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Spin-electronic devices with half-metallic Heusler alloys

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Abstract

We have integrated Co_2MnSi as a representative of the full-Heusler compound family as one magnetic electrode into technological relevant magnetic tunnel junctions. The resulting tunnel magnetoresistance at 20 K currently achieved is 108% associated with a Co_2MnSi spin polarization of 70% clearly proving that Co_2MnSi is already superior to 3d-based magnetic elements or their alloys. The corresponding room temperature value of the tunnel magnetoresistance is 42%. The presence of a step like tunnel barrier which is already created during plasma oxidation, while preparing the AlO_x tunnel barrier, has been identified as the current limitation to achieve larger tunnel magnetoresistance and hence larger spin polarization and is a direct consequence of the oxygen affinity of the Co_2MnSi-Heusler element Mn. In addition preliminarily results on Co_2FeSi as a new full-Heusler compound integrated as magnetic electrode into technological relevant magnetic tunnel junctions are shown and discussed.

Keywords: Spin-electronic devices; Heusler alloys; Tunnel magnetoresistance

1. Introduction

As a consequence of the growing theoretically predictions of 100% spin polarized half- and full-Heusler [1–8] compounds over the past 6 years, Heusler alloys are a promising materials class for future magnetoelectronic and spintronic applications. Currently, we have reported on the integration of Co_2MnSi [9,10] as a representative of full-Heusler compounds as the lower magnetic electrode into technological relevant magnetic tunnel junctions (MTJs). The resulting tunnel magnetoresistance (TMR) at 20 K was determined to be 95% corresponding to a Co_2MnSi spin polarization of 66% clearly proving that Co_2MnSi is already superior to 3d-based magnetic elements or their alloys. The corresponding room temperature value of the tunnel magnetoresistance was 33%. Structural and magnetic properties of the Co_2MnSi/AlO_x-barrier interface have been studied with X-ray diffraction, electron and X-ray absorption spectroscopy, and X-ray magnetic circular dichroism [11] and we could show that the ferromagnetic order of Mn and Co spins at this interface is only induced in optimally annealed Co_2MnSi layer. The presence of a step like tunnel barrier which is already created during plasma oxidation while preparing the AlO_x tunnel barrier could be identified [12] as the current limitation to achieve larger tunnel magnetoresistance and hence larger spin polarization and was attributed to the oxygen affinity of the Manganese in the Co_2MnSi-Heusler.

The objective of this work is to introduce a slightly modified preparation technique using a wedge shaped thickness profile for the AlO_x-barrier which enables to evaluate different AlO_x-barrier thicknesses in one measurement process. In addition, our preliminary results on a new full-Heusler compound, Co_2FeSi, will be presented.

2. Preparation of MTJ devices with one integrated Heusler electrode

The preparation strategy used so as to integrate thin Co_2MnSi or Co_2FeSi layers as electrodes in technological relevant MTJs can be divided into the following 10 steps:

(1) DC-magnetron sputtering of a 42 nm V-buffer layer onto a Si/SiO_2-substrate; the V-buffer assists the (1 1 0) texture formation of the Heusler layer upon annealing [9];

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(2) DC-magnetron sputtering of a 100 nm Co_2MnSi- or Co_2FeSi-Heusler layer from a alloyed target;
(3) DC-magnetron sputtering of a pure metallic Al layer by wobbling the shutter so as to realize a wedge shaped Al_x-layer thickness profile ranging from 0.6 to 3.0 nm;
(4) oxidizing the Al layer in a pure oxygen plasma for 150 s using a 2.46 GHz remote ECR plasma source RR 160 PQE from Roth und Rau GmbH;
(5) annealing for 40–60 min at temperatures between 350 and 500 °C to induce texture and atomic ordering into the Co_2MnSi- or Co_2FeSi-layer and simultaneously to homogenize the AlO_x-barrier;
(6) oxidizing the AlO_x layer in a pure oxygen plasma for 50 s so as to clean its surface;
(7) DC-magnetron sputtering of the upper magnetic $Co_{70}Fe_{30}$ layer and subsequent RF-magnetron sputtering of the $Mn_{83}Ir_{17}$ antiferromagnet;
(8) DC-magnetron sputtering of the upper current Cu/Ta/Au multilayered lead;
(9) ex-situ annealing for 1 h at 275 °C in an external magnetic field of 100 mT so as to establish the exchange bias between the antiferromagnet $Mn_{83}Ir_{17}$ and the upper ferromagnetic $Co_{70}Fe_{30}$ electrode; and finally,
(10) patterning the whole layer stack by optical lithography and ion beam etching to quadratic MTJ with 200 μm length; resulting patterns of quadratic MTJ stacks allow determining the TMR characteristic along 100 positions within the Al-layer thickness range of 0.6 nm up to 3.0 nm.

