SOLID-STATE COOLER - NEW OPPORTUNITIES

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The idea of engineering cooling systems and generators based on thermal transformations and energy conversion in solids has been exciting scientific minds already for several decades. In recent years, a possibility of coolers production based on the electrocaloric effect (ECE) began to become of special interest [1]. This interest is related to the substantial progress made in investigations of ferroelectric materials. Basis of the ECE theoretical description was already developed in 1878 by W.Tomson and given by [2]

$$\mathrm{d}T = \gamma \mathrm{d}E, \quad \gamma = -\frac{T}{C_{\mathrm{E}}}\frac{\partial P}{\partial T}, \tag{1}$$

where T is temperature, P the polarization, E the electric field intensity, while C_{E} is the thermal capacity at constant intensity, and γ the electrocaloric coefficient (ECC). One of the main problems of the refrigerator practical realization is transmission of refrigeration to the target which has to be cooled (so-called "switches" problem). ECE-based coolers are designed to solve this problem by direct apposition to the target but desired effect was found insufficient at the present stage of the technological processing. From our point of view, to increase the efficiency of the "ferroelectric cooler" an advantage may be achieved by employing the ECE is conjunction with another physical effect such as magnetoelectic, piezoelectric, piezomagnetic, etc.

According to [3], free energy F of the multiferroic can be written as

$$F = \frac{aP^2}{2} + \frac{bP^4}{4} - EP + \alpha\eta P^2 + \frac{\beta\eta^2}{2} - \eta\sigma, \tag{2}$$

where η is the module of deformation, σ the external field and (a, b, α, β) are constants. Eq. (2) establishes the interrelation between the ECE value and the external field σ. Fig.1 confirms this trend showing experimental evidence that the dielectric permittivity depends on the pressure. As a consequence, comparison of the electrocaloric coefficient of clumped (γ_{cl}) and free (γ_{fr}) multiferroic samples is noteworthy. In the theoretical work by Prosandeev *et al.* [4] a promising ratio $\gamma_{\mathrm{cl}} = 0.6\gamma_{\mathrm{fr}}$ was reported, which agrees well with experimental data from [5] $\gamma_{\mathrm{cl}} = 0.8\gamma_{\mathrm{fr}}$. Such a difference between two ECC may be exploited. It should be emphasized, that the process of changing of the external field can be considered as isothermal [6]. This allows for performing a Carno cycle: as the first step the electric field is supplied to the initially compressed sample, thereby inducing adiabatic heating of the sample. At the second stage the external pressure is decreased to zero (isothermal expansion). At the third step the electric field is removed and then on the forth stage the sample is isothermally compressed. The variation of the sample temperature during this cycle can be estimated as $(1 - \gamma_{\mathrm{cl}}/\gamma_{\mathrm{fr}})\Delta T$, where ΔT is the change of the temperature corresponding to the single supply of electric field ($\Delta T_{\max} = 39^o$ [7]). Thus, with consistent varying of the electric field and the external pressure it is possible to increase the ECE in $5 \sim 10$ times (parametric reinforcement).

The another opportunity to obtain an additional increase of ECE is using of multilayered structures. Calculations performed on the basis of our model [8], which take into account non-uniformities in the temperature distribution and surface effect of layer boundaries, confirm this idea. The difference between initial and obtained temperatures may reach value of $40 \sim 50\Delta T$ after 10^3 cycles of applying/removing of electric field for three-layer structure (Fig.2).

We have suggested an approach for reinforcement of the electrocaloric effect in oder to refine the cooling parameters of refrigerator, which is designed on multiferroics. This work presents basic physical ideas how to improve the solid-state cooler parameters. These ideas are supported by calculations, thereby making them vital. One of the advantages of the presented approach is its generality, i.e. (2) in this form may be applied to piezomagnetics where the external force σ is pressure induced by the external magnetic field. Also (2) can be adopted for the case barocaloric effect where σ is the electric field. Another thinkable measure how to make the ECE more prominent is employment of the second piezoelectric layer.

