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Effects of sputtering and assisting ions on the orientation of titanium nitride films fabricated by ion beam assisted sputtering deposition from metal target

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ABSTRACT

Ion beam assisted titanium nitride (TiN) film has attracted much attention because its fast texture and high conductivity can be effectively applied in all-conductive superconducting coated conductor. In this work, TiN films were prepared by ion beam sputtering deposition from a metal titanium target. Effects of sputtering ion energy, assisting ion energy, assisting ion current and deposition temperature on the orientation and surface morphology were analyzed. The results indicate that assisting ion is an important factor in orientation selection, and high assisting ions and low assisting ion current could enhance the crystallinity. However, too high assisting ion energy and current can destroy the crystallinity in IBAD–TiN. This orientation selection can be attributed to the energy exchange between assisting ions and adatoms.

1. Introduction

Ion beam assisted deposition (IBAD), defined as the bombardment of growing thin films with energetic ions, is a main method to fabricate buffer layers of high temperature superconducting coated conductors [1,2]. IBAD-MgO buffer layer has great efficiency for its fast evolution of biaxial texture [3,4]. IBAD-MgO require only 10 nm to develop texture, whereas another usual buffer layer, yttria-stabilized zirconia, needs at least 500 nm. Therefore IBAD-MgO buffer layer have been investigated extensively [5–9]. However, the coated conductors based on IBAD-MgO templates cannot achieve self-protection from quench, for MgO buffer layer is insulating.

Fortunately, researchers found that titanium nitride (TiN) can also be fast textured in the same way as MgO, which offers an interesting alternative for the choice of textured templates [10,11]. Above all, TiN films are highly conductive and can be used as buffer layer for all-conductive coated conductor. If the superconducting layer quench, large current can enter the thick metal tape through conductive TiN buffer layer and superconducting layer is protected from excessive heat. Much experimental work has been done to investigate properties of TiN films fabricated by ion beam assisted PLD [10–14] and evaporation [15–17]. However, little information has been provided about ion beam sputtered TiN thin films. In sputtering deposition, the mobility of deposited atoms is directly and significantly influenced by sputtering parameters. Therefore a possibility exists in sputtering deposition to broaden the road toward textured IBAD-TiN by modulating sputtering ion energy and current, though this technique is less efficient.

In this work, we fabricated TiN films on untextured glass substrates by ion beam sputtering deposition. In some deposition process, the growing films are bombarded by an assisting ion beam (IBAD). In order to study the influence of sputtering ions, we also fabricated TiN films without assisting ions (non-IBAD). The effects of deposition temperature, sputtering and assisting ions on the orientation of the TiN thin films were studied. New effects and conclusions will be shown and discussed below.

2. Experimental details

Two Kaufman ion sources, including a sputtering source (⌀ 8 cm) and an assisting source (⌀ 6 cm), were employed to fabricate TiN thin films. Deposition atoms were sputtered by a sputtering Ar^+ beam from a 99.99% pure metal titanium target and

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deposited on untextured glass substrates for an hour. The sputtering ion beam current for all the samples was 100 mA. The background pressure was about 4×10^{-4} Pa, and the working pressure was about 3×10^{-2} Pa. Before deposition, substrates were cleaned by assisting Ar^+ ions beam of 750 eV and 25 mA for 25 min, which was maintained by an argon flow of 2 sccm for the discharge in the assisting ion sources.

We prepared IBAD-TiN films and TiN films without assisting ions (non-IBAD) as control. The current of sputtering ion beam were kept at 100 mA for all samples. The sputtering ion beam was maintained by an argon flow of about 1.5 sccm. For the deposition of non-IBAD sample, we varied the sputtering ion energy E_s and substrate temperature. A flow of 1.5 sccm of N_2 was supplied to assisting ion source as reactive gas. For IBAD samples, the growing films were bombarded by an assisting mixed ion beam of argon and nitrogen during deposition. A flow of about 0.5 sccm argon and 1.5 sccm of N_2 were supplied into assisting ion source for discharge. All the IBAD films were deposited with E_s of 800 eV and at room temperature (RT). The incident angle of assisting ion beam was 45°. Assisting ion energy E_a and current I_a were changed. The film thickness is about 100 nm.

We studied the effect of E_a and I_a on the orientation of IBAD films. To characterize the orientation and morphology of thin films, we applied X-ray diffraction (XRD) and atom force microscopy (AFM). The orientation of the films was characterized by XRD system (D/MAX-RB) equipped with Cu–Kα1 source. The surface morphology was characterized by tapping mode of an AFM (Nanoscope IIIa) with a silicon tip (curvature radius less than 10 nm).

