1
Laboratoire Louis Néel, CNRS, Grenoble, France

2
Max-Planck-Institut für Mikrostrukturphysik, Halle

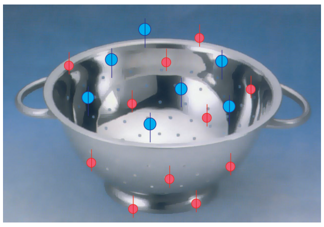
3
Departamento Física de la Materia Condensada, Universidad Autónoma de Madrid, Spain

4
Departamento de Engenharia Elètrica, Universidade do Paraná, Curitiba, Brazil

Magnetisation dynamics in spin-valves: how fast can a hard disk be read?

J. Vogel[1], W. Kuch[2], J. Camarero[3], K. Fukumoto[2], M. Bonfim[4], Y. Pennec[1], S. Pizzini[1], A. Fontaine[1], J. Kirschner[2]

How long does it take to load this text from the hard disk of your computer? With the current technology this depends on the time needed to switch the magnetisation of a soft magnetic layer in the read head of the hard disk drive (Fig. 1). The essential part of this device is a spin-valve. This could be imaged as an electron sieve, which changes the size of its holes depending on whether it reads a 1 or a 0. The spin-valve consists of a trilayer system in which two ultrathin ferromagnetic layers are separated by a non-magnetic spacer. The magnetisation of one layer is always oriented in the same way, i.e. upwards, while the orientation of the other one is switched (up or down) by the bits over which the head passes. Electrons are transported more easily if the magnetisation directions of the two magnetic layers are pointing in the same direction. If the two ferromagnetic layers of the spin-valve are antiparallel aligned, it is more difficult for the electrons to pass, thus leading to a giant magneto resistance (GMR). Presently, read and write times approach one nanosecond, corresponding to 1 GHz frequency.



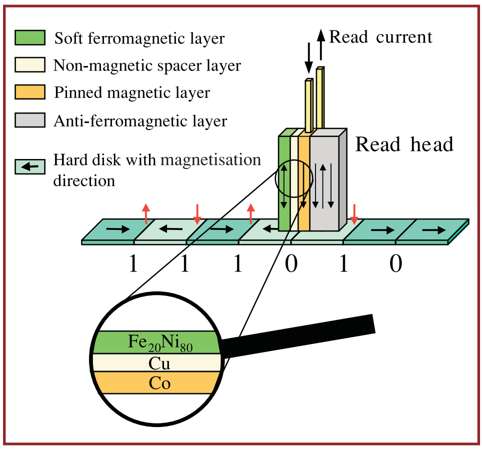


Fig. 1:
Working principle of a spin valve used in computer hard disks. The small stray field (red arrows) at the borders of the bits polarises the soft magnetic layer (green) of the read head. A small electrical current is applied parallel to the magnetic layer system. The read head has either a low resistance for parallel alignment or a high resistance for antiparallel alignment of the soft and the pinned magnetic layer (yellow).

Investigating the magnetisation dynamics in spin valves is thus very important from both a fundamental and an applied point of view.

We have carried out microscopic domain imaging measurements of the magnetisation reversal dynamics in a spin valve with time and layer resolution. Photoelectron emission microscopy (PEEM) in connection with X-ray magnetic circular dichroism (XMCD) is used to obtain magnetic domain images [1]. Because of the element selectivity of XMCD, different magnetic layers in a multilayered stack can be imaged separately [2]. Time resolution is obtained using a pump-probe approach (Fig. 2). Magnetic field pulses provided by a microcoil and a fast power supply (the pump) are synchronised with the X-ray photon pulses (the probe) in single bunch mode [3]. Images are then acquired for different constant delays between pump and probe, i.e., at different times before, during, or after the application of the magnetic field pulses. In this way the magnetisation dynamics of each magnetic layer can be visualised separately with a time resolution limited by the X-ray pulse width (about 60 ps).

A typical spin-valve sample was chosen which consisted of a 5 nm magnetically soft permalloy $Fe_{20}Ni_{80}$ layer and a 5 nm magnetically harder cobalt layer, separated by a 4 nm non-magnetic metallic Cu spacer layer, deposited on a SiO_2/Si(100) substrate. The $Fe_{20}Ni_{80}$ and Co layers are magnetically coupled across the copper spacer layer due to the presence of correlated roughness at the $Fe_{20}Ni_{80}$/Cu and Co/Cu interfaces (magnetostatic 'orange-peel' coupling [4]).

The aim of these measurements is to study the magnetisation reversal of the $Fe_{20}Ni_{80}$ layer upon application of nanosecond-long magnetic pulses, and to investigate how the interaction between the two layers influences this reversal. To obtain a good signal to noise ratio, images have to be averaged over a total acquisition time of several minutes, corresponding to several hundreds of millions of pulses [5]. This method therefore can only work for systems in which the magnetisation reversal is reproducible, i.e., it is the same for each of the applied

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magnetic pulses. The measurements were carried out at beamlines UE56/2-PGM2 and UE52-SGM, using circularly polarised soft X-rays. The magnetisation of the sample lies in the plane of the layers, and no preferential magnetisation axis exists within this plane.

