

2.2 Magnetization relaxation in MnAs nanomagnets on GaAs(001)

Thermal fluctuations in the magnetization of small magnetic particles are one of the fundamental issues of modern micromagnetics. Understanding the relaxation mechanisms is also crucial for applications such as magnetic recording devices. MnAs provides an interesting playground from the viewpoint of both physics and applications. In terms of fundamental physics, the nature of the magnetization relaxation in MnAs is anticipated to be different due to its unusual magnetic properties around the Curie temperature $T_C \approx 315$ K. The phase transition at T_C is first order and accompanies a simultaneous structural transformation with a discontinuous volume change. For applications, the abrupt disappearance of the magnetization and the strong uniaxial magnetocrystalline anisotropy of MnAs are attractive characteristics for, e.g., heat assisted magnetic recording. In this work, we investigated the magnetization reversal processes in nanometer-scale MnAs disks.

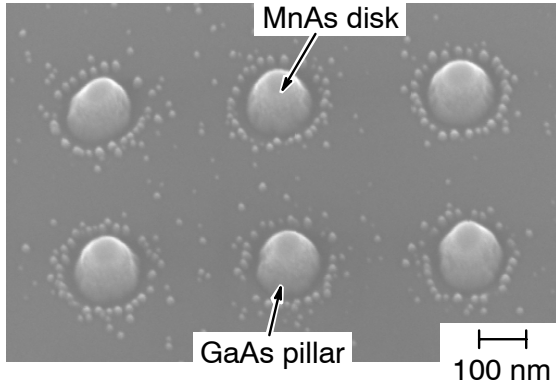


Fig. 5. SEM glancing-angle view of MnAs disks.

In Fig. 5, a scanning electron micrograph (SEM) of MnAs disks is shown. A 50-nm-thick MnAs($1\bar{1}00$) layer was grown on a GaAs(001) substrate by molecular-beam epitaxy. The disks were fabricated from the layer using electron-beam lithography and Ar ion milling. As the sputtering rate for GaAs is considerably larger than for MnAs, the MnAs disks sit on top of GaAs pillars rather than on a flat GaAs surface.

The magnetization of the disks was measured using a SQUID magnetometer. Due to the small size of the disks (diameter ≈ 100 nm), a coexistence of the ferromagnetic and paramagnetic phases is no longer possible in an individual disk. A ferromagnetic disk contains only a single magnetic domain (so-called nanomagnets).

In Fig. 6, the experimentally determined time dependence of the remanent magnetization at a temperature of 310 K is plotted (circles). Prior to the measurement, the sample was magnetized in an external magnetic field of 20 kOe applied along the magnetic easy axis, which is parallel to the MnAs $[11\bar{2}0]$ direction. The magnetic relaxation generally exhibits a logarithmic time dependence due to a distribution in the activation energy. However, because of the deviations from a simple logarithmic decay (see the inset of Fig. 6), we have chosen to perform an effective quantitative analysis of our experimental data by assuming a superposition of three exponentially decaying components

$$M(t) = M_p e^{-t/\tau_p} + M_f e^{-t/\tau_f} + M_s e^{-t/\tau_s}, \quad (1)$$

where M_i and τ_i are the magnitude and the relaxation time, respectively, of the components $i = p, f, \text{ or } s$ ($\tau_p < \tau_f < \tau_s$). The experimental behavior is well described by Eq. (1) as indicated

by the solid curve in Fig. 6. The individual components of the fit are shown by the dotted curves.

We found that the component p increases the magnetization when the sample is cooled to the measurement temperature. The component p is, therefore, identified to be directly associated with the thermal hysteresis of the phase transition between the ferromagnetic phase (α -MnAs) and the nonmagnetic phase (β -MnAs). Consequently, the components f and s are concluded to correspond to the thermal flipping processes of magnetic moments.

We show the temperature dependence of M_i and τ_i , where $i = p$ and f , in Figs. 7(a) and 7(b), respectively. For the data presented here, the fit using Eq. (1) was possible only if $\tau_s = \infty$ was assumed, i.e., the component s could not be resolved within the measurement duration, except for the case shown in Fig. 6.

The time dependence of the magnetization is drastically reduced on cooling so that the decay is barely detectable at room temperature. For temperatures between 315 and 305 K, the reduction of the relaxation takes place by decreasing the magnitudes M_i rather than increasing τ_i . The saturation magnetization in MnAs remains large even for temperatures slightly below T_C due to the discontinuous loss of the ferromagnetic order. The weak dependence of τ_i on temperature in such a narrow range is hence not unexpected. The strong temperature dependence of M_f indicates an onset of a dominant relaxation process in the thermal hysteresis regime, suggesting that the first-order phase transition enhances the flipping of magnetic moments presumably through phase fluctuations.

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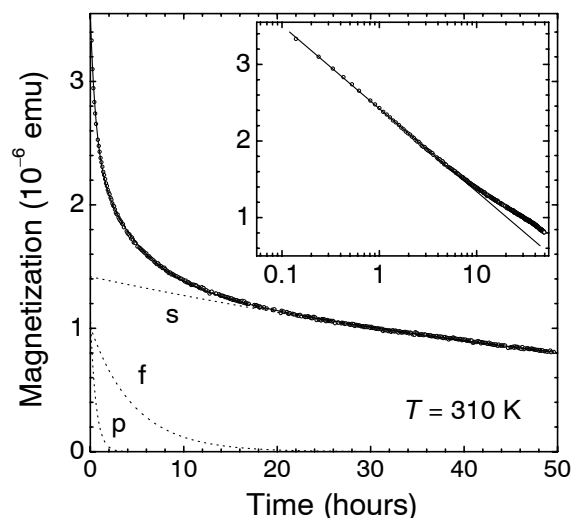


Fig. 6. Decay of the remanent magnetization in MnAs disks. The solid curve is a fit to Eq. (1). The three components are shown by the dotted curves. The solid line in the inset is a guide to the eyes.

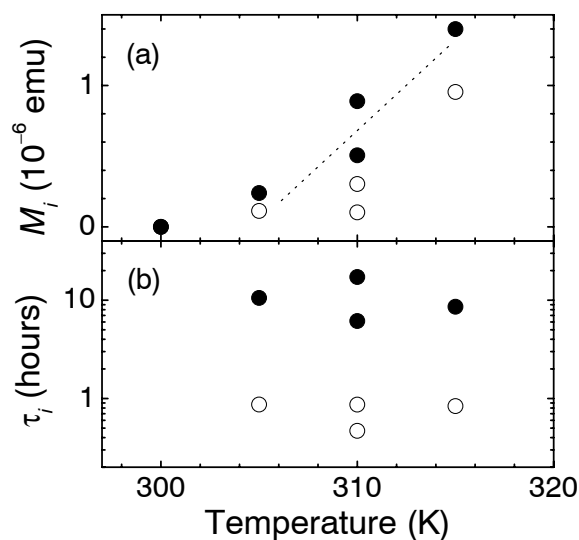


Fig. 7. Temperature dependencies of (a) M_i and (b) τ_i . The open and filled circles correspond to the components $i = p$ and f , respectively. The dotted line in (a) is a guide to the eyes.