Functional Materials

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Crystallisation and boron redistribution in CoFeB / MgO systems with Ru and Ta cap layers for magnetic tunnel junctions during annealing studied by HRTEM and EELS

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In recent years, magnetic tunnel junctions (MTJ) with crystalline MgO tunnel barrier and amorphous CoFeB (a-CoFeB) electrodes received much attention. Due to their large tunnelling magnetoresistance (TMR) ratio at room temperature, they are used as sensor element for harddrive read heads.

For industrial application the use of amorphous electrodes in MTJ is favorable due to its better growth flexibility. After annealing at temperatures up to 600°C [1] high TMR were achieved because of partial crystallization of the a-CoFeB. During annealing, boron atoms diffuse out of the CoFeB into adjecent layers which is a prerequisite for its crystallization into bcc CoFe using the MgO as a template [2]. Hence, a-CoFeB crystallization can be controlled by choosing cap layers acting as a boron sink or diffusion barrier. Here, the influence of the cap layer material on boron redistribution was studied by electron energy loss spectroscopy (EELS) and on the crystallization process of a-CoFeB by HRTEM. This study was applied to a model system consisting of a MgO substrate, electron-beam sputtered MgO (5nm), CoFeB (5nm or 100nm) and capped by respectively a 10nm Ru layer or a 10nm Ta + 3nm Ru layer. TEM images of samples with thick CoFeB layers (Figure 1) show a crystalline bcc (001) CoFe region at the interface to the MgO and, in the case of the Ru cap, an additional polycrystalline layer at the interface to the hcp-Ru layer. No noticeable EELS B-K-signal is observed in the MgO or at its interface region. In samples with thin layers (Figure 2), a-CoFeB also crystallizes into bcc CoFe at the interface to the MgO. Furthermore, the MgO and the MgO interface region did not show any presence of boron or boronoxide in EELS (Figure 3), which has been concluded as a prerequisite for high TMR [3]. This B and BO_x segregation is often found in MTJ systems with a radio frequency sputtered MgO barrier [2,4-6]. In contrast to the thick CoFeB sample, an approximately 1nm thick amorphous interlayer between c-CoFe and the Ru cap layer is visible, consisting of non crystallized CoFeB. Here, the Ta+Ru cap layer sample did not show this amorphous interlayer and the CoFeB is completely crystallized in bcc (001) CoFe. The boron diffuses from the CoFeB into the adjacent Ta layer were the boron concentration decreases rapidly with distance to the CoFe. This high boron concentration is not visible in the Ru cap layer sample. From these measurements it can be concluded that Ru serves as a diffusion barrier for boron. As a consequence, boron accumulates in an amorphous interlayer in absence of another boron sink. Ta, however, seems to be a sink for boron which promotes CoFeB crystallization into a fully crystalline layer. In summary, we can conclude that our e-beam sputtered MgO barriers are free of any B or BO_x contamination which leads to a high TMR. In addition, it was shown that Ta sputtered on a-CoFeB is a cap layer material which does not disturb the crystallization process of CoFe during annealing and acts as an important sink for boron.

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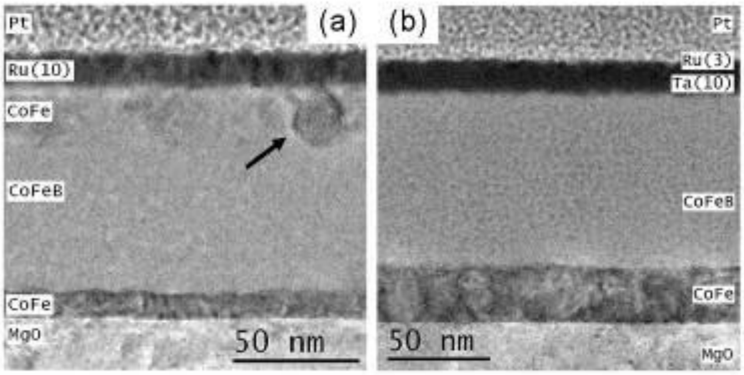

Figure 1. TEM images of samples with thick CoFeB layer with Ru (a) and Ta+Ru cap layer (b). The lower c-CoFe layer is clearly visible in both samples. A second polycrystalline CoFe region is present in the Ru cap sample at the interface to the cap layer (see arrow).

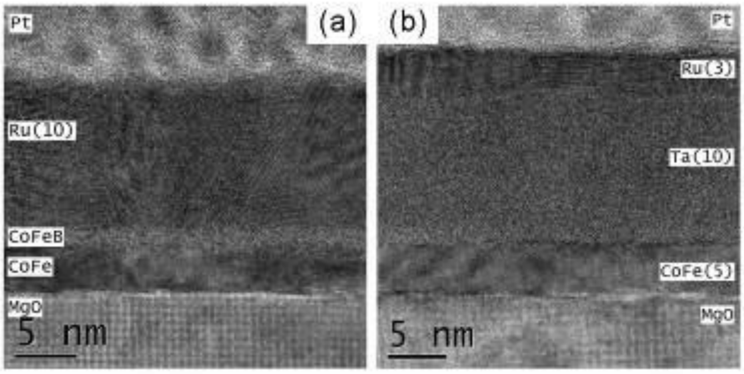

Figure 2. TEM images of samples with thin CoFeB layer. Amorphous interlayer between CoFe and Ru consisting of a-CoFeB (a). Fully crystallized CoFeB with boron containing Ta cap layer (b).

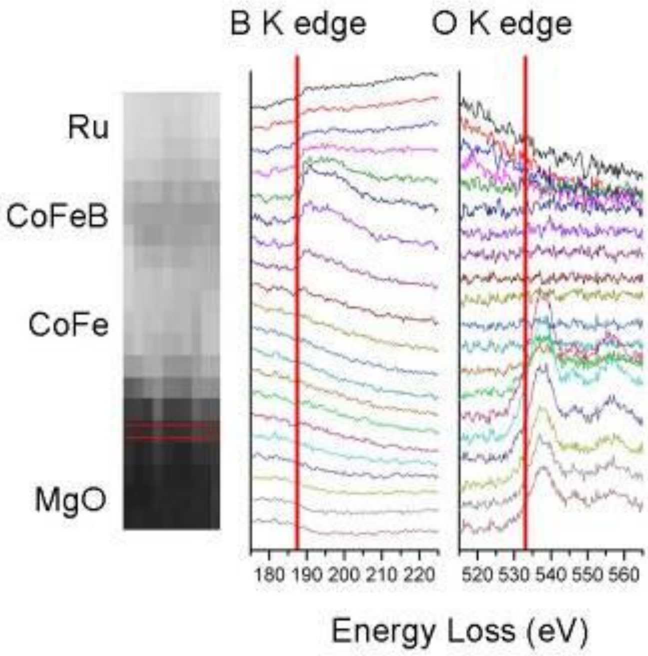

Figure 3. EEL spectra of the B-K and O-K edge from the MgO into the Ru cap. The absence of B and BO_x at the MgO and its interface is clearly visible from these spectra. Boron is only present in the amorphous interlayer between the Ru cap and the CoFe. Corresponding HAADF signal at the left.