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TEMPERATURE DEPENDENCE OF MAGNETO-OPTICAL EFFECTS ON 
Fe – Al₂O₃ GRANULAR FILMS

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Abstract. – Faraday and Magnetic Circular Dichroism measurements in the region of near infrared are performed in the temperature range 4 < T < 300 K on Fe – Al₂O₃ granular films. The intensities of the observed transitions, due to Fe³⁺ and Fe²⁺ ions, remain constant below characteristic temperatures depending on iron concentration and on the average particle’s dimensions.

Introduction

Fe – Al₂O₃ granular films, which consist of small iron particles (0 < 200 A) dispersed in an amorphous alumina matrix, have been extensively studied from a structural [I, 2] and a magnetic point of view [3, 4]. XPS [I] and Mossbauer [4] experiments have shown that the iron particles are composed of a metallic Fe⁰ core surrounded by an oxidized shell (Fe²⁺ and, in lower percentage, Fe³⁺). The oxidized fraction increases with decreasing particle size. At the surface, the iron is in a fully oxidized Fe³⁺ state, and the degree of oxidation decreases with the depth in the film.

In this paper we report the results of Faraday Rotation (FR) and Magnetic Circular Dichroism (MCD) measurements in the region of near infrared. The measurements have been performed at different temperatures extending the range of previous experiments [5] down to 4.2 K.

Results and discussion

FR and MCD give complementary information related to the imaginary and to the real part of the refractive index and therefor proportional to the magnetization of the material.

We have performed measurements on various samples with different iron concentrations and different average sized particles. (Sample S12: average diameter ø = 45 A, percentage in weight of Fe = 50 %, S13: ø = 55 A, Fe = 55 %; S17: ø = 70 A, Fe = 60 %; S16: ø = 85 A, Fe = 70 %.) At 300, 77 and 4 K the measurements have been made using the whole wavelength interval (0.8 – 2.6 μm) permitted by our experimental apparatus; whereas we followed the variation in the temperature only for the more significative wavelength values. During the measurements we utilized a magnetic field H = 4.0 KOe which remained applied in alternating direction every one minute and half.

In figure 1 the results of the 4 K measurements of both the magnetooptical effects for all the samples are reported versus wavelength. At low wavelengths it is possible to observe a very high value of FR, which lets us hypothesize possible applications of the material. The structure of the spectra shows transitions, more evident in the FR results, centered around 0.95, 1.6 and 2 μm. The first of them can be attributed to Fe²⁺ ions as confirmed by comparison with our previous measurements. With respect to these we find an increase in the FR signal due to the increase of the Fe³⁺ concentration produced by the surface oxidation process during the time between the experiments [I]. The other two transitions can be originated only by Fe²⁺ ions. The differences in the intensities for the various samples agree well with their relative fractions of oxidized iron.

Because the signals, coming from very thin samples, have a big noise, and in order to understand the behaviour of the samples in fuction of the temperature, we show in figure 2 the ratios between the FR intensities measured at 4 and 77 K.

Fig. 1. – Faraday Rotation (upper part) and Magnetic Circular Dichroism (lower part) measured at 4 K reported versus wavelength for all the samples.
that, decreasing the temperature, the magnetooptical signals coming from Fe\(^{2+}\) transitions grow up more rapidly than those due to Fe\(^{3+}\) ions. Moreover this increase is different for different samples: in the region 1.4 \(\div\) 2.6 \(\mu\)m the values of this ratio are 2 for S12, 1.5 for S13, 1.1 for S17 and 1.0 for S16. The analogous ratios between the FR intensities obtained at 4 and 300 K are around 3 for S12, S13 and S17 and only around 1.2 for S16, which alone shows a higher value at lower wavelengths. For all the samples the MCD ratios confirm those determined by FR experiments. We also followed the behaviour in temperature of FR and MCD for all the samples at the central wavelength of each transition. We report in figure 3 some results for S17 and S16: at \(\lambda = 1.6 \mu\)m decreasing the temperature increases the signal up to a constant value reached at a characteristic temperature \(T = 40 \text{ K}\) for the first sample and \(T = 250 \text{ K}\) for the second one. Similar results are obtained at 2.0 \(\mu\)m while at 0.95 \(\mu\)m the values show little change. The same phenomenon seems to be present also for S12 and S13 but it is not possible to clearly identify the characteristic temperatures because of the noise in the measurements.

Conclusions

Low field (few Oersteds) susceptibility measurements showed maxima at temperatures \(T_B\), which are associated to the blocking process of the total magnetization of each particle. We point out that, while the susceptibility is mainly due to the ferromagnetic metallic core of the particles, the optical response is more sensitive to the external oxidized shells of the particles and to the oxidized particles at sample surface, whose contribution to the susceptibility is low. The information comes from the two types of experimental techniques is therefore complementary. The characteristic temperatures, below which the intensity of the optical transitions remains constant, are related to the \(T_B\) value, following the same behaviour with the iron concentration, as they reflect the interaction between the surface and the core of the particles and the magnetic properties of the particles at the sample surface.