Journal of Alloys and Compounds, 195 (1993) 231–234
JALCOM 7455

Bi-epitaxial template grain boundaries with different in-plane angles on (100) MgO substrates.

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Abstract

Using laser ablation CeO_2 and $YBa_2Cu_3O_{7-d}$ layers have been deposited on (100) oriented MgO substrates for the creation of bi-epitaxial grain boundary weak links. X-Ray Diffraction measurements were used to measure the (in-plane) orientations of the layers. The CeO_2 layer has been structured using Ar ion beam etching or CaO lift off. Using these two structuring techniques it is possible to obtain two different grain boundary weak link angles: 18 and 27 degrees. Up till now only 45 degrees weak link angles have been reported in literature, using templates for the creation of these grain boundaries.

1. Introduction

In literature several ways to create bi-epitaxial Josephson junctions and dc SQUIDs using grain boundaries have been described. Bicrystals of $SrTiO_3$ and Yttrium Stabilized ZrO_2 have been used [1,2] giving the possibility to vary the induced weak link angle between 0 and 45 degrees. The dependence of the critical current density on this angle is reported [1,2]. A second way for the creation of bi-epitaxial Josephson junctions makes use of different in-plane orientations of $YBa_2Cu_3O_{7-d}$ on top of structured multilayers [3-5]. The first reported bi-epitaxial template grain boundary junctions were obtained using $(1\bar{1}02)$ Al_2O_3 substrates, an MgO template layer and a $SrTiO_3$ buffer layer [3]. An improvement of this technique was achieved using $SrTiO_3$ substrates, an MgO template layer and a CeO_2 buffer layer [4]. All reported grain boundaries achieved in this way have an in-plane rotation of the $YBa_2Cu_3O_{7-d}$ of 45 degrees between both sides of the grain boundary. A lower grain boundary angle has the advantage of higher critical currents and of lower expected noise.

This work is financed by the "Stichting voor Fundamenteel Onderzoek der Materie", which is financially supported by the "Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO)".

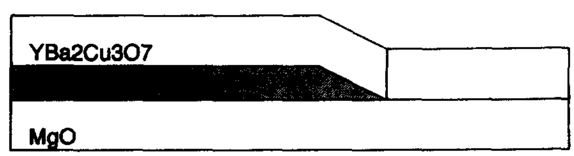

Figure 1. Schematic of the template structure.

In this report we discuss the growth and orientation of CeO_2 and $YBa_2Cu_3O_{7-d}$ on (100) oriented MgO substrates. To obtain a bi-epitaxial grain boundary weak link, the CeO_2 layer has to be structured (see figure 1). The effect of the structuring technique (Ar ion beam etching or CaO lift-off [6]) with respect to the orientation of the deposited $YBa_2Cu_3O_{7-d}$ on MgO has been investigated. RBS measurements have been used to look for remainders of Ar and Ca, due to the structuring of the CeO_2 template layer.

2. Experimental

All layers have been deposited by laser ablation. Deposition of $YBa_2Cu_3O_{7-d}$ took place using a polycrystalline $YBa_2Cu_3O_x$ target. The CeO_2 was deposited using an amorphous/polycrystalline CeO_2 target. The CaO was deposited using a polycrystalline CaO target. The deposition of the $YBa_2Cu_3O_{7-d}$ and the CeO_2 took place at elevated

0925-8388/93/$06.00

temperatures, CaO was deposited at room temperature.

The orientation of the layers perpendicular and parallel to the substrate surface was checked using (P)XRD.

Structuring of the CeO_2 layer took place by Ar ion beam etching under an angle of 40 degrees with the substrate surface (Kauffmann source, beam voltage 500 volt, beam current 10 mA) or using the CaO lift-off technique.

