A Study Of The Martensitic Transition In NiMnIn Heusler Alloy Under A Magnetic Refrigeration Cycle

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Abstract

Solid-state magnetic refrigeration near room temperature, based on the magnetocaloric effect (MCE), is being investigated as an environmentally friendly and sustainable alternative to traditional vapor-compression systems (responsible for the 7.8% of greenhouse gas emissions) [1] [2], since it exhibits zero ozone depletion and global warming potential [3] [4] . Among the families of magnetocaloric materials, Ni-Mn-In Heusler alloys have gained significant attention due to their composition of earth-abundant elements and their ability to display a significant MCE driven by a first-order ferromagnetic-to-paramagnetic transition [5]. This change is also accompanied by a structural martensitic phase transformation, which strongly influences the thermal and magnetic response of the material during cyclic operation [6].
In this work, a two-dimensional time-dependent model of a magnetic refrigeration system with an active magnetic regenerator (AMR) is developed to capture the thermal and structural behavior of a NiMnIn Heusler alloy subjected to a magnetic refrigeration cycle. The physical model consists of an AMR, two heat exchangers for the hot and cold sides of the device, and a working fluid. The cyclic flow is described by the Navier-Stokes equations for an incompressible fluid, meanwhile the thermal energy conservation equation accounts for the heat transfer in the fluid, solid, and the solid-fluid interfaces. The diffusionless reversible martensite to austenite phase transition is modeled using the Metal Phase Transformation module under the Metal Processing physics interface [7]. Then, the coupling between these three physics is developed by using the COMSOL Multiphysics® Conjugate Heat Transfer option, that combines the Heat Transfer in Solids and Fluids [8] and the Laminar Flow [9] under the Non-Isothermal Flow Multiphysics interface, and the Phase Transformation Latent Heat, which add the latent heat produced by the material phase transformation. The magnetocaloric effect is introduced here by the inclusion of a source term in the energy relation that is dependent on the adiabatic temperature change and the specific heat of the magnetocaloric material. The latter two parameters are inserted into the model by using interpolated functions based on experimental behavior data for the Heusler compound.
The computational framework presented allows the study of the propagation of the transformation fronts, the development of the thermal gradient of the magnetocaloric material over time, and the energy redistribution associated with the structural transitions, especially during rapid cycling. This model encourages future studies in which Heusler-based regenerators can be evaluated and optimized by varying operating conditions, field protocols, and material configurations where structural and thermal couplings are decisive, also providing a predictive simulation tool for solid-state cooling technologies based on phase transformation behavior.

Reference

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[8] Comsol AB, Comsol Multiphysics-Heat Transfer Module, User's Guide, Version 6.2, 2023.
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Figures used in the abstract

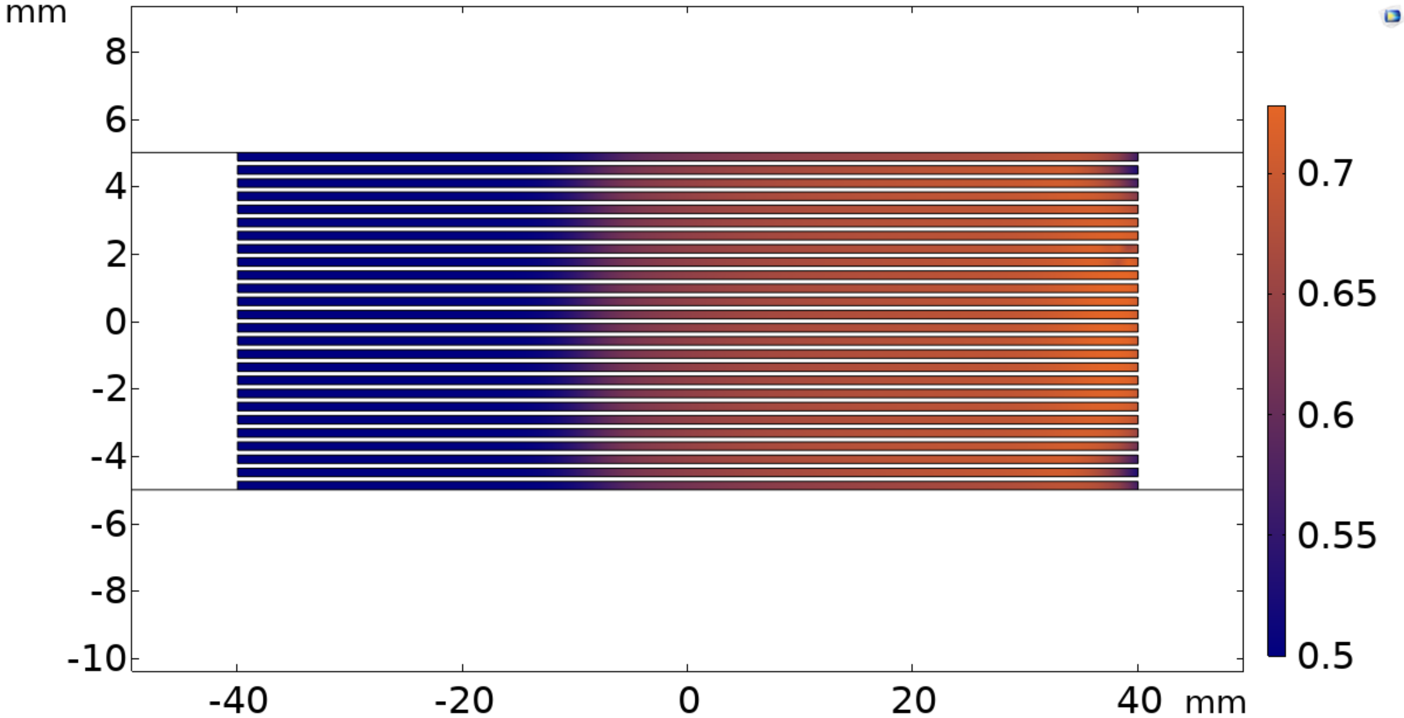

Figure 1 : Martensite phase fraction over the NiMnIn magnetocaloric regenerator at 1200s.