In Fig. 3 we show time-resolved images of the $Fe_{20}Ni_{80}$ layer (domain contrast presented in blue and green) and of the Co layer (domain contrast red and yellow). The projection of the X-ray incidence direction on the sample surface is pointing up in the images, and is parallel to the direction of the field for positive fields. The magnetisation of the sample is first saturated in the negative direction (pointing down in Fig. 3), giving rise to completely green and yellow images for the FeNi and Co layer, respectively. Short bipolar magnetic pulses as shown at the left bottom of Fig. 3 were then applied to the sample. The repeated application of these pulses quickly leads to the zero field $Fe_{20}Ni_{80}$ and Co domain structures shown in panels a and d, respectively. Once this domain structure is stabilised, the magnetic pulse has no further influence on the Co magnetisation, which shows the same pattern as in panel d for all times, i.e. the magnetic pulse amplitude is adjusted so that the magnetisation of the cobalt layer is not affected by the magnetic field. In the $Fe_{20}Ni_{80}$ layer, the positive part of the magnetic field pulses favours the growth of the blue domains through propagation of domain walls (panel b). Negative fields favour the growth of green domains (panel c).

The shape of the domains is very irregular due to the absence of a preferential direction of magnetisation (or anisotropy) within the plane of the layers. The interaction through the Cu spacer layer favours a parallel alignment of the magnetisation direction of the two magnetic layers. One would therefore expect that for field values close to zero the domain structures in the two layers were the same. In Figs. 3b and c the red domains of the Co layer have been schematically outlined by black lines onto the $Fe_{20}Ni_{80}$ images. A certain correlation exists between the domain structures in the two layers, but this correlation is not perfect for any value of the field. The role played by the intrinsic properties of the permalloy layer, in particular the anisotropy and the pinning of the domain walls by small defects, is at least as important as the local coupling with the Co layer. Measurements on similar samples have shown that the competition between intrinsic properties and local coupling strongly depends on sample characteristics. The combination of temporal, spatial and chemical resolution makes this technique extremely powerful for studying magnetisation dynamics in heterogeneous magnetic systems.

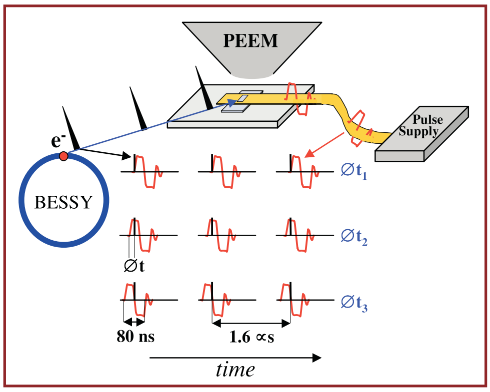

Fig. 2:
The principle of a pump-probe experiment with PEEM microscopy. A short magnetic field pulse is periodically applied to reverse the magnetisation of the soft layer. The magnetic pulses (red) are synchronised with the photon pulses (black) in single bunch mode. Images are taken for several time delays Δt between field pulses (pump) and synchrotron X-ray pulses (probe).

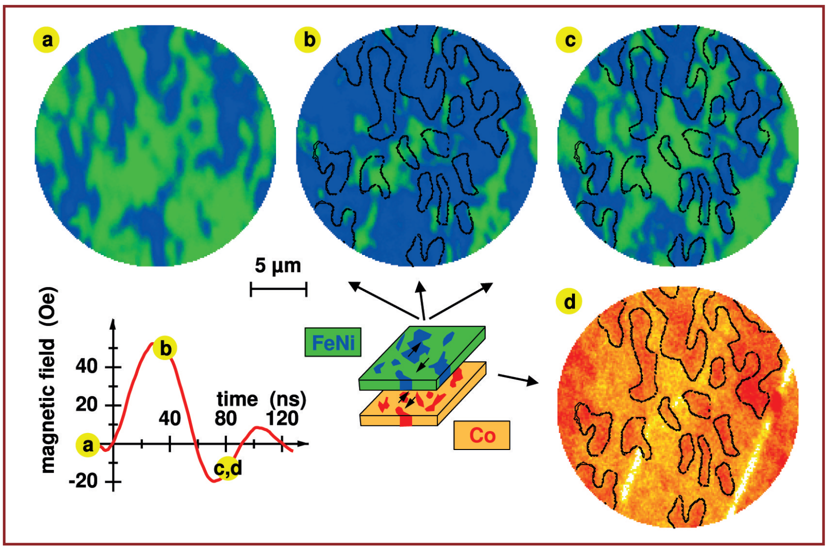

Fig. 3:
Time and layer-resolved XMCD-PEEM images (diameter 22 µm) for the magnetisation state of the $Fe_{20}Ni_{80}$ (a-c) and Co (d) layer in a $Fe_{20}Ni_{80}$/Cu/Co spin valve. The magnetisation direction points up for blue and red domains, while it points down for green and yellow domains. The different time delays with respect to the magnetic pulse are indicated on the graph at the bottom left, which shows the temporal shape of the magnetic field pulses. The most clearly visible red domains in the Co layer are denoted by black lines, and shown superimposed on the permalloy images b and c.

Contact:
Jan Vogel
vogel@grenoble.cnrs.fr
Wolfgang Kuch
kuch@mpi-halle.de