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Tunneling spin polarization and annealing of $Co_{72}Fe_{20}B_8$

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Abstract

We present measurements of tunneling spin polarization (TSP) of $Co_{72}Fe_{20}B_8$ alloys in $Al/Al_2O_3/Co_{72}Fe_{20}B_8$ tunnel junctions to further unravel the role of crystallization of the CoFeB electrodes. Whereas the TSP of films of a few hundred Ångstrom is rather insensitive to anneals up to 500 °C, a 50 Å film shows a strong reduction of TSP. It is hypothesized that these differences are related to a rather inhomogeneous crystallization of the $Co_{72}Fe_{20}B_8$. Magneto-optical Kerr-effect measurement on 300 Å thick CoFeB wedges are used to relate the measured coercivity to these crystallization processes.

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Keywords: Magnetic tunnel junctions; Spin polarization; CoFeB

1. Introduction

CoFeB ternary alloys have received considerable attention several decades ago, mainly for their excellent soft-ferromagnetic properties. Recently, a renewed interest can be witnessed for the implementation of these compounds as a magnetic electrode material in magnetic tunnel junctions, yielding tunnel magnetoresistance (TMR) ratios superior to those when using traditional 3d ferromagnetic layers such as binary NiFe or CoFe. Enhanced TMR is not only observed in alumina-based junctions [1], but also in junctions with MgO barriers that are now heavily studied for their enormous magnetoresistance ratios at room temperature [2,3]. However, from a fundamental point of view the reason for the high TMR or the related tunneling spin polarization (TSP) when using CoFeB is not yet resolved. Especially the role of the crystal structure, that can be transformed from amorphous to crystalline by post-deposition heat treatments, is an outstanding problem in this field. In a previous paper [4], we have demonstrated that TSP of a 700 Å film of $Co_{72}Fe_{20}B_8$ is as high as +53% and is not affected by annealing up to $T_A = 450\,°C$ despite a progressive crystallization of CoFeB films in this temperature regime.

It is the aim of this paper to further explore the role of annealing for TSP of CoFeB, in relation to the thickness and structure of these layers. In contrast to the results for thicker films it is observed that TSP is significantly reduced when a thin film of 50 Å is annealed, suggesting that the crystallization may not be fully homogeneous over the full thickness of a ferromagnetic CoFeB top electrode.

2. Experimental results and discussion

For the determination of TSP, we have fabricated superconducting junctions by magnetron sputtering through shadow masks, combined with in-situ plasma oxidation of the Al. The structures are basically consisting of $Al/Al_2O_3/Co_{72}Fe_{20}B_8/Al$ where the thickness t of the ferromagnetic layer is 50, 120, and 700 Å (previous work). In superconducting tunneling spectroscopy (STS), the in-field magnetic-field dependence of the low-temperature conductance dI/dV allows for a direct determination of TSP when fitting the data with the Maki-theory [5].

The spin polarization in as-deposited, amorphous samples is insensitive to the thickness variation of the ferromagnetic layer and is typically $+53 \pm 0.5\%$. An

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experimental example of STS is shown in Fig. 1a for a $Co_{72}Fe_{20}B_8$ layer of 120 Å, annealed at $T_A = 300\,°C$ under ultra-high vacuum conditions. In the figure the open (closed) symbols are the data for a magnetic flux density of 0 T (2 T); the Maki-fit is the solid curve. In line with the data for the 700 Å sample [4], there is only a slight reduction of TSP at this anneal temperature (which is generally true for layers thicker than roughly 100 Å). In striking contrast, it appears that for thinner CoFeB a significant suppression is observed when annealing at 300 °C and higher. This is shown in Fig. 1b for 50 Å $Co_{72}Fe_{20}B_8$, where a TSP of $+43 \pm 0.5\%$ is found for $T_A = 450\,°C$ ($+49 \pm 0.5\%$ at 300 °C). In this respect, it is important to mention that preliminary X-ray experiments (not shown here) reveal that the crystallization of the initially amorphous CoFeB may not be uniform throughout the sample, especially for thicker films. This in turn may be resolved in the magnitude of TSP due to its sensitivity of the electronic structure specifically át the interface between CoFeB and Al_2O_3. Note that magnetization studies [6] rule out that a significant amount of boron is segregating to the barrier interface.

