

## Motivations

Due to the enormous interest in magnetic data storage devices, the current induced domain wall movement by the so-called spin-transfer torque effect is one of the most widely studied areas of magnetism. Increasing the DW velocities as well as reducing the power needed to reverse the magnetization are currently important subjects of research. The influence of the current on the magnetization dynamics is often studied by solving the Landau-Lifshitz-Gilbert (LLG) equation.

$$\dot{\vec{m}} = \gamma_0 \vec{H} + \alpha \vec{m} \times \dot{\vec{m}} - (\vec{u} \cdot \nabla) \vec{m} + \beta \vec{m} \times [(\vec{u} \cdot \nabla) \vec{m}]$$

In the 1D simplest approach the DW velocity is expressed as  $v_{DW} = (\beta/\alpha)u$  where  $u$  is the rate of spin angular momentum transfer from the conduction electrons to the local moments in the DW.

$$u = \frac{JPg\mu_B}{2eM_s} = \frac{JPh}{2eS} = \frac{JPh}{2e(S_{Cd} + S_{Co})}$$

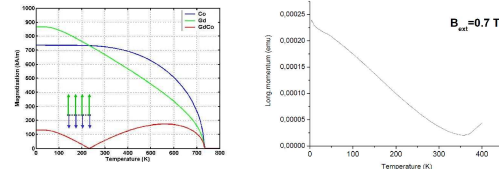
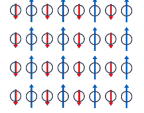
S...total angular momentum  
J...current density  
g...Landé factor

We study ferrimagnetic GdCo alloys, which have the advantage in comparison with a ferromagnetic system that we can significantly tune the spontaneous magnetization by changing either the temperature or the composition of the alloy. The direct consequence of the 1D model is that the spin torque effect is supposed to be enhanced in the vicinity of the angular momentum compensation.

Due to the different Landé factor of Gd and Co spins ( $g_{Gd}=2.2$ ,  $g_{Co}=2$ ) the angular momentum compensation temperature is always higher than magnetization compensation temperature. For example in the case of  $Gd_{20}Co_{80}$   $T_{Mcomp} \sim 235K$  and  $T_{Scomp} \sim 295K$ .

## GdCo properties

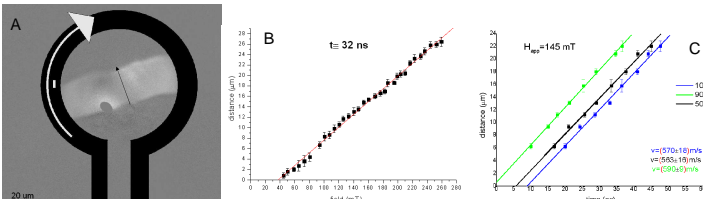
We use a ferrimagnetic alloy  $Gd_{1-x}Co_x$  where the two magnetic sublattices are aligned antiferromagnetically. Since the temperature dependence of the magnetization of each sublattice is different, then in a certain range of concentration ( $x=0.80 \pm 0.05$ ) a compensation temperature ( $T_{comp}$ ) can be obtained.



The GdCo films are deposited on Si substrates by using facing-target magnetron sputtering. Most samples present deposition-induced perpendicular magnetic anisotropy. By using targets of composition  $Gd_{17}Co_{83}$  and  $Gd_{14}Co_{86}$ ,  $T_{comp}$  is slightly above room temperature.

## Field induced domain wall motion

One of the goals is to investigate the DW motion in a compensated material. The field induced DW displacement is governed by the precessional and damping terms of the LLG equation. An ultrafast micro-coil which can provide sufficiently short and high magnetic pulses is used for this purpose. The DW is first injected into the coil and then its displacement is detected by taking differential images by MOKE as a function of applied field or pulse duration (A).

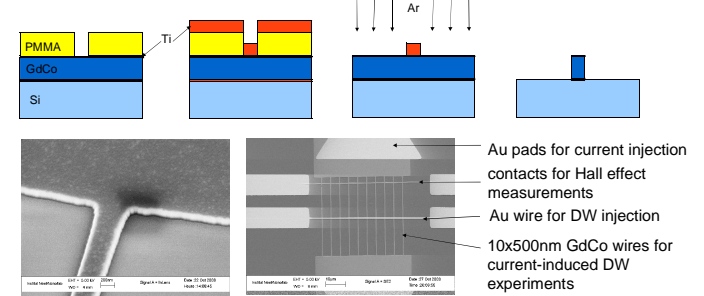


From the measurements it follows that a relatively high field of about 35mT is needed to unpin the DW. Then the flow regime is very quickly achieved, i.e. the DW velocity is proportional to the field amplitude (B). By applying pulse of 145mT the DW velocity of about 560 m/s was measured (C). The DW velocity slightly depends on the definition of the pulse length as is indicated in the plot (D). It is also difficult to determine the depinning time of the DW.