3. Results

3.1. Orientation

Using (100) oriented MgO substrates and a CeO_2 template layer it is possible to create an in-plane rotation of $YBa_2Cu_3O_{7-d}$ on CeO_2 on MgO with respect to $YBa_2Cu_3O_{7-d}$ deposited directly on MgO. On the MgO substrates CeO_2, $YBa_2Cu_3O_{7-d}$ and $YBa_2Cu_3O_{7-d}/CeO_2$ layers have been deposited. Powder X-Ray Diffraction measurements have been performed on these layers to look for their orientations

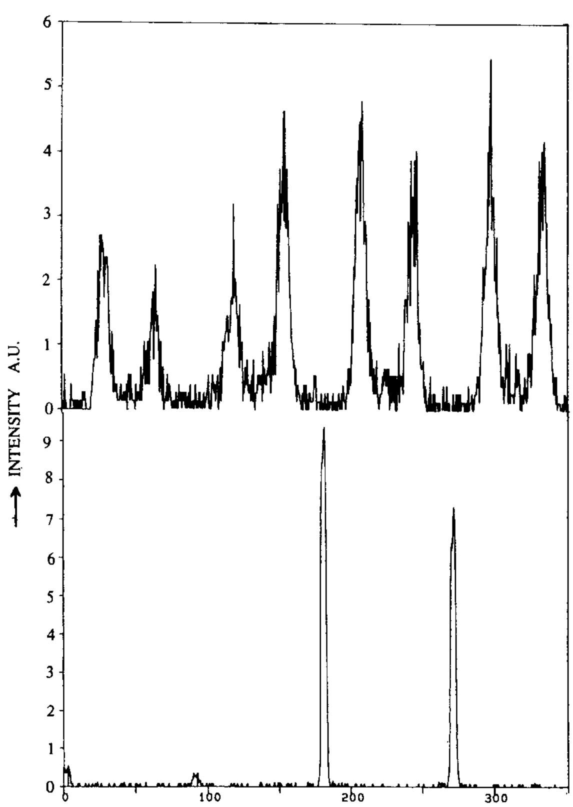

Figure 2. Phi scan of a CeO_2 layer on a MgO substrate. Shown are the (204) MgO reflection (bottom) and the (113) CeO_2 reflection (top).

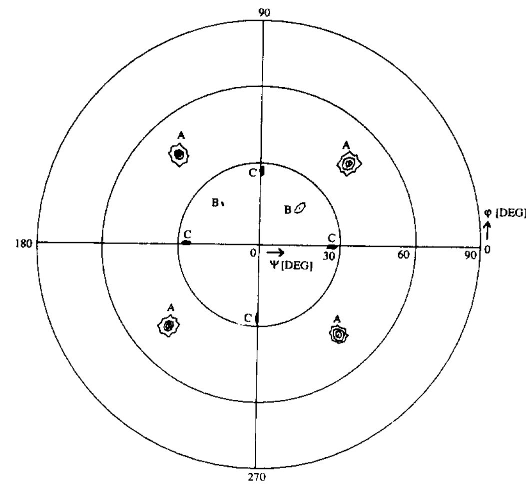

Figure 3. Pole diagram of $YBa_2Cu_3O_{7-d}$ on Ar ion beam etched MgO. A=(206) $YBa_2Cu_3O_{7-d}$, B=(108) $YBa_2Cu_3O_{7-d}$, C=(204) MgO.

perpendicular to the substrate.

CeO_2 layers deposited at deposition temperatures T_{dep} between 700 and 750°C, an oxygen pressure P_{O2} of 20 Pa, a laser fluence I of 2.0 J/cm^2 and a target-substrate distance d of 35 mm, show 95% (h00) and 5% (hhh) oriented material. In figure 2 a phi-scan of a 100 nm thick CeO_2 layer (T_{dep}= 700 °C) on top of an MgO substrate is given. The (113) CeO_2 reflection is shown in the upper part of the figure 2, whereas in the lower part the (204) reflection of the MgO substrate is given. The in-plane direction of the CeO_2 layer is ± 18 degrees rotated with respect to the cubic to cubic orientation as mentioned in literature [4,5].