To substantiate the strong dependence of the annealing-induced crystallization on the thickness of the CoFeB, we have measured the coercivity (H_C) of $Co_{72}Fe_{20}B_8$ grown on Al_2O_3 and capped with Al. This is motivated by our previous work, where data on the 700 Å film suggests a strong correlation between the observed gradual crystallization and H_C. In Fig. 2, the results are shown for a 300 Å CoFeB wedge. A sharp metal mask, linearly retracted during sputter deposition of the layer, is used to create the wedge profile. Although there are many details not yet understood in the observed behavior (which we postpone for a future publication), it is evidently seen that coercivity heavily depends on the thickness of the ferromagnetic film when annealed up to 500 °C, which is directly related to crystallization of the layer. In line with the TSP data, in the as-deposited (amorphous) sample the variation of H_C is only very modest over the full thickness range.

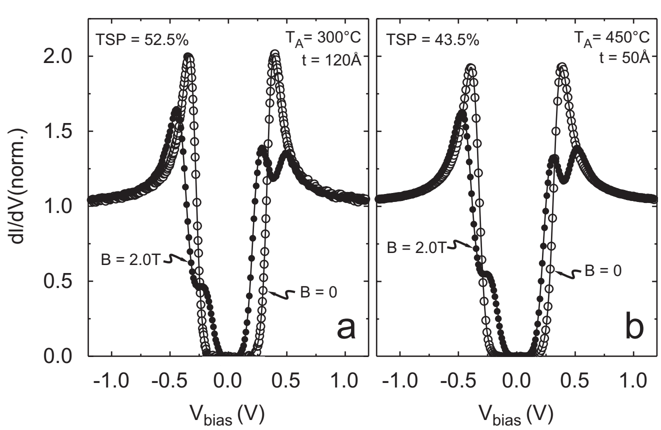

Fig. 1. Tunneling spin polarization (TSP) of CoFeB measured at $T \approx 0.3\,K$ in $Al/Al_2O_3/Co_{72}Fe_{20}B_8$: (a) 120 Å thick CoFeB film annealed at 300 °C and (b) 50 Å thick CoFeB film annealed at 450 °C. The zero-field data (○) show the superconducting gap of Al. After the application of a 2.0 T in-plane flux density, the asymmetry in the Zeeman-split conductance curve reflects the presence of TSP (●). A fit (solid lines) using Maki theory [5] reveals the amount of TSP.

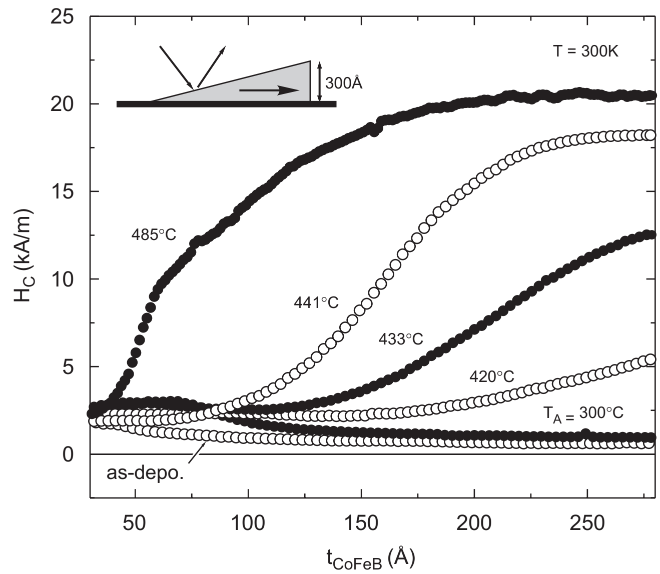

Fig. 2. Room-temperature coercivity (H_C) of $Co_{72}Fe_{20}B_8$ as a function of the film thickness t, using magneto-optical Kerr-effect (MOKE) on a wedge-shaped layer from 0 to 300 Å. As indicated, the annealing temperature T_A is varied between 300 and 485 °C.

We suggest that the strong thickness dependence in both TSP and coercivity may be explained by crystallization nucleating preferentially at the top (Al) interface, creating a structurally rather inhomogeneous CoFeB film comprised of both amorphous and crystalline regions, especially when the films become thicker. Given the experimental fact that the thinnest film (50 Å) has the lowest TSP when annealed at 450 °C, it could be that crystalline CoFeB has an intrinsically lower TSP as compared to its amorphous counterpart (both against an alumina barrier). High-resolution transmission electron microscopy is currently performed on these films to further elucidate these structural aspects, in particular focusing on the interface structure close to the Al_2O_3 barrier.

3. Conclusion

In conclusion, the TSP of $Co_{72}Fe_{20}B_8$ is strongly dependent on the thickness of the layers when annealed up to temperatures of almost 500 °C. As shown indirectly via the coercivity of separately grown CoFeB wedges, the crystallization process could be rather inhomogeneous. This could lead to an interfacial structure different from other regions in the ferromagnetic layer, thereby directly affecting the TSP.

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