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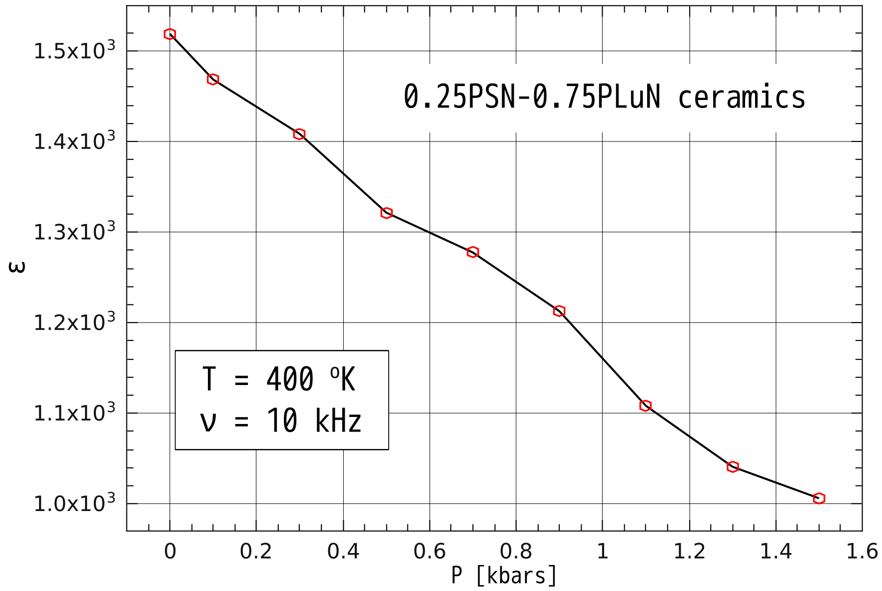

Figure 1: The pressure dependence of the dielectric permittivity at the frequency of 10 kHz and temperature 400 ^{o}K for the $0.25PSN - 0.75PLuN$ ceramics.

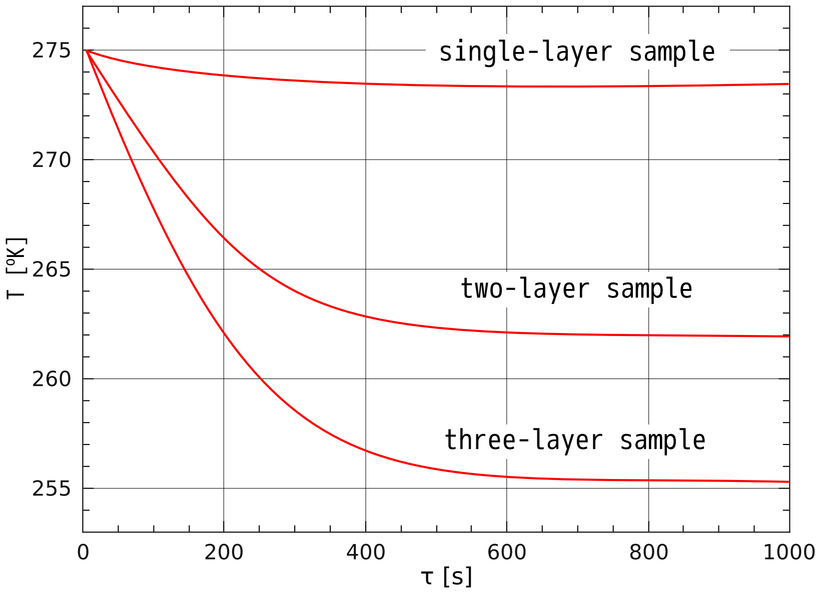

Figure 2: Simulation of the temperature dependence on number of described cycles for a layered multiferroic. The increase in the layers number results in a better refrigeration.