Magnetic measurements based on magneto-optical Kerr effect on pnictide $Ba(Fe_{1-x}Co_x)_2As_2/Fe$ thin film

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Magnetic measurements based on magneto-optical Kerr effect on pnictide $Ba(Fe_{1-x}Co_x)_2As_2$/Fe thin film

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Abstract: We present characterization of $Ba(Fe_{1-x}Co_x)_2As_2$ thin film using a magneto-optical Kerr effect setup based on photoelastic modulation. The magneto optical technique has been used to analyse the thickness and the temperature dependence of the magnetic properties of epitaxial $Ba(Fe_{1-x}Co_x)_2As_2$/Fe thin films grown on MgO substrate. The first harmonics, of the reflected laser beam intensity from pnictide thin films is compared with a reference Fe thin film. The hysteretic loops of such samples at room temperature and at 5K are presented.

1. Introduction

Magneto-optics studies the interaction of light with a medium exerting action of an external magnetic field, including changes in the polarization state and in the propagation direction of light. It greatly contributes to the development of modern optical measurement techniques. For this reasons the magneto-optical Kerr effect MOKE has emerged as a powerful experimental technique to study the magnetic properties of thin films and multilayers.

Compared to other elegant techniques such as superconducting quantum interference device magnetometry, magnetic force microscopy, etc., the advantages of MOKE [1] include high sensitivity down to the monolayer resolution, high temporal and spatial resolution, simplicity, and straightforward in situ implementation all of that at very low costs in comparison with its alternatives. MOKE has been extensively employed to investigate several important phenomena of modern magnetism. Some of them are: determination of electronic structure [2], discovery of the oscillations in exchange coupling between ferromagnetic layers separated by an antiferromagnetic or nonmagnetic layer [3-4], observation of perpendicular anisotropy in ultrathin films [5], test of two-dimensional Ising model in monolayer films [6], spin reorientation transition, and correlation between magnetic anisotropy and lattice symmetry breaking [7]. MOKE measurements can be realized with various setups. Here we focus on the analysis of the widely used modulation technique in longitudinal configurations. The performance of the realised MOKE set up has been tested on Fe- based superconductors thin films. The recent discovery of superconductivity with transition temperature T_c up to 55 K in iron–pnictide systems [8] has attracted enormous interest in this class of materials. Investigations on this new class of superconductors have revealed for instance, a multiband nature, and a short coherence length. A common phase diagram for Fe–pnictides suggests the existence of an antiferromagnetic spin density-wave (SDW) ground state that is stabilized by Fermi-surface nesting [9] as well as by strong antiferromagnetic (AFM) spin interactions along the Fe-square-diagonal [10]. Moreover, in underdoped compounds a coexistence of SDW and superconducting phase can be present. In this work, AFM characterization of the Co-doped Ba-122/Fe thin films with a thickness of 20nm and 40nm is reported. Moreover, the MOKE characterization in terms of hysteretic loop at 300K and 5K has been carried out.

2. Experimental set-up

As reported in figure 1 (right) the components of the MOKE set up include: an He-Ne laser having wavelength = 633nm and an output power of 15 mW, a polarizer *P*, the sample *S* among Helmholtz coils, a photoelastic modulator *PM*, an analyzer *A*, and the photodetector *D*. Since the Kerr rotation angle θ_K and ellipticity θ'_K are typically small, i.e., 10^{-3} rad, optimization of the signal-to-noise S/N ratio is very crucial. In order to achieve an optimum S/N ratio, appropriate placements and orientations of the optical components are crucial.

The laser produces a nearly linearly polarized beam allowing for s-polarized electric field vector oscillating perpendicular to the plane of incidence or p-polarized electric field vector oscillating in the plane of incidence configurations. Subsequently, we discuss s-polarized incoming light only. In our setup, due to geometrical constraints of the Helmholtz coils the laser beam makes only an angle of about 20° with the normal of the sample surface as reported in figure 2 (right).

The laser beam then passes through a Glan–Thompson polarizer (Edmund Optics) with an extinction coefficient of 10^{-6} which produces high degree of polarization. A lens of focal length *f* =300 mm and diameter of *D* =50 mm is used to focus the light beam onto the sample surface.

The reflected beam is periodically modulated between left and right circularly polarized light by the photoelastic modulator *PEM*-90 (Hinds Instruments). Modulation takes place with a frequency of 50 kHz. The modulation signal is used as reference signal for a lock-in amplifier (EG&G 7260 Instruments). The beam then is transmitted through an analyzer and is finally detected by a photosensitive fast responding diode (Nirvana detector-Model 2007) providing the input signal to the lock-in amplifier. An electromagnet, home made, in the Helmholtz configuration, capable of generate a magnetic field of more than 50mT, powered by a bipolar power supply Elind KL 1200 has been used. The intensity of the magnetic field has been measured by a Hall sensor model 516-60, realized by Leybold. The sample was mounted on a cold finger in a temperature controlled liquid helium continuous flow optical cryostat realized by Oxford Instruments, operating between 4.2 and 350 K.

