# Evolving magnetization dynamics in $Mn_{3-x}Ga$

**J.M. Wikberg, I. Razdolski, A. Kirilyuk, Th. Rasing**

Institute for Molecules and Materials, Radboud University Nijmegen, Heyendaalseweg 135
6525 AJ Nijmegen, The Netherlands

**J. Sadowski**

MAX-lab, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden

**M. Ottoson**

Department of Materials Chemistry, Uppsala University, P.O. Box 538, SE-751 21 Uppsala, Sweden

**Y. Wei, P. Svedlindh**

Department of Engineering Sciences, Uppsala University, P.O. Box 534, SE-751 21 Uppsala, Sweden

m.wikberg@science.ru.nl

Magnetic materials with high magnetic coercivity ($H_c$), magnetic anisotropy ($K_u$) and low Gilbert damping ($\alpha$) are of great importance for future spintronics devices. For instance, for spin-transfer-torque (STT) memory devices low $\alpha$ and high $K_u$ are desired. Such a combination of material properties includes a built in contradiction since both $K_u$ and $\alpha$ are dependent on the spin-orbit interaction (SO); a high $K_u$ material is expected to have a high α. However, recent experimental investigations of $Mn_{3-x}Ga$, a material exhibiting high Curie temperature ($T_c$) > 700 K and (out-of-plane) perpendicular anisotropy, have shown that such a contradictorily low α and high $K_u$ material exists [1]. Depending on Mn-concentration, $Mn_{3-x}Ga$ can form a $L1_0$ (x = 1-2) or a $D0_{22}$ (x<1) structure, which can be epitaxially grown on ordinary semiconductors such as GaAs or oxides, e.g. MgO, at moderate temperatures. Theoretical predictions [2] together with experimental results [3], of low $\alpha = 0.0003$ (0.001), high perpendicular anisotropy $K_u$ = 26 (20) Merg/cm$^3$, moderate saturation magnetization (Ms) of 845 (305) emu/cm3 and high spin polarization of 71% (88%) in $L1_0$ ($D0_{22}$) materials make $Mn_{3-x}Ga$ an excellent candidate for future spintronic applications.

Epitaxial films of $Mn_{3-x}Ga$ (x = 0-2) have been grown with molecular beam epitaxy (MBE) on GaAs substrates with a growth temperature of 150° C. The

 
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growth was monitored with a reflection high-energy electron diffraction (RHEED) system and a short (5 minute) post growth annealing was performed at 250° C. The structural properties of the films have been investigated with x-ray diffraction, while the magnetic properties were investigated with SQUID and VSM magnetometry as well as time-resolved magneto-optical Kerr effect (TRMOKE) in a conventional all-optical pump-probe set-up. The latter allowed time-resolved measurements of the magnetization dynamics as a function of the pump fluence ($F_0$) and magnetic field ($H$) strength.

Our structural measurements confirm the epitaxial film structure and that the nominal Mn-concentrations were reached. The magnetic measurements show that all films exhibit high $T_c > 700$ K and an order of magnitude variation of $M_s$ (42 – 440 emu/cm$^3$) as well as an anisotropy field ($H_a$) from 40 to ~100 kOe as x changed from 0 to 2. Because of the high Ha values and limitations of the used equipment (unable to reach saturation in the magnetic hard axis direction) $H_a$ had to be estimated at times and $K_u$ was evaluated with the relationship:

$$K_u = \frac{M_s H_a}{2} + 2\pi M_s^2 \qquad 1$$

yielding values between 0.85 and 21 Merg/cm$^3$.

Strong influence of the Mn concentration and optical pump beam parameters on the magnetization dynamics was found in the studied samples. The TRMOKE results display characteristic behavior for pump-probe measurements [4] with an ultrafast demagnetization in the first few hundreds of femtoseconds followed by a slow (sub-nanosecond) recovery. The oscillatory dynamics of the transient MOKE signal was proven to be of magnetic nature and corresponds to the uniform precession of the magnetization vector around its new equilibrium with a frequency up to 200 GHz. We observe and analyze the dependence of frequency, amplitude and damping of the oscillations on $Fp$ as well as $H$. From fits of the experimental data the spin precession frequency and lifetime can be obtained and together with the expressions derived from the Landau–Lifshitz–Gilbert equation values for $\alpha$ were extracted.

Hence, we demonstrate the evolvement of $\alpha$ and $K_u$ with changes in Mn concentration over the ferro-/ferrimagnetic phase transition. The results will deepen the understanding of the role of SO interaction on $K_u$ and $\alpha$ in $Mn_{3-x}Ga$ and give valuable insights in designing materials with desired properties.

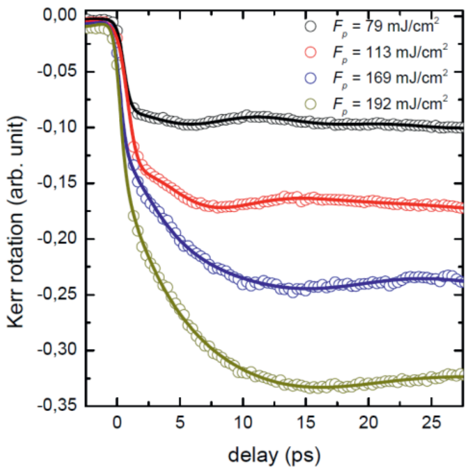


**Fig. 1.** Results from TRMOKE studies on a MnGa (x = 2) sample with $H$ = 10.2 kOe at an angle of 78° with respect to the normal of the sample plane and different pump fluences. Open symbols give the experimental results while the solid lines are fits to the experimental results using an exponentially damped sine function.

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