3. Results and discussion

That the resulting TMR-effect amplitude is very sensitive to the annealing conditions chosen for step 5 during preparation can be seen in Fig. 1 by comparing two sets of MTJ patterns annealed for 60 min at 380 °C (MTJ I) and 40 min at 450 °C (MTJ II), respectively. The evolution of the TMR-effect amplitude with increasing Al_x-layer thickness of both sets of MTJ patterns is characterized by a pronounced TMR-effect plateau of about 20% follow by TMR maxima of 31.2% and 42.5% at an Al-layer thickness of about 2.3 nm. The origin of the TMR-effect plateau region can be resolved by employing X-ray absorption spectroscopy (XAS) applied on half-MTJ stacks which were identically prepared but terminated after step 5. That way the Heusler/AlO_x-interface can be probed with XAS in total electron yield geometry (TEY). The Mn-spectra taken at different Al_x-layer thickness as indicated in Fig. 1 reveal the presence of MnO at the tunnel barrier for Al_x-layers below 2.3 nm. In combination with our previous investigations [10,11] it can be concluded that the MnO is a fingerprint of a thin $MnSiO_x$-interfacial layer which is already formed during the oxidation procedure of the Al layer and disturbing the atomic ordering of Co_2MnSi at the barrier interface. The missing peak doublet at

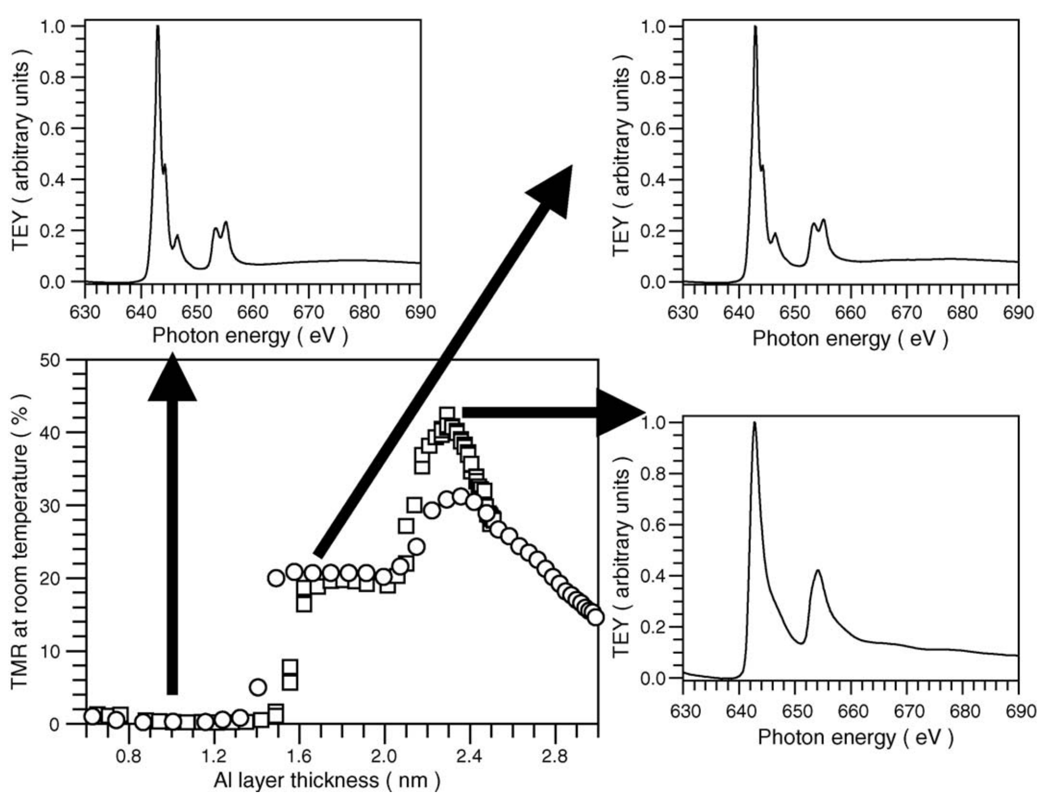

Fig. 1. TMR-effect amplitude of two sets of identical MTJ patterns annealed for 60 min at 380 °C (◯) and 40 min at 450 °C (□), as a function of increasing Al_x-layer thickness measured at room temperature with a bias voltage of 10 mV. The detailed MTJ stacking sequence is: V (42 nm)/Co_2MnSi (100 nm)/Al_x (x nm)/$Co_{70}Fe_{30}$ (5.1 nm) $Mn_{83}Ir_{17}$ (10 nm). Mn-X-ray absorption spectra taken at different Al_x-layer thickness as indicated reveal the presence of MnO at the tunnel barrier for Al layers below 2.3 nm.