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Structure evolution of the biaxial alignment in sputter-deposited MgO and Cr

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Abstract

The growth of biaxially aligned layers, i.e. layers with both a preferential out-of-plane and an in-plane crystallographic orientation, on non-aligned metallic substrates is investigated. Unbalanced magnetron sputtering on an inclined substrate is used to deposit the layers.

This method enables us to grow biaxially aligned layers for different classes of materials with different physical and chemical properties. The results for biaxially aligned MgO which is a cubic metal oxide (FCC rocksalt structure), and pure metallic chromium films (BCC) are presented.

A comparison between biaxially aligned MgO and Cr concerning the microstructure and crystallographic texture is discussed. A correlation between the sputter deposition parameters on the biaxial alignment of both materials is observed. Both materials have a columnar V-shape structure with a faceted surface, corresponding to zone T of the well known structure zone model of Thornton. The MgO layers exhibit a [111] out-of-plane orientation, while Cr layers have an [100] preferential orientation. MgO as well as Cr show a strong in-plane alignment.

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1. Introduction

Thin film properties of buffer layers are strongly influenced by the crystallographic orientation and the microstructure of the grains.

The development in superconducting wire has proved the benefits of biaxially aligned buffer layers (i.e. layer with both a preferential out-of-plane and in-plane orientation). The critical current density of superconductors is tightly connected to the angle between the orientation of the grains in the buffer layer, which emphasizes the need for highly oriented buffer layers [1]. The use of biaxially aligned MgO as buffer layer for superconductors, such as $YBa_2Cu_3O_{7-x}$, provides similar functionality to single crystalline films. The most common techniques to grow biaxially aligned MgO are Ion Beam Assisted Deposition (IBAD) [2–5] and Inclined Substrate Deposition (ISD) [6–8].

Another example of a buffer layer is Cr which is commonly used as underlayer for thin film magnetic recording media. The initial crystallographic alignment of Co-based magnetic films as well as its magnetic properties such as coercivity, is controlled by the Cr buffer layer [9–11]. In general, the research is focussed on the out-of-plane alignment of the Cr thin film [12–14]. Zhao et al. [15] and Janssen et al. [16] reported the growth of biaxially aligned Cr layers, and explain it in terms of anisotropic stress.

In this work we describe the crystallographic and microstructural properties of biaxially aligned MgO and Cr deposited by unbalanced magnetron sputtering on an inclined substrate (ISD). Corresponding observations for MgO and Cr suggest a general growth mechanism. This is emphasized by the successful growth of biaxially aligned TiN, YSZ and ITO by magnetron sputtering [17,18].

2. Experimental details

MgO and Cr thin films were deposited by unbalanced magnetron sputtering, using a type II planar unbalanced magnetron with an inner to outer magnetic field ratio of 1 : 9 for MgO and 1 : 3 for Cr. The deposition system used is similar to the system described in Ref. [19]. A 2 in. circular metallic target was sputtered in a pure argon atmosphere for Cr and in a argon atmosphere with addition of the reactive gas O_2 for MgO. Non-aligned electropolished stainless steel (ferrite for MgO, austenitic for Cr) was used as substrate and was at floating potential (i.e. −10 V). For both materials the target substrate distance was in the order of 10 cm and the discharge current was fixed at 0.70 A. The optimized working pressure was 0.45 Pa for MgO and 0.35 Pa for Cr. The angle α between substrate normal and incident

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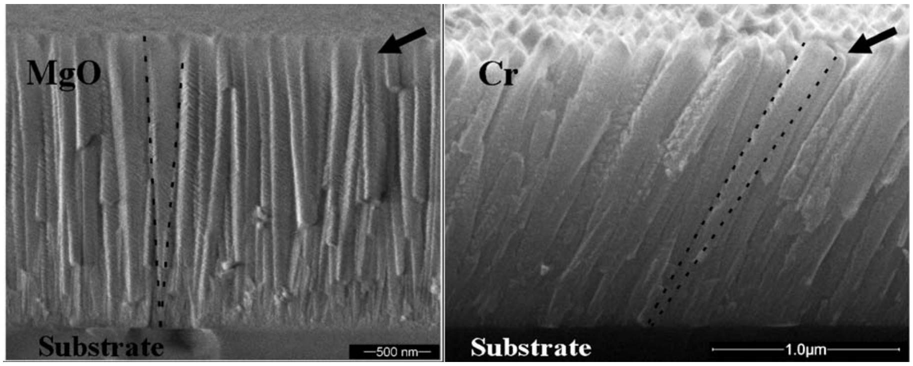

Fig. 1. SEM cross sections of biaxially aligned MgO and Cr thin films with a thickness of 1.5 μm grown on an inclined substrate. The arrow indicates the direction of the incoming material flux.

material flux, which causes the biaxial alignment to occur, was fixed at 55, which seems to result in a good balance between a high degree of biaxial alignment and deposition rate [8].

