Second harmonic of magnetization analyzer (SHMA) as a new promising instrument for investigating and examining magnetic properties of the materials

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Installation is presented, which registers a second harmonic of magnetization (M_2) of a material placed in parallel *ac* ($h(t)=h\sin\omega t$) and steady (H) magnetic fields. The main sources of SHM generation are (i) nonlinearity of a magnetization curve $M(H)$ and (ii) an *ac*-magnetic field effect on the relaxation processes of magnetization [1]. An important point is that M_2 is a pseudovector and an even function of h. Therefore, $M_2(H)$ is odd in H with $M_2(H) \propto H$ at $H \to 0$ in a paramagnetic (P) phase. As a result, it is very sensitive to the appearance of spontaneous magnetization of a sample, because in this case $M_2 \neq 0$ at $H = 0$. Thus, SHMA can be served as a very sensitive magnetometer. Its high sensitivity is due to registration of M_2 on a background of a thermal noise of an input amplifier. This excludes a problem of conventional *ac*-magnetometry when linear response is detected on background of a large exciting *ac*-field. The main operational characteristics of SHMA are frequency $\omega/2\pi \approx 15.7$ MHz, $h \leq 50$ Oe. The real and imaginary parts of M_2 (2ω) are recorded as functions of H ($|H| \leq 500$ Oe) at sample temperatures ($80\text{ K} \leq T \leq 350\text{K}$). Measurements are carried out under a condition $M_2 \propto h^2$ when $M_2(\omega, H) \propto \chi_2(\omega, H)\, h^2$ (where χ_2 is the dynamic susceptibility of the second order with $\chi_2(0,H) = \mathrm{Re}\chi_2(0,H) = 1/2\partial^2 M/\partial H^2$, $\mathrm{Im}\chi_2(0,H) = 0$ [1]), since the evident expressions of $\chi_2(\omega, H)$ have been obtained for a number of the most important systems [1-4]. This gives basis for quantitative analysis of the data. SHMA has been described in detail earlier [5].

Applications. As our recent works shown, SHMA is the irreplaceable tool for studying the magnetic phase transitions. Its high sensitivity made it possible to investigate a weak ferromagnetism of the doped cuprates [2] and manganites [3,4]. In addition, this method can easy determine a type (first or second) of P-F transition, since, above T_C, $\mathrm{Re}\chi_2$ has the opposite signs for them in a regime $\mathrm{Re}\chi_2(H) \propto H$ if $\mathrm{Re}\chi_2$ dominates in the response. SHMA can be used for numerous other applications such as testing purity of materials, for example, Si, biochemical reagents etc., with respect to contents of the magnetic impurities (Fe, Ni, FeO). As estimations show, its sensitivity is higher than that of expansive activation analysis [5]. It is also a promising tool for investigating the modern materials: the nonlinear optical fibers that contain rare-earth ions, and materials used in semiconductor spintronics where even determining a type of their magnetic state can be a complicated task [6]. SHMA can give unique information on their properties in the weak H, including spin dynamics, which is difficult or impossible to obtain with ESR and/or SQUID. This work was supported by Russian Foundation for Basic Research, Grant No 02-02-81012_Bel2002_a.

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