Solid State Cooling Device Based on Electrocaloric Ceramic Multilayers

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The electrocaloric effect (ECE) refers to the change in temperature and/or entropy of a dielectric material due to the polarization change induced by external electric field. Giant ECE is discovered in $BaTiO_3$ ceramics by modifying its invariant critical points to promote coexistence. However, the ECE ceramics require high voltage due to its thickness. To generate high electric field with low applied voltage for practical cooling applications, one approach is to develop EC multilayers making use of commercial multilayer ceramic capacitor (MLCC) technology. Thus, we designed a unique EC multilayer based on commercial Y5V ceramic composition. Thickness of each layer in the multilayer is 10μm so 20MV/m electric field could be generated on the multilayer with 200V electric voltage. What is more, a thin layer of low temperature ceramic is pressed on the surfaces of EC multilayer to protect the external electrode and get better surface flatness. So after co-firing and polishing, EC multilayer with extremely flat surface could be obtained without damaging external electrode, resulting in better heat exchange between EC multilayers. The temperature change of EC multilayer varies with different voltage and the largest one can reach 0.9 K under 200V.
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In addition, we have prototyped a solid state cooling device based on our unique EC multilayers. The newly designed cooling device is consisting of a series of two-ring pairs. In each two-ring pair, two rings of EC elements are rotating in opposite direction with same rotation speed. Elements in one ring are thermally separated from others but they can exchange heat with the elements on the other rings. For each ring, half of the elements are subjected to field, all elements leave field areas (absorb heat) and enter in field area (eject heat) at same locations, called cold end and hot end. Two heat exchangers are placed on both ends. During the operation, the EC elements are exchanging heat with the element beneath them, and form a self-regeneration process instead of traditional regeneration process by exchanging heat with external cooling agent, resulting in an extension of temperature span between cold end and hot end of cooling device beyond the temperature change of a single material. The temperatures of two ends are measured by thermocouple. During rotation, temperature span between two ends varies with different voltages and the largest can reach around 2 K under 200V. The ratio between temperature span of the whole device and the temperature change from single piece of EC multilayers is an important parameter to evaluate the regeneration process of the cooling device. Here, we call it regenerative factor. From the results, the regeneration factor under different voltages all exceed 2 and the maximum regenerative factor of around 3 is achieved under 100V. This large regeneration factor under such low voltage shows the great potential in making real ECE cooling device. If EC multilayer with larger temperature change is developed in the future, large temperature span more than 10K could be easily obtained from the cooling device based on this prototype.