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Experimental and theoretical studies of kinetics of phase transitions in magnetocaloric materials.

A. P. KAMANTSEV[1], V. KOLEDOV[1], V. SHAVROV[1], I. TERESHINA[2], D. A. KUZMIN[3], I. V. BYCHKOV[3]

1. Kotelnikov Institute of Radioengineering and Electronics of RAS, Moscow, Russian Federation; 2. Baikov Institute of Metallurgy and Material Science of RAS, Moscow, Russian Federation; 3. Chelyabinsk State University, Chelyabinsk, Russian Federation

In recent years, a large number of new magnetically ordered compounds with magnetic, metamagnetic and structural phase transitions (PTs) of the 1st and 2nd orders, which accompanied with anomalies of magnetic, thermal and mechanical properties is created and studied around the world [1]. And, despite the fact that the PTs in magnetics was studied during long time both theoretically and experimentally, at the moment there is no sufficiently deep understanding of kinetics phenomena accompanying PTs. Theoretically, the growth of the new phase at PT of the 1st order is described by the kinetic equation of the Fokker-Planck [2]. The relaxation processes near PT of the 2nd order is described by the Landau-Khalatnikov equation [2]. However, the applicability of these equations for the magnetic PT has not been tested until now.

The problem of rate of PTs requires an indispensable solution, because the creation of new technologies based on “giant” effects in vicinity of PTs in magnetic materials is impossibly without solving of this problem. For example, the magnetocaloric effect (MCE) reaches its peaks near the PTs in magnetics [1], therefore knowledge of PT’s rate is necessary for creation of new technology of magnetic refrigeration at room temperature [3]. The rate of PT limits the frequency of thermodynamic cycles. Accordingly, the power of refrigeration will depend on the frequency of cycles, and it is difficult to judge the profitability and competitiveness of the creation of this machine without determining the parameters of power. In this paper, we present a new technique for experimental study of the kinetics of the magnetic PTs under low alternating magnetic field, and the theoretical calculations of respective kinetic processes.

The new dynamic thermo-magnetometer (DTM) is proposed for solving the problem of the experimental study the rate of the magnetic PT with response time of 10 ms. DTM is designed for measuring the time dependence of the magnetic susceptibility of thin plates of ferromagnets at an abrupt temperature change in water flow (Fig. 1). The experimental measurements of the magnetic susceptibility of the samples were carried out with the help of a three-coil differential transformer. An AC signal with a frequency of 1-10 kHz was supplied to the outside coils. The amplitude of the magnetic field excitation is about 1 Oe. The measured signal was taken from the central coil. The selective nanovoltmeter was used to amplify the measured signal. The temperatures of both samples and water were measured using thin differential thermocouples. As a result of experiments for Gd near $T_C = 20\ ^0C$ relaxation time of magnetization is about 50 ms [4]. Then the frequency of the cycles of a magnetic refrigerator with a working body made of Gd plates will be restricted to a value of $f = 1/(2\tau) = 10$ Hz.

Calculations of kinetics of 1st and 2nd order PTs made by a joint solving of self-consistent system of equations, consisting of the heat conduction equation and the equation of motion of the order parameter (Landau-Khalatnikov equation). As a result of calculations the temporal and spatial dependences of the temperature and the order parameter were obtained. The calculations were performed for various boundary conditions: at given time dependence of the temperature of one of the sample boundaries, and at given time dependence of the heat flow on one of the sample boundaries. Calculations show that the rate of the phase boundary is not constant and depends strongly on the regime of heating/cooling at times close to change of the sample’s state. With the course of time the rate of the phase boundary reaches a constant value, practically independent of the heating regime (Fig. 2).

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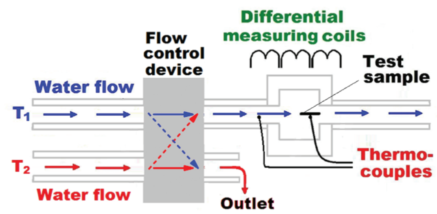

Fig.1. The scheme of the dynamic thermo-magnetometer. The method is based on the measurement of the change of magnetic susceptibility of a ferromagnetic sample in the vicinity of the phase transition in response to an abrupt change of the sample temperature.

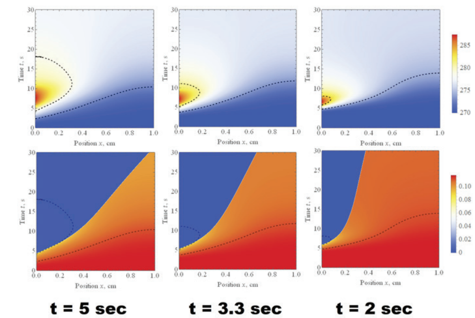

Fig.2. The simulation of the linear change of heat flow in a sample with the thickness of 1 cm at different duration of heating / cooling.