3. Results and discussion

Fig. 1(a) shows the XRD θ–2θ patterns of the non-IBAD TiN films deposited with a different sputtering ion energy E_s. Several weak low index diffraction peaks appear. The peaks in the films deposited with higher E_s are a little stronger than that in the films of lower E_s, which reflects that higher sputtering energy helps the films crystallize. Fig. 1(b) shows the XRD results of the non-IBAD films deposited at a different substrate temperature T. We can see that the influence of T lies mainly on the (220) peak. As T increases, (220) peak is enhanced significantly, while the intensity of (111) and (200) peak is changed a little. This result indicates that higher deposition temperature enhanced the (220)-oriented crystallinity in our parameter range.

The results above can be attributed to different surface binding energy of low index crystal planes. For rock salt structure as TiN, according to the in-plane atom arrangement, the surface binding energy is ordered as $(001) > (111) > (110)$. The formation of oriented grains with higher binding energy needs higher mobility of adatoms. The energy in new-coming atoms is transported to adatoms through collision, and the surface mobility of the adatoms is enhanced consequently. The higher the sputtering energy, the higher the mobility of the adatoms are. Thus the crystallinity is enhanced by increasing sputtering energy. The energy from sputtering ions is too low to induce preferred orientation, as shown in Fig. 1(a). Heating substrate can supply higher energy to adatoms, and higher temperature enhanced (110) orientation.

The XRD results of IBAD films are shown in Fig. 2. The influence of assisting ion energy E_a is indicated in panels (a) and (b). Only a weak (200) peak appears in the non-IBAD film. For IBAD films of I_a=2 mA, with E_a increasing, (220) peak and (111) peak turn stronger. However, the similar law does not appear when I_a=6 mA (panel (b)). The intensity of (111) peak and (220) peak in the films deposited at I_a of 6 mA appears till E_a=500 eV, and decreases significantly at E_a=750 eV. The influence of assisting ion current I_a at stable assisting ion energy is shown in Fig. 2(c) (200 eV) and 2(d) (500 eV). In both (c) and (d), the intensity of (111) peak is improved by increasing I_a below 4 mA, and depressed at 6 mA, but (220) peak behaves differently. When E_a=200 eV (c), (220) peak appears only at I_a=2 mA; while a relatively strong (220) peak exists in all the IBAD sample when E_a=500 eV (d), and its intensity does not obviously changed by I_a. Maybe a conclusion can be drawn that (111) orientation prefers moderate assisting ion energy

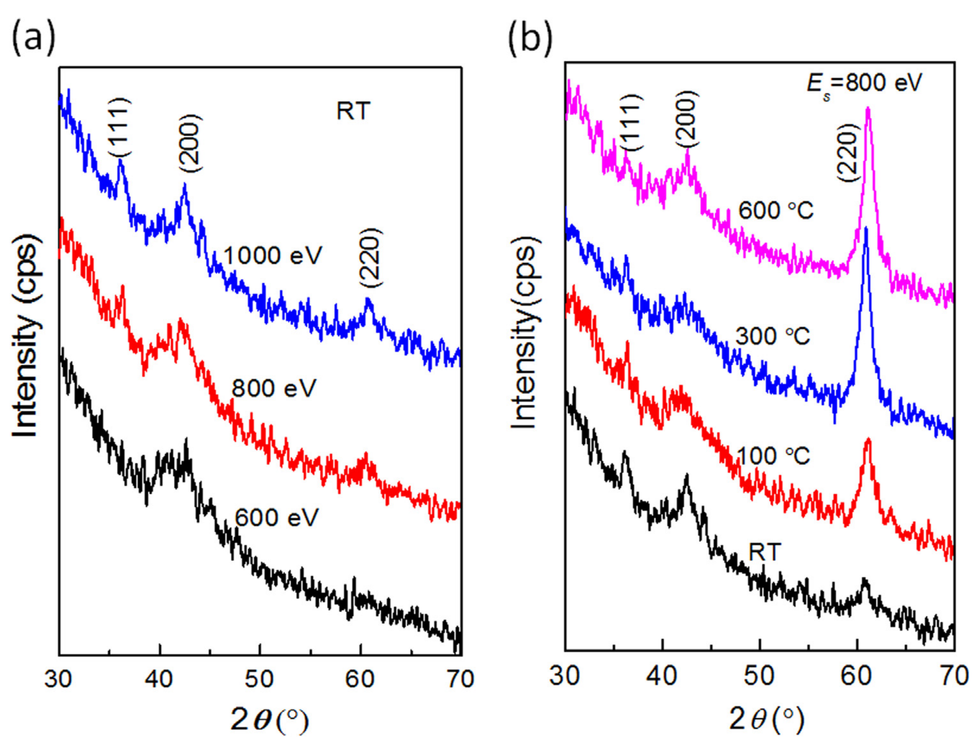

Fig. 1. XRD θ–2θ scan patterns of non-IBAD TiN thin films deposited with a different sputtering ion energy (a) and at a different substrate temperature (b).