Mössbauer and magnetic study of interface structure of Fe/Si_xFe_{1-x} multilayers with antiferromagnetic interlayer coupling

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The structural and magnetic properties of Fe/Si_xFe_{1-x} multilayers (Mls) have been studied by the conversion electron Mössbauer spectroscopy (CEMS) and magnetic measurements. The Fe/Si system is extensively studied because the origin of antiferromagnetic (AF) interlayer coupling has not been clarified and due to its potential applications in electronics. We have studied the Fe/Si_xFe_{1-x} (x = 1, 0.66, 0.5) Mls deposited by magnetron sputtering. The magnetic measurements revealed that the appearance of the antiferromagnetic interlayer coupling in Fe/Si Mls is neither related to RKKY-like type nor to quantum interference mechanism. The AF coupling can be mediated by the formation of nonmagnetic Fe-Si system at the interfaces, *e.g.*, ε-FeSi, nonstoichiometric c-$Fe_{1-x}Si_x$ crystalline silicides and/or intermixed crystalline or amorphous Fe-Si. The interface structure was investigated by CEMS. The CEMS spectra recorded at room temperature for Fe/Si Mls consist of three components: the Zeeman sextet with the hyperfine field $H_{hf} \approx 32.8$ T, and the isomer shift $\delta = 0.00$ mm/s, characteristic of the bcc- Fe phase of Fe layers, and two spectral components related to Fe-Si system at interfaces: (i) magnetic broadened sextet with $H_{hf} \approx 29$ T and $\delta \approx +0.05$ mm/s, originating most probably from Fe atoms at various interfacial step-sites and (ii) nonmagnetic component consisting of a quadrupole doublet with the splitting QS ≈ 0.60 mm/s and $\delta \approx +0.20$ mm/s. The last component could be related either to a small gap ε-FeSi semiconductor, the crystalline c-$Fe_{1-x}Si_x$ metallic phase or to an amorphous FeSi phase rich in Si. The CEMS spectra of $Fe/Si_{0.66}Fe_{0.33}$ Mls with two different thickness of SiFe layers (1.4 and 3 nm) show the spectra consisting of similar three components, but the spectral contribution of the QS doublet is significantly larger for thicker SiFe layer.

Basing on the QS and δ values of the nonmagnetic spectral component it is difficult to determine the exact structure of the interfacial phase. Taking into account our estimated 200 meV energy gap of this phase, we suggest that the Fe-Si silicide responsible for the AF coupling in Fe/Si multilayers is a semiconducting amorphous-like $Fe_{1-x}Si_x$ phase rich in Si. The existence of the amorphous-like $Fe_{1-x}Si_x$ phase is confirmed by thermal annealing of the Mls (1 h at 220°C) after which the multilayers show the ferromagnetic coupling only.

We demonstrate that the AF coupled Fe/Si multilayers can be successfully applied as artificial antiferromagnets in the magnetoresistive $(Fe/Si)_{15}$/Fe/Co1/Cu/Co2 pseudo-spin-valve (PSV) system.

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