General Working Characteristics of Magnetocaloric Materials in High Magnetic Fields.

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A big interest is attracted to the application of materials with a large magnetocaloric effect (MCE) at magnetic and magnetostructural phase transitions (PT) for creation of household refrigerators, operating near room temperature. The high cooling power of such devices can be achieved only at high frequency of heat transfer cycles and at large amounts of heat, which can be transferred in one cycle from cold end to hot end. In this work we concentrate on experimental measurement of transferred heat q, coefficient of performance (COP) and restrictions on frequency of magnetic refrigeration cycle for materials with MCE. We suggest the new experimental approach for the direct measurements of MCE at quasi-isothermal q, adiabatic conditions ΔT and COP simultaneously. We report the results of direct measurements of ΔT, q and COP in high magnetic fields of Bitter coil magnet (up to 120 kOe) on Gd sample. If a sample of MCE material is placed in good thermal contact with a massive nonmagnetic block with determined specific heat and high thermal conductivity, then we can experimentally estimate the transferred heat (per unit of the sample mass) q from the sample to the block at quasi-isothermal conditions by measuring ΔT_b – the quasi-isothermal temperature change of the block at magnetic field change: $q \approx (M_b/m)\times C\times\Delta T_b$, where M_b– the mass of the block, C – the specific heat of the block, m – the mass of the sample $(M_b >> m)$. The maximal values of MCE obtained from direct experiments on Gd were: $\Delta T = 17.7$ K and $q = 5900$ J/kg at $T_0 = 293$ K [1]. The in situ measurement shows that magnetization versus magnetic field dependence *M(H)* of the Gd sample during switch on/off magnetic field has hysteretic character (Fig. 1). The calculation of integral of *HdM* on a closed loop allows to determine the work of magnetic field during cooling cycle and to calculate the COP of magnetic refrigeration cycle. It was found that at $T_0 = 298$ K under magnetic field change 120 kOe, COP = 13. By reducing the magnetic field down to H = 20 kOe, COP increases up to 92. The fundamental restrictions on COP are imposed by Carnot's theorem [2]. Also we present a new technique for experimental study of kinetics of PTs and direct measurement of the MCE in pulsed magnetic fields by using the fast response temperature probe with infrared fiber optical (IRFO) sensor (pyrometric principal). The device consists of optical fiber made of $AgCl_xB_{1-x}$ (0<x<1) compound by vacuum extrusion through a die, and a photoresistor made of narrow-gap semiconductor Cd-Hg-Te, which is placed into cryostat with liquid nitrogen. The optical fiber is transparent in IR wavelength range 5-15 μm, the photoresistor is sensitive in the same range. One optical fiber end is connected to the photoresistor, the other optical fiber end is connected with a surface of the MCE sample. The sample with MCE under investigation is placed into a pulsed coil magnet with magnetic field up to 130 kOe and pulse duration of 12.5 ms at room temperature. The electronic part includes analog amplifier of a signal from the photoresistor, and analog-to-digital converter, connected to PC. The initial temperature of the sample was controlled by small thermostat with conventional Pt thermoresistor temperature sensor [3]. The direct MCE for Gd at initial temperature 298 K was found: $\Delta T = 21.3$ K under pulsed magnetic field $H = 127$ kOe. However, the value of MCE, measured by the IRFO sensor, exceeds nearly by 10 % the value obtained by a semiconductor diode temperature sensor in Bitter coil magnet for the Gd sample of the same series [1]. The 10 % difference can be explained by the fact that the conditions are closer to adiabatic in the pulse experiment, and the use of non-contact temperature measurement method by IRFO sensor excludes additional heat loss provided by conventional sensor. The second sample was $Fe_{48}Rh_{52}$, its magnetic properties were describe earlier in [4]. The inverse MCE for $Fe_{48}Rh_{52}$ sample at initial temperature 305.1 K: $\Delta T = -4.5$ K under pulsed magnetic field $H = 85$ kOe. Fig. 2 shows the inverse MCE and magnetization dependence on the magnetic field at two consistent impulses with different directions. The magnetization curve has characteristic for the 1st order PT hysteresis loop. The energy losses on magnetization are irreversible work of magnetic field in cycle of magnetic cooling. We can calculate this work as square of hysteresis loop $W = \int HdM$. From our experiments on $Fe_{48}Rh_{52}$ at $H = 85$ kOe this value was obtained $W = 45$ J/kg and maximal COP can be about 100 [4]. The new system demonstrates the fast response (better than 1 ms) and higher noise immunity than existing systems based on micro-thermocouples and thin film thermoresistors. The measurements in magnetic fields of Bitter coil magnet were supported by Russian Science Foundation (grant # 14-22-00279). The measurements in pulsed magnetic fields were supported by Russian Foundation for Basic Research (grant # 17-58-540002) and National Foundation for Science and Technology Development of Vietnam (grant # 103.02-2014.35).

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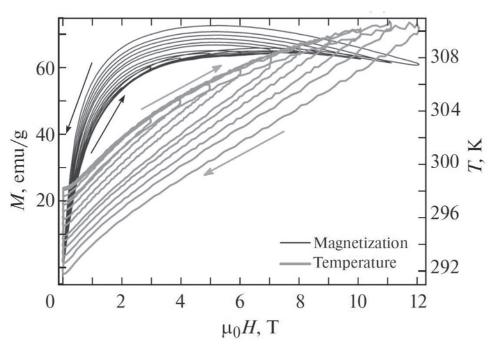

Fig.1. Magnetization and temperature dependences on the magnetic field for Gd sample in quasi-adiabatic conditions. The initial temperature $T_0 = 298$ K.

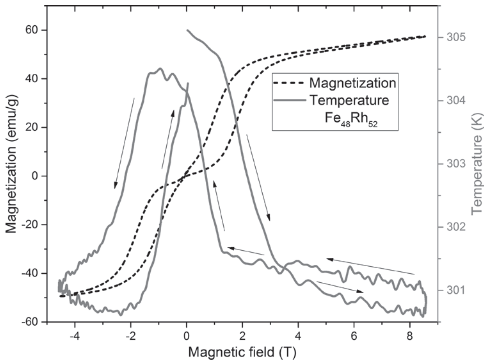

Fig.2. Measurements of MCE by the IRFO temperature probe on $Fe_{48}Rh_{52}$ sample. Temperature and magnetization vs. magnetic field at two consistent impulses with different directions, arrows show direction of magnetic field change.