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Annealing-induced crystallization of amorphous CoFeB layers in CoFeB/MgO/CoFeB magnetic tunnel junctions

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Magnetic tunnel junctions (MTJs) with a MgO insulating barrier and CoFeB ferromagnetic layers exhibit magnetoresistance (MR) ratios above 200% on the basis of coherent tunnelling.[1] Amorphous CoFeB is deposited beneath and on the MgO layer with sputtering, and the CoFeB layers crystallize by annealing. Grain-to-grain epitaxy achieved between the MgO and CoFeB layers during the annealing satisfies the requirements for the coherent tunnelling.[2, 3] The present paper describes crystal growth of CoFeB by annealing through transmission-electron-microscopy (TEM) observations and electron diffraction (ED). Specimens of MTJ stacks of (Ta or Ru)/CoFeB/MgO/CoFeB/Ru/CoFe/PtMn/Ta were fabricated using a magnetron sputtering apparatus on thermally oxidized Si wafers at room temperature and were annealed at 270-400°C for 2h in vacuum. In the stacks, thicker CoFeB reference layers (50 nm) compared to practical MTJ devices were deposited to investigate the crystallization of the CoFeB layers. Dependence of microstructure of the CoFeB layers on annealing temperature was investigated using x-ray diffraction (XRD), TEM, and ED. CoFeB is reported to crystallize with (001) out-of-plane texture employing the (001)-textured MgO layer as a template.[2-4] Crystal grains with 10-20 nm in size were observed at the interface with MgO in the CoFeB layers from the stacks annealed at 330°C or higher temperatures in cross-section TEM images. Such grains were not observed at the interfaces with the Ta and Ru layers and in the region apart from the interface with the MgO layer. Electron diffraction revealed that the CoFe grains formed at the MgO interface have bcc (001) out-of-plane texture. These results indicate that crystallization of CoFeB preferentially commences at the interface with the MgO layer, which probably works as a template. It was also confirmed that the size of the CoFe crystals increases with the increase of annealing-temperature at a given annealing time; XRD results supported the evolution of the crystallization observed in the cross-section TEM images. The XRD pattern of the stacks annealed at 400°C showed that not only CoFe crystals but also Co or Fe borides are formed. Larger crystals were observed also in the region apart from the interface with the MgO layer in the TEM image of the specimen; the crystals are probably the borides because boron composition in the region is much higher than in the region near the MgO interface, where the CoFe crystals were formed, due to the diffusion of boron.

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Exchange-bias effect and its training of nano-structured anti-ferromagnetic oxide in IrMn/CoFe/oxide/CoFe/Cu/CoFe spin valves

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Nano-structured antiferromagnetic oxide is attracting much attention in magneto-electric multiferroics of late [1]. In addition exchange-bias and its accompanying training effect are fundamental interface phenomena in coupled magnetic thin films. In this study the magnetism and structure of the nano-structured Co-Fe and Cr oxides inserted in the pinned layer of spin valve is discussed. After magnetic field cooling was performed from R.T.to ~5K in the pinning direction, the exchange-bias effect and its training of IrMn/$Co_{0.9}Fe_{0.1}$/Cu/$Co_{0.9}Fe_{0.1}$ spin valves (SVs) with $Co_{1-x}Fe_x$/Cr nano-oxide-layer (NOL) inserted in the pinned layer were examined at low temperature to R.T. The detailed SV film design is seed/Ir-Mn 5.5/$Co_{0.9}Fe_{0.1}$ 1/$Co_{1-x}Fe_x$ 1/Cr 0.08/Natural Oxidation/$Co_{0.9}Fe_{0.1}$ 2/Cu 2/$Co_{0.9}Fe_{0.1}$ 2/Ta 3(nm) (x : 0.1~0.7). In the SV film with $Co_{0.9}Fe_{0.1}$/Cr-NOL, very clear exchange-bias assist with less training is observed comparing with $Co_{0.9}Fe_{0.1}$-NOL (anti-ferromagnetic CoO-FeO oxide [2]), which is thought to result from nano-structured alpha Cr_2O_3 and/or Cr_2O_3-Fe_2O_3 antiferromagnetic oxide formed at the interface [3]. Further $Co_{1-x}Fe_x$ and $Co_{1-x}Fe_x$/Cr NOL with higher Fe content shows many kinds of oxide magnetism such as weak ferro-magnet and ferrimagnet. Especially the magnetic and electric properties of the CPP-SV with a Cr_2O_3 oxide are very interesting in the aspect of magneto-electric effect. In this paper the exchange-bias and its training are reviewed in the wide Fe content and the magnetic and structural properties of the $Co_{1-x}Fe_x$ (/Cr) NOL are also considered.

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