The CeO_2 layer is structured using two different techniques: Ar ion beam etching and CaO lift-off. By structuring the CeO_2 layer with Ar ions, also the toplayer of the MgO substrate is etched. Using the CaO lift-off technique the MgO substrate is for a period of about 10 minutes in contact with distilled water, possibly causing some damage to the MgO surface.

$YBa_2Cu_3O_{7-d}$ layers have been deposited on two differently treated MgO substrates. The first substrate has been etched for 80 seconds using Ar ions. On the second MgO substrate a CaO layer has been deposited at room temperature, followed by a heat treatment at 700 °C for 10 minutes, representing the heat treatment for CeO_2 deposition. Finally the CaO has been removed by putting the substrate into an ultrasonic bath with distilled water for ten minutes. $YBa_2Cu_3O_{7-d}$ layers which have been grown on top of these substrates show c-axis

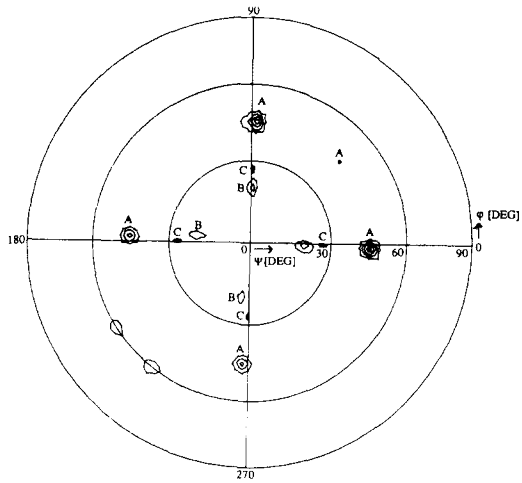

Figure 4. Pole diagram of $YBa_2Cu_3O_{7-d}$ on MgO after CaO lift-off. A=(206) $YBa_2Cu_3O_{7-d}$, B=(108) $YBa_2Cu_3O_{7-d}$, C=(204) MgO.

orientation. In figure 3 the pole figure of the (206)/(108) $YBa_2Cu_3O_{7-d}$ and the (204) MgO reflections are given for the first substrate. It can be seen that the [110] direction of $YBa_2Cu_3O_{7-d}$ is parallel to the [100] direction of the MgO. No other in-plane orientations are found (see also [7]). The in-plane orientation of the $YBa_2Cu_3O_{7-d}$ layer on the second MgO substrate is [100] $YBa_2Cu_3O_{7-d}$ parallel to [100] MgO as can be seen in figure 4. The unmarked reflections can be explained by (110) oriented $YBa_2Cu_3O_{7-d}$ as observed by PXRD.

The CaO lift-off procedure doesn't effect the critical temperature of the $YBa_2Cu_3O_{7-d}$ layer on top of the MgO substrate.

$YBa_2Cu_3O_{7-d}$ grown on top of a CeO_2 layer on a MgO substrate has the c-axis perpendicular to the substrate surface. The in-plane orientation of this layer on CeO_2 is 45 degrees rotated with respect to the cubic to cubic orientation as reported by Char et al. [4].

The resulting grain boundary angle of the structure of figure 1 will be 18 degrees if the CeO_2 is Ar ion beam etched, and 27 degrees if the CaO lift-off technique is used.

