3D printed energy efficient magnetocaloric cooling devices with controlled microchannels, functional grading and magnetic anisotropy

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Introduction: Air conditioning and refrigeration, is regarded as one of the most energy-intensive technologies in demand today. Currently, 15% of the world's electric power is devoted to cooling, with that value increasing to 20% in the U.S. and to 25% in Japan; associated with this technology are significant carbon emissions and environmentally damaging leaks of chemical refrigerant [1]. Novel cooling technologies are required to minimize global energy consumption and environmental impact. To drive the development of efficient, sustainable and green cooling technologies, we have **fabricated magnetocaloric regenerators for retroactive integration into existing active magnetic regenerator (AMR) magnetic cooling devices which is almost twice energy efficient** and environmentally-friendly alternative to conventional vapor-compression cooling.

A magnetic refrigerator's key component is a magnetocaloric regenerator (also known as heat exchanger) consisting of a magnetocaloric material (MCM) with voids to enable flow of a heat transfer fluid, Figure 1. The heat exchangers are modular in design, as they must be cycled in and out of a magnetic field to transfer thermal energy evolved due to the magnetocaloric effect (MCE). Typically, MCM regenerators are shaped as porous particle beds or as stacked plates separated by spacers to provide channels [2]. Both structures possess inherent processing challenges that significantly reduce their theoretical performance once integrated into a device prototype. Microchannel geometries along the fluid flow direction with different cross-sectional shapes (circular, square) are presently the most attractive option. Instead of drilling the channels, which wastes material, sophisticated additive manufacturing (AM) methods are desirable. To address this issue, a novel extrusion-based additive manufacturing scheme is used based on the design invention entitled as, "*3D printed magnetocaloric devices with controlled microchannels and magnetic anisotropy and methods of making the same*" (patent pending).

Experimental Details: *This manufacturing approach's prime novelty lies in the 3D ink formulation and printing process itself (see Fig. 1).* The polymers act as binding agents for the magnetic particles, most of which are burned off during the post-treatment process. Additives, mainly graphene nanoplatelets, enhance heat transfer and mechanical strength of the printed magnetocaloric devices, in addition to functioning as viscosity modifier for ink formulation.

Results: As a proof of concept of the development of 3D printed magnetocaloric regenerators we have 3D printed regenerators of La0.7$Ca_{0.3}MnO_3$ (LCMO), $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) and $La(Fe_xCo_ySi_{1-x-y})_{13}$ system of materials. The entropy change was measured of unprinted particles and 3D printed regenerators at different applied magnetic fields. There was a small difference in the entropy change between the particles and the 3D printed regenerators which can be minimized by controlling the anisotropy and minimizing the post-sintered polymer residue. It is worth noting that an external magnetic field may be applied to align the mangetocrystalline anisotropy of the magnetic particles to their easy axis, thus enhancing the magnetofunctional

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response as published by the investigators [3], [4]. This printing method allows the realization of "*compositionally graded*" regenerators where the magnetic transition (Curie) temperature (T_c) changes continuously, providing superior system efficiency. The device heat flow can be tailored in both operating temperature range and direction, enabling more complex and efficient porous geometries, reaching system efficiency that exceeds those of conventional vapor-compression cooling (coefficient of performance, $COP_{cooling}$~4).

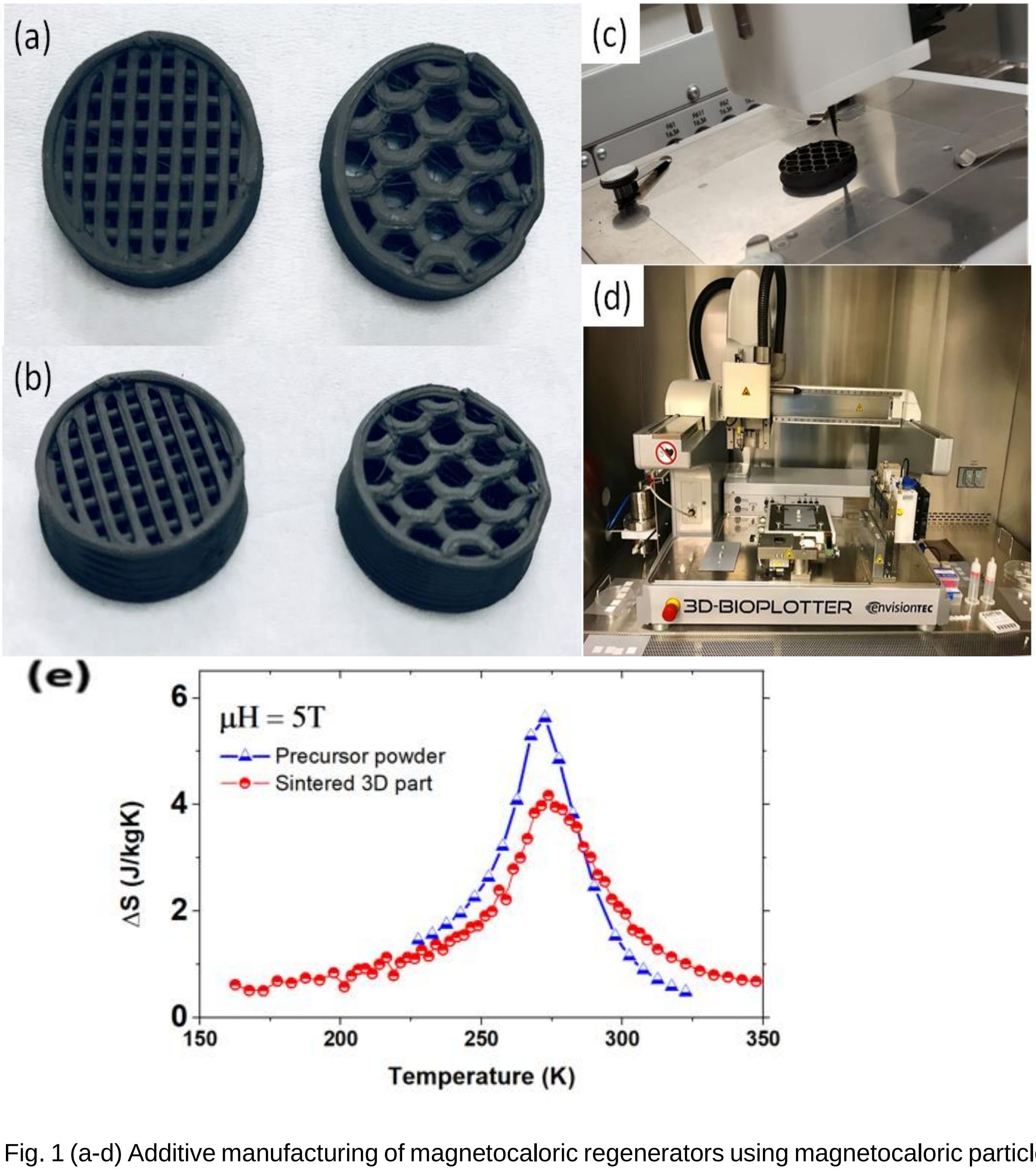

Fig. 1 (a-d) Additive manufacturing of magnetocaloric regenerators using magnetocaloric particles and binder polymer, polyethylene glycol (PEO). Note, the magnetic alignment is not shown. (e) entropy change for an applied field of 5 tesla of particle and printed regenerators after removing the PEO.

Reference:

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