Structural disorder and magnetism in equiatomic CoFeMnSi epitaxial thin films

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Among the large family of Half-metallic ferromagnetic materials, Co-based Heusler alloys attracted lot of attention due to their high spin polarization with high Curie temperatures [1,2]. Equiatomic quaternary Heusler alloys (EQHAs), with Y-type crystal structure are relatively new class of materials and explored very little [3]. CoFeMnSi (CFMS) is one of the EQHAs, which has been predicted as a nearly spin-gapless semiconductor and the spin-polarization was relatively high in bulk form [4, 5]. However, there is no report available on magnetic tunnel junctions (MTJs) with CFMS thin film electrode.

In this study, we investigate the structural and magnetic properties of CFMS epitaxial thin films and also investigate tunnel magnetoresistance (TMR) for MTJs. 30 nm thick CFMS films were grown on single crystalline (001) MgO substrate buffered by 40 nm thick Cr layer using the UHV magnetron sputtering system with a base pressure of less than 2 X 10^{-7} Pa. Samples with CFMS annealed at Ta = 300, 400, 500 and 600ºC were prepared. The composition of the deposited CFMS films was confirmed to be $Co_{25}Fe_{24}Mn_{24}Si_{26}$ (at. %) using the inductively coupled plasma (ICP) analysis, which is almost ideal stoichiometric composition for EQHAs.

The out-of-plane XRD patterns show CFMS (002) and (004) peaks for samples with Ta ≥ 400ºC as shown in Figure 1(a), which indicate that the films are grown with high degree of crystal orientation with respect to (001) of MgO. Crystallinity of the thin films improves with increase in the CFMS post-annealing temperature. The respective $L2_1$ and B2 order parameter for CFMS could be obtained using the extended Webster model [6]. The respective Mn-Si $B2$ order and $L2_1$ order parameters are related to the intensity ratio for I_{002}/I_{004} and I_{111}/I_{220}, respectively, where I_{hkl} is the experimental x-ray diffraction intensity for (hkl) plane. Figure 1(b) shows the values of the intensity ratio of I_{002}/I_{004} and I_{111}/I_{220} with respect to the CFMS post-annealing temperature. Saturation magnetization (M_S) value increases with increase in Ta and it attains a value of 590 emu/cm^3 for sample with Ta = 600ºC. TMR was observed with respect to the ex-situ annealing. Preliminary measurements on the MTJs show maximum TMR ratio of 40% for the ex-situ annealing of 300ºC.

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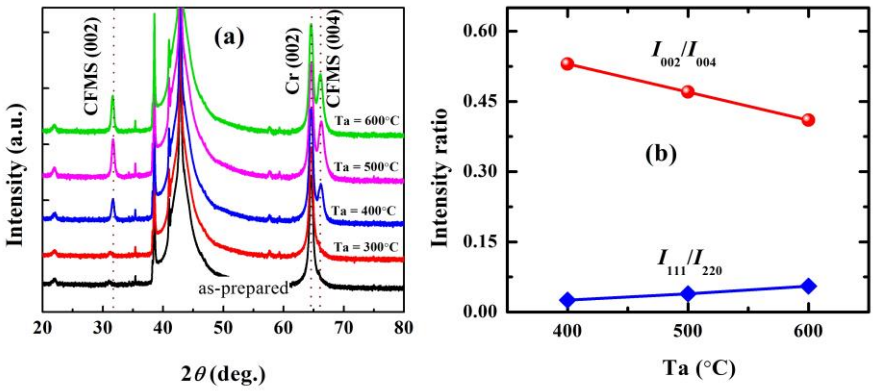

Figure 1. (a) the out-of-plane XRD measurements. (b) the experimental intensity ratios (I_{111}/I_{220} and I_{002}/I_{004}) with respect to the CFMS post-annealing temperature.