3.2. RBS

In figure 5 part of the random RBS spectrum of substrate one is given. At an energy of 1.25 MeV an extra amount of backscattered He ions (FWHM=37 keV; the FWHM for a monolayer Au on SiO_2 on Si is 17 keV with the settings used in this experiment.) is visible which is not visible in RBS spectra of

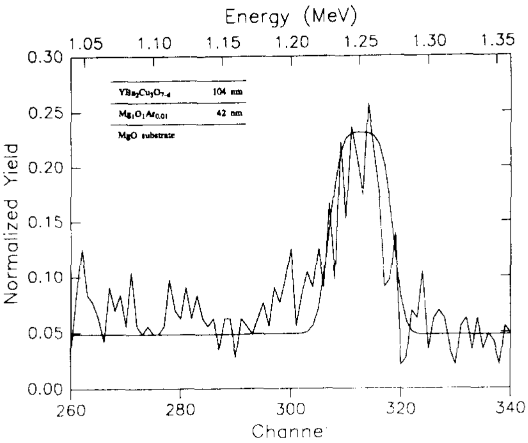

Figure 5. Part of the RBS spectrum of substrate one. Shown are the measurements and a simulation of a model (see inset).

$YBa_2Cu_3O_{7-d}$ layers on non Ar etched MgO. The extra peak can not be explained by Ar atoms just at the interface of the MgO and the $YBa_2Cu_3O_{7-d}$ because of its FWHM value. It can be explained by taking a substrate toplayer of 42 nm with the nominal composition Mg:O:Ar = 1:1:0.01 into account (see inset of figure 5). Because the accelerator voltage of the Ar ions is only 500 volt during etching the Ar ions will not penetrate 42 nm into the MgO substrate. Due to the heat treatment caused by the deposition of $YBa_2Cu_3O_{7-d}$ on the Ar etched substrate, probably diffusion of the Ar ions into the substrate has taken place.

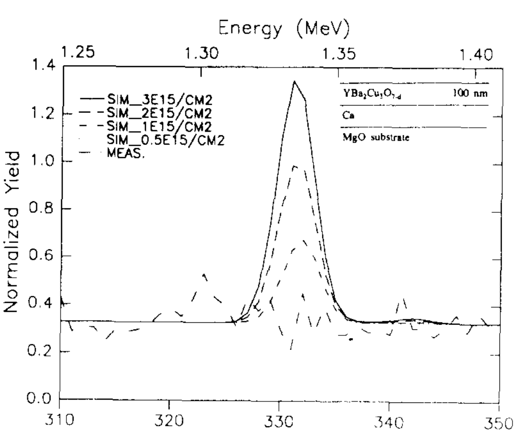

Figure 6. Part of the RBS spectrum of substrate two. Shown are the measurement and simulations of a model (see inset) with different Ca densities.

In figure 6 part of the random RBS spectrum of the second sample is given. To increase the sensitivity the angle between the incoming He^+ ions and the detector has been increased to 60° resulting in a FWHM value of 17 keV for the same monolayer gold as mentioned above. Apart from the measurement also simulations of different Ca densities at the MgO surface are given. It can be seen that the upper limit of Ca near the MgO surface equals $1 \cdot 10^{15}$ atoms/cm^2. This means that at maximum one Ca atom per MgO unit cell surface area is present.

3.3. dc SQUIDs

Using the layers and applying the structuring techniques as described above, washer type dc SQUIDs have been structured in the $YBa_2Cu_3O_{7-d}$ layers using Ar ion beam etching.

Voltage modulation up to 79 K has been observed. At 77 K the maximum voltage modulation was 1.5 μV. The highest modulation voltage we have observed was 90 μV at 4.2 K, with a flux to voltage transfer $\partial V/\partial \phi$ = 310 μV/ϕ_0. More details of the electrical measurements will be published elsewhere [9].

4. Summary

Using a CeO_2 template layer on MgO substrates it is possible to create bi-epitaxial grain boundary weak links in the $YBa_2Cu_3O_{7-d}$ layer on top of this structure. If the CeO_2 is structured using Ar ion beam etching an angle of 18 degrees results. CaO lift-off results in a weak link angle of 27 degrees. Washer type dc SQUIDs structured in the $YBa_2Cu_3O_{7-d}$ (CeO_2 etching took place using Ar ion beam etching) show voltage modulation up to 79 K.

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