a probable mechanism of the strong nonlinearity of the I-V characteristic of amorphous chalcogenides. Together with Joule heating this mechanism leads to switching to the conductive state. The model qualitatively and quantitatively agrees with the available experimental data on the switching effect.

Key words: phase-change memory, switching effect in chalcogenides, negative-U centers, multiphonon tunnel ionization.

The phase change memory (PCM) technology has been progressing rapidly during the last decade. This technology as compared with the flash-memory has a number of desirable properties specifically very fast read and write speed, low power consumption and large endurance.

PCM technology is based on a rapid and reversible transition between amorphous and crystalline phases in chalcogenides. In high electric fields an amorphous chalcogenide switches from a highly resistive to a conductive state. The switching effect decreases the resistivity of an amorphous chalcogenide. Consequently the Joule heat increases and heats the material above the softening temperature and the active region crystallizes. Therefore, switching is extremely important for memory recording. Understanding of the physical mechanism of switching is essential to perform numerical simulation of PCM cells and predict their characteristics.

It is known that chalcogenide glassy semiconductors (CGSs) contain a high concentration of negative-U centers. In weak electric fields the center ionization and carrier trapping pin the Fermi level and consequently determine the electrical properties of CGSs.

$$D^- \leftrightarrow D^0 + e$$
$$D^0 \leftrightarrow D^+ + e$$

Here we denote the neutral state of the center as D^0 and the positively and negatively charged states as D^+ and D^- respectively. By analogy the hole transitions may occur.

The probability of negative-U center ionization increases exponentially with increasing electric field. Consequently, the concentration of free carriers and the conductivity increase. In [1-3] we have shown that in high fields multiphonon tunnel ionization of negative-U centers is most likely. In a threshold electric field, the Joule heating increases the temperature of the sample. Consequently, the ionization probability increases and this leads to a switching to a conductive state.

The developed 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 I-V characteristic of amorphous chalcogenides (Fig. 1).

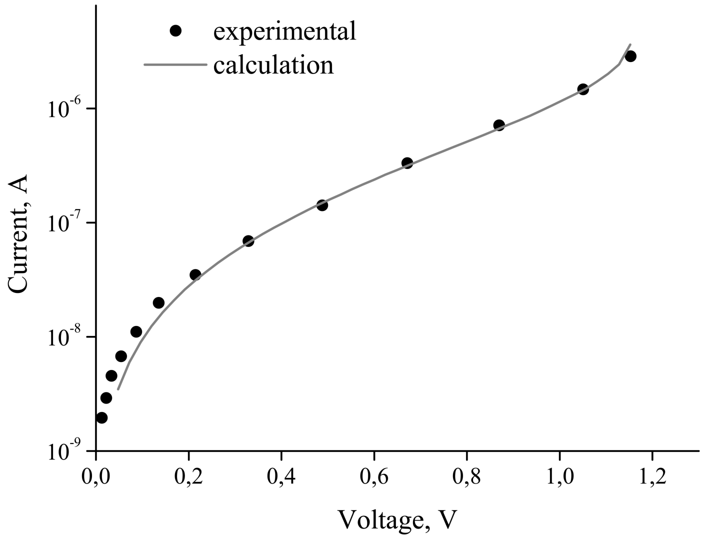

Fig. 1 Comparison of the calculated I-V characteristic with experimental data [4].

The role of heating has always been a subject of discussion. Calculation show that the heating in the threshold point is equal to several tens of degrees and the temperature in the conductive state is close to the melting temperature of CGSs. The model agrees with experimental dependences of the threshold electric field on the film thickness and qualitatively correlates with observed dependences of the threshold field on temperature. Also it qualitatively describes the experimental dependence of the threshold current density on the film thickness. This suggests that the multiphonon tunnel ionization of negative-U centers and heating is a probable mechanism of the switching effect in chalcogenides. The model was applied to forecast the dependence of the PCM cell characteristics on microscopic material parameters. Obtained results may be used to select the most suitable compounds for the PCM applications.

REFERENCES

1. N. A. Bogoslowsky and K. D. Tsendin, Semiconductors 43, 1338 (2009).

2. N.A. Bogoslovskij, and K.D. Tsendin, J. Non-Cryst. Sol. 357, 992 (2011).

3. N.A. Bogoslovskiy, and K.D. Tsendin, J. Opt. Adv. Mat. 13, 1423 (2011).

4. D. Ielmini, Phys. Rev. B 78, 035308 (2008).

Biographies

Nikita Bogoslovskiy is a Ph.D. student at the Ioffe Physical-Technical Institute, Saint-Petersburg, Russia. He received the MS diploma at the Saint-Petersburg State Polytechnical University in 2010 and at the Academic University in 2011. Since 2006 his research is concerned with the switching and memory effect in chalcogenide glassy semiconductors and their application.