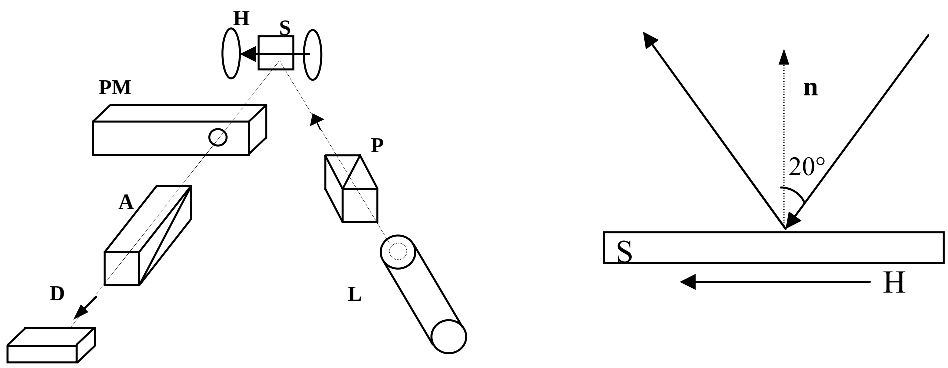

Figure 1. (left) used MOKE set-up: L = He-Ne laser, P = polarizer, S = sample surface, H= magnetic field direction, PM = electro-optical modulator, A= polarizer used as analyzer, D = detector; (right) represents the longitudinal MOKE configuration in which the orientation of the magnetic field H is parallel both to the sample surface and the plane of incident light.

3. Results and discussion

Using the experimental set-up reported in figure 1 different magneto-optical measurements have been performed. The investigated samples are $Ba(Fe_{1-x}Co_x)_2As_2/Fe$ having thickness of 20nm and 40nm where the Fe layer is 20nm and the substrate of MgO is 0.5mm. the content of Co-doping is nominally 8%. Moreover, a Fe 20nm thick thin film has been used as reference. More details about the fabrication of the sample are reported elsewhere [11]. The transport properties of the sample used in this experiment are quite different, in particular the 20nm thin film shows a superconductive behaviour with a critical temperature of T_c about of 9.5K, while the sample of 40nm thick shows a T_c of 16.5K.

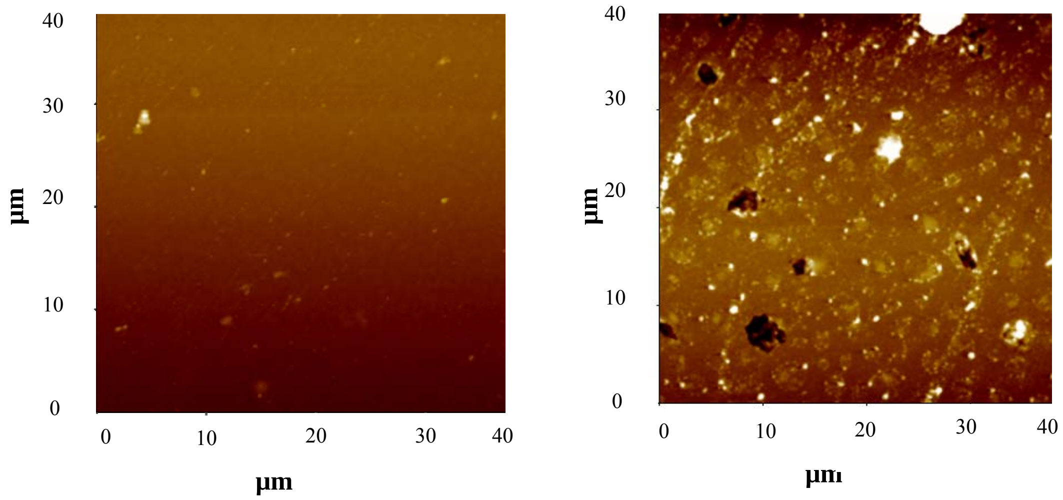

Figure 2. AFM of the samples having thickness of 40 (left) and 20nm (right) respectively.

