Deanship of Graduate Studies

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Synthesis, Magnetic Properties, and Crystal Structures of Magnetocaloric Materials in the System $(Mn_5Ge_3)_x(MnFe_4Si_3)_{1-x}$

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Thesis Approval

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Dedication

I lovingly dedicate this thesis to my great parents for their endless love, support and encouragement. To my sisters Reem and Sujoud. To my brothers Tammam and Qassam. To my nieces Raheeq and Rawasy.

Kinan Khaled Jameel Al-Namourah

Declaration

I, Kinan Khaled Al-Namourah, declare that this thesis "Synthesis, magnetic properties and crystal structures of magnetocaloric materials in the system $(Mn_5Ge_3)_x(MnFe_4Si_3)_{1-x}$" and the work presented in it are my own and have been generated by me as the result of my own original research and that they have not been submitted earlier elsewhere.

I confirm that this work was done under the supervision of Prof. Salman M. Salman from the Physics Department, Al-Quds University, Palestine, and PD Dr. Karen Friese from the Jülich Centre for Neutron Science-2 (JCNS-2), Forschungszentrum Jülich, Germany*.

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Abstract

The polycrystalline samples of several compositions in the system $(Mn_5Ge_3)_x(MnFe_4Si_3)_{1-x}$ with x = (0.2, 0.4, 0.6, 0.8) were prepared using cold crucible induction melting. Chemical analysis was performed using iCAP 7600 ICP-OES, in order to make sure that the synthesized compounds have the correct stoichiometry, and to confirm that the synthesize process was going well.

The crystal structures of these magnetocaloric compounds were investigated by performing X- ray powder diffraction using two types of diffractometers. Using the LeBail and Rietveld refinement, two main phases were detected in all samples. The volumes of the unit cell of the samples decrease with decreasing x parameter in the two phases. However, an unusually large value was observed at x = 0.2 for one of the phases. The polycrystalline samples x = 0.8 and 0.6 have a preferred orientation in the direction [0 0 1].

The magnetic properties of the compounds in the system $(Mn_5Ge_3)_x(MnFe_4Si_3)_{1-x}$ were investigated using a PPMS. Mass magnetization measurement as a function of temperature (isofield magnetization measurements) and magnetic field (isothermal magnetization measurements) were performed. The transition temperatures for all samples were different under field cooling compared to field warming. All samples showed a thermal hysteresis. The transitions were observed at temperatures slightly above the room temperature. The maximum transition was for the x = 0.6 composition at around 331 K for field cooling and around 337 K for field warming. From effective paramagnetic moment values, we conclude that we did not inter the Curie-Weiss regime.

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List of Abbreviations

JCNS	Jülich Centre for Neutron Science
MCE	Magnetocaloric effect
CFCs	Chlorofluorocarbons
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
H	Magnetic field
$S(T, H)$	Total entropy
T	Temperature
S_M(T; H)	Magnetic entropy
S_{lat}(T)	Lattice entropy
S_{el}(T)	Electronic entropy
T_c	Curie temperature
ΔS_M	Magnetic entropy change
ΔT_{ad}	Adiabatic temperature change
M	Magnetization
C	Heat capacity
RC	refrigerant capacity
RCP	Relative cooling power
MCM	Magnetocaloric material
GMCE	Giant magnetocaloric effect
M_S	Saturation magnetization
M_r	Remanence
H_C	Coercive field
χ	Susceptibility
C	Curie constant
ϑ	Weiss constant
P	Paramagnetic
F	Ferromagnetic
AF	antiferromagnetic
T_N	Neel temperature
μ_{eff}	Effective paramagnetic moment
μ_B	Bohr magneton