$L2_1$-atomic order and spin-polarization in Co_2MnZ (Z = Ge, Sn) Heusler thin films

Varun Kumar Kushwaha, Yuya Sakuraba, Tomoya Nakatani, and Kazuhiro Hono
National Institute for Material Science, 1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047, Japan

Half-metallic Co_2-based Heusler alloys have attracted much interest for spintronic applications because of their predicted 100% spin-polarization (P) and high Curie temperature (T_C), which are expected to enhance the performance of spintronic devices. In fact, several experimental studies have already demonstrated their effectiveness in enhancing the giant-magnetoresistance, tunnel-magnetoresistance and spin-accumulation effects. Despite large magnetoresistance (MR) ratio observed in Heusler-based devices, structural disorder is still one of the remaining issues which lowers the spin-polarization. Therefore, a high degree of structural ordering is necessary to realize the half-metallicity. An enhanced MR has been reported in various devices using Co_2-based Heusler alloys such as Co_2MnSi and $Co_2FeGe_{0.5}Ga_{0.5}$ by promoting the structural order ($B2$ → $L2_1$-ordering) by annealing at high temperature (> 500 °C). For various applications, however, applicable maximum annealing temperature is limited, e.g., less than 300 °C is required for a magnetic read head for HDD because of the temperature tolerance of the NiFe shield. Therefore, it is desirable to search for other Heusler alloys which crystallize in $L2_1$-order below 300 °C. The present work is motivated by the Okubo *et al*. [1]'s report, where the $L2_1$ to $B2$-order transition temperature of Co_2MnZ (Z = Ge, Sn) alloys is found to be above 1500 K; and hence $L2_1$-ordering is expected to appear even by annealing at relatively low temperature.

Epitaxial Co_2MnZ (Z = Ge, Sn) (30 nm) and $Co_2FeGe_{0.5}Ga_{0.5}$ (50 nm) films were grown on MgO (001) single crystal substrate using ultra high vacuum magnetron sputtering at room temperature and subsequently annealed *in-situ* at T_{ann} = 200-700 °C to promote the Heusler ordering. Here, Co_2MnZ (Z = Ge, Sn) films were grown on $Co_{50}Fe_{50}$ (3 nm) buffer layer. The degree of $L2_1$-ordering (S_{L21}) as a function of T_{ann} of Co_2MnZ (Z = Ge, Sn), $Co_2FeGe_{0.5}Ga_{0.5}$ and Co_2MnSi (Ref. [2]) films is displayed in Fig. 1(a). In case of $Co_2FeGe_{0.5}Ga_{0.5}$ and Co_2MnSi, $L2_1$-ordering was observed above 500 °C; whereas that of Co_2MnZ (Z = Ge, Sn) films appeared even in as-deposited and varies systematically with increasing T_{ann}. Non-local spin-valve (NLSV) devices were micro-fabricated to estimate the spin-polarization P of Co_2MnZ (Z = Ge, Sn) and $Co_2FeGe_{0.5}Ga_{0.5}$ films by measuring the spin-accumulation signal in Cu channel. A systematic variation in P with increasing T_{ann} was observed in these alloys [Fig. 1(b)]. At T_{ann} = 300 °C, the spin-polarization P of Co_2MnSn and $Co_2FeGe_{0.5}Ga_{0.5}$ were found to be very close (~0.56) whereas that of Co_2MnGe film was higher (~0.67) which would be due to higher degree of $L2_1$-ordering. These results suggest that Co_2MnGe alloy might be a better ferromagnetic electrode for practical applications.

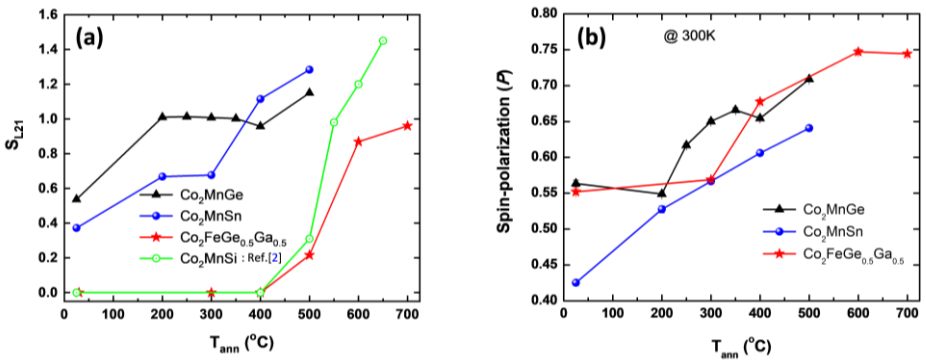

Figure 1. Annealing temperature dependence of **(a)**. degree of $L2_1$-ordereing (S_{L21}), and **(b)**. bulk spin-polarization (P) measured in NLSV devices. S_{L21} exceeding 1 is expected to be caused by off-stoichiometry in films.

[1] A. Okubo, R. Y. Umetsu, K. Kobayashi, R. Kainuma, and K. Ishida, Appl. Phys. Lett. **96**, 222507 (2010).
[2] Y. Sakuraba, K. Izumi, T. Iwase, S. Bosu, K. Saito, K. Takanashi, Y. Miura, K. Futatsukawa, K. Abe, and M. Shirai, Phys. Rev. B **82**, 094444 (2010).