The preferential out-of-plane alignment was determined by X-ray angular scans while X-ray pole figures were performed to confine the in-plane alignment. Therefore, a Bruker D8 apparatus with a quarter Eulerian cradle and parallel beam optics has been used. A scanning electron microscope was used to reveal the topographical and cross-sectional microstructure and to investigate the texture evolution of the layers. The thickness was measured using a conventional profilometer with a sensitivity of 40 nm.

3. Results and discussion

Fig. 1 shows the cross sections of the biaxially aligned MgO and Cr layer, revealing a clear columnar structure which corresponds to zone T of the structure zone model of Thornton [20]. In this zone the adatom surface mobility is too low to allow grain boundary diffusion, but is high enough, for an adatom to find an energetic stable place on the grain. The structure develops by competitive grain growth which results in V-shaped grains (Fig. 1). The columns of the Cr thin film are tilted towards the incident material flux, but no columnar tilting is observed for MgO.

XRD measurements, angular scans (not shown) and pole figures (Fig. 2(c)), indicate that MgO is preferential [111] out-of-plane oriented while Cr has a preferential [100] out-of-plane orientation. Those directions correspond to the fastest growing direction for both materials (MgO has a FCC rocksalt crystal structure; Cr has a BCC structure) During nucleation, islands with a random crystallographic orientation are formed on the substrate. Adatoms landing on an island which offers a high mobility, can reach the edge of that island, and will contribute to the lateral growth (it cannot diffuse to another island because the mobility is too low (zone T growth)). On the other hand, if the island offers a low mobility, the perpendicular growth will be promoted. This results in high but tiny islands, for low mobility islands, and low but broad islands, for islands which offer a high mobility. At coalescence, the islands with the highest perpendicular growth speed will overgrow the others. For rocksalt MgO the (111) planes have the largest number of nearest neighbours and so offer the

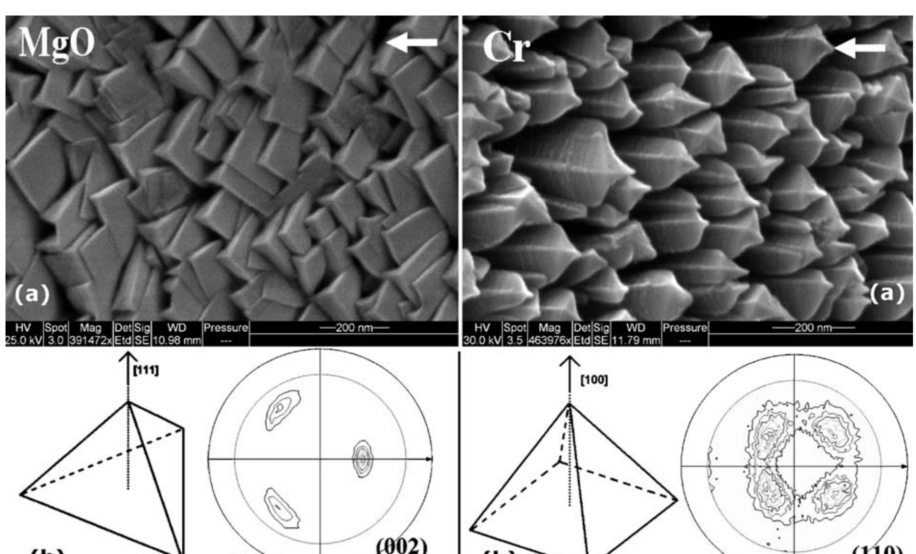

Fig. 2. Comparison between biaxially aligned MgO (left) and Cr (right). (a) SEM plan view of MgO and Cr, (b) A schematic representation of the crystal habit for both materials, (c) XRD pole figures corresponding to the biaxially aligned layers. For MgO a (200) pole figure is shown, for Cr a (110) pole figure.