Microstructural investigation of Co-P by transmission electron microscopy

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Since the description of the electrodeposition process of amorphous cobalt-phosphorous [1], the material has attracted interest as a soft magnetic material with high specific resistivity. Many reports describe the magnetic anisotropy exhibited by this material, in which a magnetisation parallel to the film growth direction seems to be preferred. A hysteresis loop of Co-P deposited under constant current conditions typically contains 3 distinct regions (low field, saturation, and intermediate, figure 1). Together with other magnetic characteristics (e.g. dependence of permeability on previous magnetisation [2]) this indicates a slight preference for perpendicular magnetisation.

The anisotropy has often been attributed to a cellular or columnar microstructure of this electrodeposited material. Even though the original measurements on which this conclusion was based were later refuted [3], many discussions on the magnetic properties are still centred around an alleged columnar structure, especially when pulse plated layers are considered [e.g. 4,5]. However, a direct observation of such a columnar structure has so far not been attempted. In this work, electrodeposited Co-P films obtained from DC and pulse-plating conditions were investigated. Cross-sections of the material suitable for TEM investigation were achieved by ultra-microtomy.

Ultra-microtomy was found to be a suitable technique for obtaining cross-sections of the amorphous magnetic film. Artifacts introduced in the cutting process (scratches, wrinkles) could be readily identified (figure 2).

In TEM, electrodeposited Co-P material shows no columnar or cellular structure. Instead, the magnetic anisotropy should be attributed to a different phenomenon, possibly ordering at the atomic scale.

When pulse-plating conditions are employed, the Co-P layer consists of clearly distinguishable sub-layers. The low roughness of the multi-layers is remarkable and can be contrasted against the problems of roughening of poly-crystalline metallic multi-layers of similar thickness due to the differences in surface energy of different crystallographic planes (e.g. for Co/Cu of 100 nm sub-layer thickness).

The TEM results indicate that Co-P multi-layers with small sub-layer thickness can be obtained with sharply defined sub-layers.

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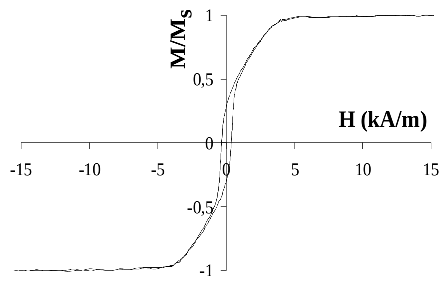

Fig. 1: Hysteresys loop obtained from a 2.3 µm thick DC electrodeposited Co-P film for a field applied in the plane of the film (AGFM).

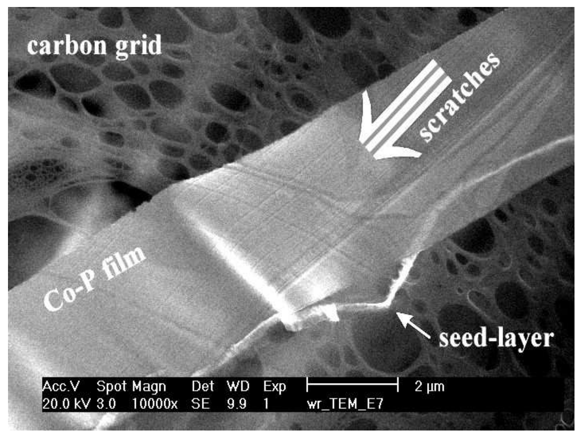

Fig. 2: Co-P slice showing wrinkles (perpendicular to the cutting direction) and scratches (parallel to the cutting direction) introduced by the ultra-microtomy sectioning. Since wrinkles and scratches are perpendicular to each other, they are easily identified as artifacts when the cutting direction is not parallel to the film plane.

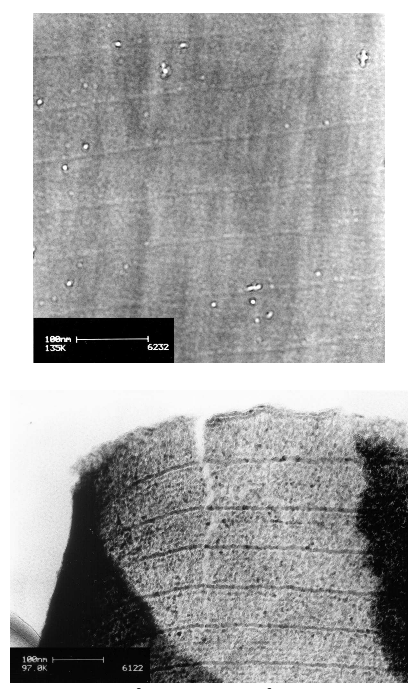

Fig. 3: TEM bright field image of pulse-plated Co-P as deposited (top) and after crystallisation (bottom).