Comment on "Magnetoresistance Associated with Antiferromagnetic Interlayer Coupling Spaced by a Semiconductor in Fe/Si Multilayers"

In a recent Letter, Inomata, Yusu, and Saito [1] reported the observation of a negative magnetoresistance (MR) for Fe/Si multilayers (MLs) with two different temperature dependences as a function of Si thickness (t_{Si}). The observed MR effects were more than 2 orders of magnitude smaller than encountered in MLs with metal spacers.

For $t_{\mathrm{Si}} = 1.2$ nm magnetization loops indicated antiferromagnetic (AFM) coupling with $M_R/M_S = 0.3$ at 300 K and almost complete ferromagnetic (FM) alignment with $M_R/M_S \approx 1$ at 77 K [2]. Noting that the dependence of $-\ln(M_R/M_S)$ on inverse temperature was similar to that of the carrier concentration in an impurity semiconductor, the authors argued that the AFM coupling is mediated by charge carriers in the Fe-Si alloy spacer which are thermally excited from the valence to the conduction band, as suggested earlier [3]. With decreasing temperature this excitation is significantly diminished, causing a transition from AFM to almost complete FM coupling.

We criticize this conclusion as the value of M_R/M_S may *not* be taken as a measure of the strength of the AFM coupling. The M_R/M_S ratio rather is a measure for an *incomplete* AFM alignment, which frequently is caused by a fraction of the layers which are FM coupled by the presence of ferromagnetic bridged (pinholes) in the spacer layers.

Instead of M_R/M_S, the true coupling strength is given by the energy difference $2J = -\frac{1}{2}\mu_0 M_S H_S d$ between antiparallel and parallel magnetization alignment, where H_S is the saturation field at which parallel alignment is reached.

Inspection of Fig. 3 of Ref. [1] for the (2.6 nm Fe)/(1.2 nm Si)$_{22}$ ML shows that at $T = 298$ K the resistance saturates at $H_S \approx 300$ Oe. However, at $T = 4$ K the resistance, after a very small jump near $H = 0$, steadily decreases and does not saturate even at the maximum field of 1000 Oe. Actually, this is in accordance with our observation [4], see Fig. 1, that H_S, as measured from magnetization loops, and thus the AFM coupling strength, *increased* strongly with lower temperature, as in the case of magnetic MLs with metal spacers [5]. It is also to be noted that our H_S values were much larger than those reported in Ref. [1] and that we observed a *limited* increase of M_R/M_S to only ~0.25 with lower temperature (Fig. 1).

It is very plausible that with a distribution of ferromagnetic and paramagnetic bridges, the latter become also ferromagnetic on cooling, causing a rise of M_R/M_S. In the work of Refs. [1,3] evidently on cooling a situation is reached in which the distance between magnetic bridges has become so small that the FM coupling almost completely destroys the antiparallel alignment due to AFM coupling, although the intrinsic strength of the latter is increased. So we conclude that the conversion of AFM to FM coupling, suggested to be caused by a strong reduction in the thermal excitation of charge carriers in the iron silicide spacer [1,3], does not take place at all.

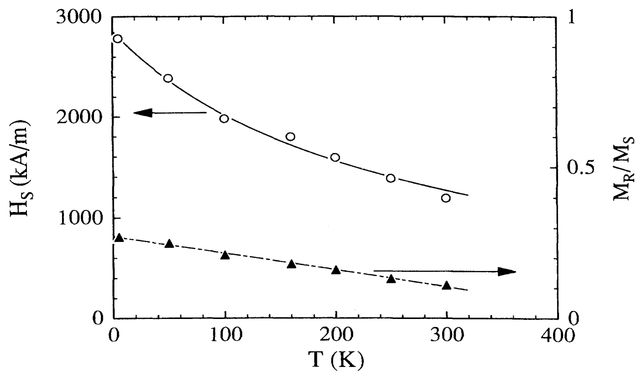

FIG. 1. Saturation field and M_R/M_S of a $20 \times$ [(3.0 nm Fe)/(1 2 nm Si)] multilayer vs temperature.

A second criticism concerns the negative MR at $t_{\mathrm{Si}} = 3.5$ nm, which was attributed without any evidence to AFM coupling across amorphous Si [1]. In our work we observed from $t_{\mathrm{Si}} = 1.2$ to 1.6 nm a steady decrease of the AFM coupling strength. From $t_{\mathrm{Si}} = 1.8$ up to 4.8 nm the magnetization loops showed no clear sign of AFM coupling, but shapes and saturation fields of ~50 kA/m determined by the cubic anisotropy and the polycrystalline [110] texture of the magnetic layers. We suggest that in this thickness range the coupling is only magnetostatic which becomes weaker with thicker Si. In the absence of any coupling the planar magnetization directions in consecutive magnetic layers become random. Applying a field then brings about a parallel alignment, so that as a consequence of some spin-dependent conduction a small negative MR results.

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Received 26 April 1995
PACS numbers: 75.50.Rr, 72.15.Gd, 73.40.Sx, 75.30.Et

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 0031-9007/95/75(16)/3026(1)$06.00