**Perspectives:** measuring DW velocity as a function of magnetization and/or temperature.

## Sample fabrication

The typical composition of our samples is  $Si/SiO_2/Ti(5nm)/GdCo(50nm)/Ti(5nm)$ . The magnetic layer is grown on a buffer layer and protected by 5 nm thick capping layer which should preserve the magnetic layer from parasitic oxidation.

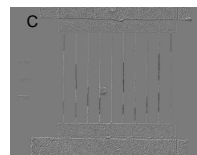
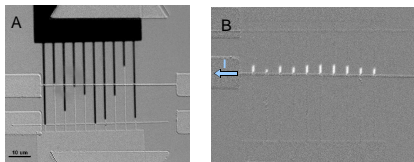


E-beam lithography coupled with ion etching technique are used for this purpose. This technique allows to obtain typical lateral roughness about 20nm. If lateral roughness is not treated properly, then imperfections and notches induce an additional pinning of the DW and consequently increase critical current density. The structure consists of two pads which are connected by ten 500nm wide nanowires, allowing easier statistical measurements on current-induced DW motion in these wires.

## Domain wall injection

Domain wall can be injected into the wires by two ways:

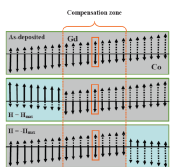
- slowly reversing applied field – injected DWs (A)
- reversing magnetization by Oersted field generated by short current pulse (B)



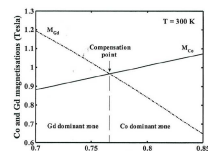
Clear spin-torque effects have not been observed so far. DW motion can be triggered by many factors: temperature distribution along the wire, composition gradient along the wire, spin-torque effect, Oersted field by the line itself, etc. (C)

## Composition-controlled compensation domain wall

The layers are deposited by using targets of composition  $Gd_{17}Co_{83}$  and  $Gd_{14}Co_{86}$ . The composition of the targets always differs from the composition of the film (Gd-rich compared to the targets) – because of the difference between the ratio of Gd and Co deposition rates. Due to the different sputtering angles for Gd and Co, a composition gradient is present throughout the film.



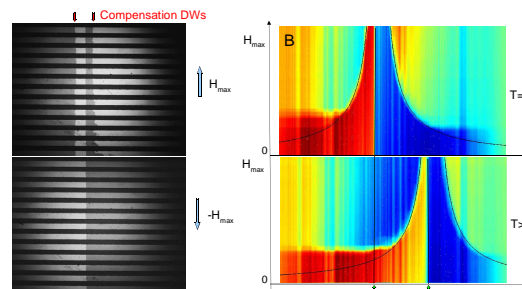
The coercive field is a function of magnetization - the smaller the magnetization is, the larger the coercive field is. The compensation domain walls are taking place where the coercive field is equal to the applied field, the position of the compensation domain wall depends on the applied field.



The compensation composition depends on T, for  $T=300K$  the compensation point takes place for  $x_{comp}=0.76$  (Co fraction).

## Experimental study of compensation domain wall

Thanks to the perpendicular anisotropy of  $Gd_{1-x}Co_x$  thin film, the compensation domain wall can be observed by using polar Kerr imaging. The total magnetization can be observed even at  $M=0$  since Kerr rotation is mainly sensitive to Co magnetization (A).



Because  $M(x)=0$  is a function of temperature, one can expect that, in a  $Gd_{1-x}Co_x$  thin film with in-plane gradient of composition, the compensation surface will move when the temperature changes. We confirmed this by heating the wire using an electric current (C).

Magnetization reversal is mainly controlled by domain wall propagation. Considering a single type of pinning center, a crude model can be proposed where the Zeeman energy is equal to the pinning energy at the coercive field. Then  $H_c = E_p/\mu_0 M$ . The pinning energy is used to fit the DW position as a function of field (B).

**References:** N.T.Nam: *Fabrication and study of magnetic and transport properties of GdCo thin films, GdCo-based multilayers and Fe/Cr multilayers*, PhD.Thesis (2007)  
Hansen et al.: *Magnetic and magneto-optical properties of rare-earth transition-metal alloys containing Gd, Tb, Fe, Co*, J.Appl.Phys. 66(2), 1989.

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