Thermodynamic Foundations of Solid-State Cooler Based on Multiferroic Materials

A. Starkov[1], O. Pakhomov[1], and I. Starkov[2,⋆]

[1] *Institute of Refrigeration and Biotechnologies, St. Petersburg National Research University of Information Technologies, Mechanics and Optics, St. Petersburg, Russia*
[2] *Institute for Microelectronics, Vienna University of Technology, Wien, Austria*
⋆ *corresponding author e-mail: starkov@iue.tuwien.ac.at*

In view of the increasing requirements on energy saving, as well as the necessity to cool the growing number of on-chip components, the alternative cooling principles not associated with the traditional refrigerants become more and more actual. The most promising are the solid-state cooling devices, among which are widely used systems based on the Peltier effect. However, due to the low refrigerating factor of these systems, methods of cooling based on the caloric effects [1, 2] seem more perspective.

Caloric effects describe the change of temperature or the thermodynamic entropy of the system by the application (or removal) of an external force. If this external force is the electric field there is the electrocaloric effect (ECE), if the magnetic – the magnetocaloric effect. In the case of the elastic stress application it is the piezocaloric effect. Such an effects are more intensive near the phase transition points, where the internal parameters of the system as the polarization, the magnetization and the deformation are strongly dependent on the temperature. In literature we were able to find consideration of the impact of various external fields on the temperature independently from each other. At the same time, extremely promising and attracting the attention type of materials are multiferroics [3], in which there are at least two of the three possible interactions between these fields. In particular, for multiferroics-ferromagnetics the main feature is the relationship between the electric and magnetic fields (magnetoelectric effect) that allows to control the electric field using the magnetic and vice versa. It is offered to use this physical feature in order to create a fundamentally new solid-state cooler.

We have investigated the temperature dependence of the multiferroic sample subjected to a periodic electrical, magnetic and elastic fields (the heat exchange with the environment is taken into account). It is possible to increase the sample temperature by controlling of the electric field employing the magnetic field. The change of the temperature during one cycle is proportional to the magnetoelectric coefficient. As a consequence, for a large number of applied cycles the resulting temperature change may reach value in 5-10 times higher than in the case of the only electric field presence. Such a result is very promising for practical realization of a high-performance solid-state cooler devices.

Numerical calculations performed in [4] on the basis of simplified model demonstrate a significant increasing in the electrocaloric effect employing the modulation of the electric field by an elastic force. It is obvious that the additional opportunity for influence the electric field by magnetic field result in more effective ECE reinforcement. A simple case of periodic changes in the electric and magnetic fields has to be considered:

$$E = E_0 \sin(wt), \quad H = H_0 \sin(wt + \varphi), \tag{1}$$

where E_0, H_0 are the amplitudes, ω is the frequency, φ is the phase shift. The time dependence of the sample temperature is shown in Fig.1. One can see that the difference between initial and steady-state temperatures depends strongly on the phase shift.

We have proposed an approach for reinforcement of the ECE in order to refine the cooling parameters of refrigerator, which is designed on multiferroics. This work has presented basic physical ideas how to improve the solid-state cooler parameters. These ideas are supported by calculations, thereby making them vital. Our study may provide a theoretical basis and physical insights for the further refinement of solid-state cooler characteristics.

References

[1] *Muller, K., Fauth, F., Fisher, S., Koch, M., Furrer, A., Lacorre, Ph.: Appl. Phys. Lett., 73 (1998) 1056.*
[2] *Strassle, Th., Furrer, A., Hossain, Z., Geibel, Ch.: Phys. Rev. B, 67 (2003) 054407.*
[3] *Khomskii, D.: Physics, 2 (2009) 20.*
[4] *Starkov, A., Pakhomov, O., Starkov, I.: Tech. Phys. Lett.,37 (2011) 105.*

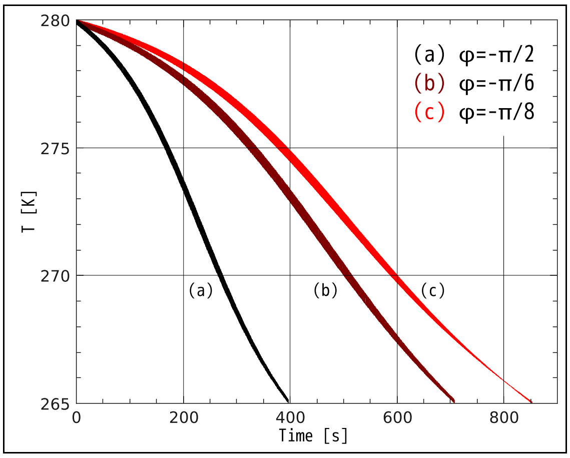

Fig.1. The time dependence of the sample temperature in response to periodic oscillations of the applied electric and magnetic fields with a relative phase shift of (a) $\phi = -\pi/2$, (b) $\phi = -\pi/6$ and (c) $\phi = -\pi/8$.