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Spin-transfer Magnetization Switching in CPP-GMR Films with Half-metallic Co_2MnSi

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The perfect spin polarized materials, which called half-metallic ferromagnets (HMFs), have been greatly important in spin electronic devices because these materials have a possibility to improve MR ratio on GMR or tunnelling magnetoresistance (TMR) junctions. Half-metallic property in full-Heusler alloys such as Co_2MnSi and Co_2MnGe was theoretically predicted by some groups. As some experimentally results, Heusler alloys indicated high TMR ratio which suggest the potential of HMFs. In the case of Co_2MnSi, it has been observed an extremely large TMR ratio at low temperature by Sakuraba et al. 1) In this work, we report spin-transfer magnetization switching in current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) with a stacking of Co_2MnSi (30 nm)/Cu (6 nm)/$Co_{75}Fe_{25}$ (5 nm). The Co_2MnSi which is half-metallic Heusler alloy is used as a source of highly spin-polarized current.

X-ray diffraction pattern (XRD) of MgO substrate/Cr (40 nm) /Co_2MnSi (30 nm) showed the Co_2MnSi (200) and (400) peaks, indicating perfect (100)-oriented growth of Co_2MnSi. Also the pole-figure of the A2 (220) showed four hold symmetries, indicating that Co_2MnSi was epitaxially grown. The magnetoresistance ratio of the CPP-GMR film was 1.2%. Fig. 1shows the pulsed currents duration dependence of switching current I_c plotted as a function of ln (τ_p / τ_0), where tp is the pulsed current duration, τ_0 is the attempt frequency. Consistent with other reports, the I_c gradually increase with decreasing the pulsed currents duration. The estimated $J_{c0}^{P\rightarrow AP}$ was -6.3×10^6 A/cm^2, and $J_{c0}^{AP\rightarrow P}$ was 8.7×10^6 A/cm^2 (7.5×10^6 A/cm^2 in average). The observed critical current density is the smallest value compare to those reported for CPP-GMR elements so far. In AP→P transition, the critical switching current density J_{c0} for the sample with the Co_2MnSi-spin-filter was about 1/6 of that for the sample with CoFe-spin-filter. If the spin-polarization P changes from 0.50 to 0.75, the J_{c0} is expected to be about 1/6 using Slonczewski model[2]. This result indicates that the reduction of the switching current density in CPP-GMR with Co_2MnSi electrode is due to increase of the spin-polarization of the spin-filter layer, suggesting that Co_2MnSi has a great advantage to reduce the switching current.

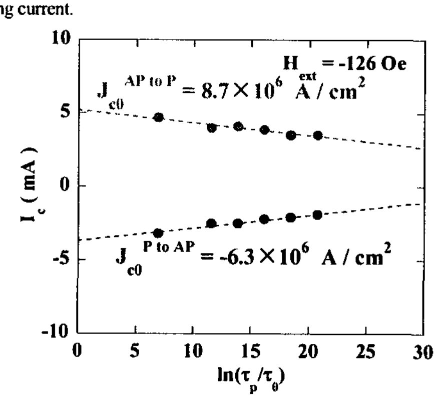

Fig. 1. The pulse duration dependence of Ic. Dashed lines are the results of a least-square fit.

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Spin Dependent Scattering of Nonequilibrium Holes in Co

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Spin-dependent scattering of electrons in a ferromagnet is essential to the understanding and application of various magnetic systems. The spin-dependent transport involves not only electrons at the Fermi level (EF) but in many cases also nonequilibrium (hot) carriers. One example is the magnetic tunnel junction which exhibits a large tunnel magnetoresistance (TMR) at low bias where electrons near E_F are of relevance, while the TMR drops significantly at higer bias where states away from E_F also participate in the tunneling process. The transmission of hot electrons injected into the empty states above E_F of FM layers has been extensively studied, which shows the FM layers preferentially transmit hot electrons in the majority spin bands, leading to a spin filtering of hot electrons in a FM layer. On the other hand, the spin-dependent transport of carriers below E_F (hot holes) is not well understood.

Here, we present on the spin-dependent transmission of holes injected into a ferromagnetic Co using a p-type magnetic tunnel transistor (p-MTT), which combines a magnetic tunnel junction and a p-type semiconductor. In a p-MTT, spin-polarized holes are injected into the states below E_F of the FM base by a tunnelingand they are collected in the valence band of the p-type semiconductor after spin-dependent transmission through the FM base. The magnetic response of the p-MTT device, so-called magnetocurrent (MC) is determined by the spin-dependent tunneling from the emitter, as well as spin-dependent scattering of the holes in the base. MTT's of p-type Si/Au(8nm)/Co/Al_2O_3(2nm)/ NiFe(5nm) were deposited by e-beam evaporation in a molecular beam epitaxy system and patterned by standard photolithography. The MC and the transfer ratio have been studied as a function of Co base thickness and tunnel bias voltage applied to the emitter. For a p-MTT with large Co base thickness and/or large emitter bias, the MC has the usual positive sign. Thus, the transmission of holes in the majority spin band of Co is larger than that of minority spin holes. Surprisingly, for smaller Co thickness and bias near the collection threshold (0.3 eV), the MC reverses sign and becomes negative. Moreover, the hole transmission decays exponentially not with a single attenuation length but with two different attenuation lengths in the low and high thickness regime, respectively. The results are explained in terms of a competition of two scattering contributions, elastic and inelastic, with opposite spin asymmetry. Up to a critical thickness of about 3nm, (quasi)elastic scattering dominates with a short attenuation length (less than 1nm) and preferential attenuation of holes in the majority spin bands, consistent with spin-wave emission. At a larger Co thickness, inelastic scattering dominates with a larger attenuation length (~4nm) and opposite spin asymmetry.