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MAGNETIZATION AND MAGNETORESISTANCE MEASUREMENTS ON MONOATOMIC SCALE IN MnSb/Sb SANDWICHES AND MULTILAYERS

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Abstract. – We have investigated, by means of magnetization and magnetoresistance measurements, the magnetic properties (critical temperature, magnetic anisotropy, coercive field) of single film and multilayers of a few atomic MnSb monolayers sandwiched by Sb.

In this paper, we present experimental data on single sandwich Sb/MnSb/Sb and multilayers (MnSb/Sb)_n. Mn and Sb are insoluble with each other but form easily intermetallic compounds (MnSb, Mn₂Sb). MnSb is known to be ferromagnetic ($T_c = 500$ to 600 K for different Mn compositions near 50 % atomic percentage, Ref. [1]). Due to the high reactivity of Mn with Sb near room temperature, the MnSb compound is easily formed on Sb surfaces even during high vacuum Mn deposition (X-ray diffraction patterns suggest that the compound is nearly stoichiometric, Ref. [2]).

Since the lattice mismatch between Sb and MnSb is 4.5 %, one can expect to obtain multilayers with epitaxial well defined ferromagnetic monolayers in order to investigate two-dimensional magnetism.

Sample preparation and characterization

The multilayers (MnSb/Sb)_n were prepared in Kyoto University and Sb/MnSb/Sb sandwich in the Institut d'Optique, Orsay. First a Sb buffer layer is deposited on polished glass or kapton at room temperature. This Sb substrate of good crystallographic quality is formed by very large crystals (about 2000 nm and up in lateral size). From TEM and HREM images, we can say that there is no evidence of defects. X-rays and electron diffraction patterns show a privileged orientation with the [00.1] axis, perpendicular to the surface of Sb substrate (Ref. [3]). Mn and Sb layers were deposited alternatively under ultra-high vacuum (10^{-9} Torr during deposition) with a deposition rate of about 0.5 Å/s .

Both X-ray diffraction and electron diffraction were used for samples characterization. In the multilayers, superlattice reflection appears both at small and middle angles in the X-ray diffraction pattern (Refs. [2, 4]). High-resolution cross sectional TEM images show a good structural coherence between adjacent Sb layers: some atomic steps are observed in MnSb layers, perfectly flat monolayers extend over about 50 Å (Ref. [5]).

We have studied here the following samples:

S1:glass/Sb(500 Å)/[Mn(2 Å)/Sb(50 Å)]₉₂
S2:glass/Sb(700 Å)/[Mn(1 Å)/Sb(50 Å)]₉₀
S3:kapton/Sb(700 Å)/[Mn(1 Å)/Sb(50 Å)]₉₀
S4:glass/Sb(390 Å)/[Mn(1.5 Å)/Sb(3.7 Å)]₃₀/Sb(165 Å)

(the S4 single sandwich Sb/MnSb/Sb is obtained by alternated deposition of monolayers of Mn and Sb).

Hysteresis curve and magnetoresistance measurements

Hysteresis curves have been recorded in Kyoto University with a commercial SQUID magnetometer. All samples show ferromagnetic properties at low temperature. Due to small perpendicular interface anisotropy, only S2 and S3 samples exhibit perpendicular easy axis (Ref. [2]). In the thicker ones the easy magnetization axis lies in the film plane. The magnetoresistance (MR) measurements have been performed at 4.2 K with the field up to 5.5 T (Ref. [6]). Despite the fact that the resistance R of the films is essentially due to the thicker Sb layers, the magnetic contribution of ferromagnetic MnSb layers is clearly observed in the hysteretic magnetoresistance at low temperature (Fig. 1). For high magnetic fields the magnetoresistive contribution of Sb, $R_{ab}(H)$, is described nearly by a parabolic law. The hysteretic contribution of MnSb: $\delta R = R(H) - R_{ab}(H)$ exhibits a maximum δR_c for the field H_c . Assuming that the MnSb contribution is proportionnal to the number of domain walls, we can deduce M/M_s from δR by the simple formulae (Ref. [7]):

$$M/M_s = (1 - \delta R / \delta R_c)^{1/2} \quad (1)$$

In this model, H_c corresponds to the coercive field.

We have observed in MnSb samples similar qualitative MR results as in Co layers (Ref. [6]): large relative magnetoresistance $\delta R_c/R$ (up to 3 %) in ultra-thin ferromagnetic layers and small relative one in the thicker S4 sample. ($\delta R_c/R = 10^{-4}$). Significant hysteretic magnetoresistance was observed only with the field along easy magnetization axis (except for the sample S1). Only monolayer of MnSb exhibits perpendicu-

Fig. 1. - Measured hysteretic resistance of sample 1 versus applied transversal in-plane magnetic field H . White triangle: increasing field; black triangle: decreasing field.

lar anisotropy. S1 (2.5 MnSb monolayers) has already easy magnetization axis in the film plane ($M_{R\parallel}/M_s = 0.5$; $M_{R\perp}/M_s = 0.2$). We have obtained at 4.2 K the following values of the coercive fields: 1200 Oe (S1), 850 Oe (S3), 1350 Oe (S4).

Figure 2 shows the hysteresis curve $M(H)$ and the dc-demagnetization curve $M_d(H)$ along the easy magnetization axis (sample S4) measured directly by SQUID susceptometry. One can see a nearly good agreement with MR determinations of $M(H)$ and $M_d(H)$ following equation (1). $M_d(H)$ dependence is a picture of irreversible behaviour alone (in the contrary to $M(H)$) and has rather square shape.

Ferromagnetic transition temperature

We have also checked the critical region near the transition temperature in these samples with a low field SQUID susceptometer in Orsay (Ref. [8]). We have studied zero field cooled magnetization (ZFCM) and reversible field cooled magnetization (FCM) for

Fig. 2. - Relative magnetization M/M_s versus parallel applied magnetic field H in sample 4. Hysteresis curve (square) and dc-demagnetization curve (triangle) are measured by SQUID susceptometer (black symbols) or MR (white symbols).

Fig. 3. - Zero field cooled magnetization (white triangles) and field cooled magnetization (black triangles) versus temperature for sample 2 in a 0.1 Oe applied magnetic field. Solid and dashed lines are guide for the eyes.

S1, S2 and S3 samples in the field range 0-20 Oe with remanent field as low as 0.2 mOe. We have measured the transition temperatures: $T_c \approx 250$ K for 2.5 MnSb monolayers (S1) and $T_c \approx 80$ K (S2) or ≈ 70 K (S3) for 1.25 MnSb monolayers. ZFCM and FCM thermal variations are identical above T_c and separate below T_c . The samples S1, S2 and S3 exhibit the same qualitative behaviour (Fig. 3): the separation between thermal variations of ZFCM and FCM is smooth even in very low field (0.1 Oe) and ZFC thermal variation doesn't exhibit sharp peak as observed in Au/Ni/Au sandwiches (Ref. [9]). As T_c varies very rapidly with the thickness for a few monolayers of MnSb, we can interpret the smoothness of transition as the signature of a distribution of transition temperatures of the individual uncoupled MnSb layers in the multilayer structure due to the small thickness dispersion and interface roughness.

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