The laser spot used in the MOKE measurements is about 0.8 $(mm)^2$ where the optical penetration depth is about 15-20nm. It is interesting to note that the surface roughness of the two sample is quite different as reported in the figure 2, in fact the surface of the sample of Ba-122 (20nm) thick is full of FeO based outgrowth. Measurements by a conventional VSM (Vibrating Sample Magnetometer) has been performed on the same sample analysed in this work. The results, not shown here, cannot enable us to detect different behaviours with respect to the sample thickness and cannot be useful for clarify the role of iron layer on the magnetization at room temperature.

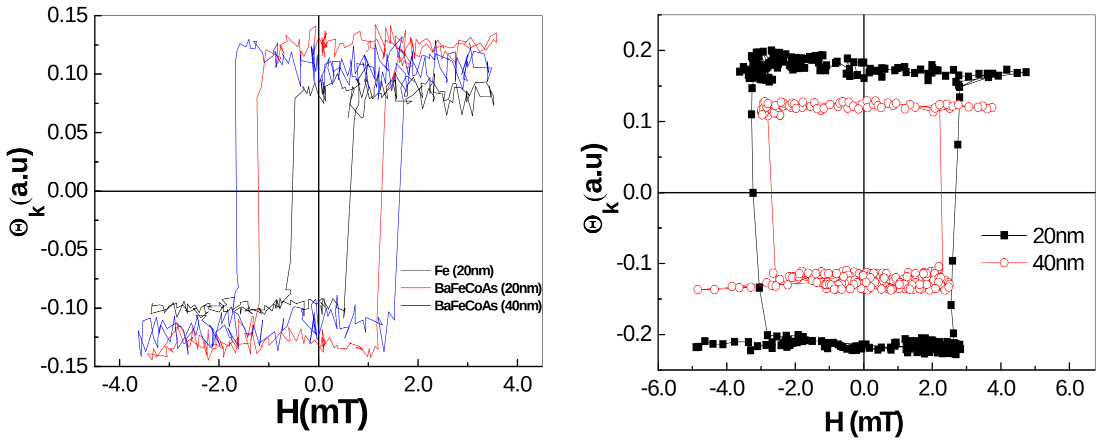

Figure 3. (left) MOKE measurements at room temperature of the 20nm and 40nm Ba-122/Fe are compared with the Fe 20nm thick thin film; (right) comparison of MOKE measurements of the Ba-122/Fe thin film of 20nm and 40nm measured at 5K.

The MOKE measurements at 300K show (figure 3 left) that the coercitivity of the sample increases with the thickness of layer of Ba-122 instead the measurement performed at 5K, reported in the (figure 3 right), indicate an opposite behaviour. In the latter case the coercitivity of the thin film reduces when the thickness of the sample increases. At room temperature we obtain for Ba-122/Fe of 20nm thick a coercitivity of H_c=(1,3±0,1) mT while for Ba-122/Fe 40nm it is H_c = (1,8 ±0, 1) mT. Both the samples show an H_c larger than that of the only iron thin film 20nm thick.
This result demonstrates that the MOKE measurements reveal the contribution to the magnetic behaviour mainly due to the Co-doped Ba-122 thin films. Moreover, since the H_c is larger than the only Fe thin film, it is reasonable that the hysteretic loops of Ba-122/Fe of 40nm and 20nm include also the Co magnetic contribution. Then, considering that the Ba-122 Co-doped of 20nm has a thickness comparable to the optical penetration depth, the hysteretic loop of such samples at 300K

includes two contributions: the first due to the FeO outgrowths, and the second due to the interface between the Fe and the $Ba(Fe_{1-x}Co_x)2As_2$ layer. Moreover, regarding the figure 3 (right) the increasing of the H_c at low temperature for both Ba-122 samples could be addressed to the possible coexistence of the SDW and superconducting phase. This statement could be due considering the hypothesis that the samples are not 8% Co-doped but they are underdoped samples since a strong Co diffusion into the Fe buffer can be observed [12]. Moreover, further experiments are currently in progress aiming to better understand the nature of such result.

4.Conclusion

MOKE measurements and AFM have been realized on superconductive $Fe/Ba(Fe_{1-x}Co_x)_2As$ thin film at room and low temperature. The AFM measurements shown that the surface of the thin film 20nm thick is full of outgrowth due to the iron diffusion inside the Ba-122 film. The magnetization of the 20nm thin film is greater than the magnetization of the 40nm $Fe/Ba(Fe_{1-x}As_x)_2Co$ thin film measured at 5K. The MOKE set up shows a good sensitivity and a good signal to noise ratio that enable us to perform hysteretic loop, from room temperature up to 5K, due to the superconducting Ba-122 thin films even if they are grown on Fe buffer layer.

Acknowledgment

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Corrigendum: Magnetic measurements based on magneto-optical Kerr effect on pnictide $Ba(Fe_{1-x}Co_x)_2As_2$/Fe thin film

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