International Conference on Superconductivity -Icsc

International Conference on SUPERCONDUCTIVITY — ICSC

January 10–14, 1990
Bangalore, India

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World Scientific
Singapore • New Jersey • London • Hong Kong

Published by

World Scientific Publishing Co. Pte. Ltd.
P O Box 128, Farrer Road, Singapore 9128
USA office: 687 Hartwell Street, Teaneck, NJ 07666
UK office: 73 Lynton Mead, Totteridge, London N20 8DH

INTERNATIONAL CONFERENCE ON SUPERCONDUCTIVITY

ISBN 981-02-0150-8

Printed in Singapore by Utopia Press.

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We gratefully acknowledge receipt of financial support from the following governmental agencies, institutions and industries and their participation in the Conference.

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PREFACE

We are delighted that the response to the International Conference on Superconductivity in Bangalore was most encouraging. We, in India, are trying hard to contribute to this fast-growing area of considerable importance. In this effort, we depend on the world community of scientists working in this area for information, support and encouragement. We consider sharing of information and exchange of ideas to be crucial to the development of the subject as well as for the improvement in the quality of our own effort. It was a fine experience for us to have the International Conference here which enabled the members from the world fraternity in superconductivity to be with us.

We are thankful to the plenary lecturers, and invited speakers for providing us with the manuscripts. The volume looks quite impressive and useful. We are thankful to the National Superconductivity Programme Management Board and the Department of Science and Technology, Government of India for sponsoring this conference. Our thanks are also due to CSIR, DAE, INSA, DRDO, DNES, DOE, UGC, IISc., Government of Karnataka and also to some of the Industries for their support.

April 1990

S K Joshi
C N R Rao
S V Subramanyam

CONTENTS

HETERO-EPITAXIAL GROWTH OF YBaCuO-MgO SYSTEM

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ABSTRACT

The double-heteroepitaxy of $Y_1Ba_2Cu_3O_y$-MgO-$Y_1Ba_2Cu_3O_y$ system by the reactive rf magnetron sputtering and the interface microstructure have been closely investigated.

1. INTRODUCTION

The high quality thin film formation of the high T_c superconducting (HTSC) materials has been required from both the sience and engineering fields for the close exploring of the physical properties of the material itself. This is because the well-established thin film technologies can produce the HTSC crystal surpassing the single bulk crystals. So far, the highest critical current J_c and the lowest surface resistance at the frequency from the micro to millimeter wave range have been obtained in the thin film HTSCs. The reduced crystal imperfection in the thin film is thought to be responsible for them.

Differed from the physical explorations, the superconductivity electronic application basically demands much more than the simple thin film structure stated above. Utilization of the simple thin film structure seems to be in a narrow way. In Table I, the extension of the HTSC applications with the progress of the thin film technology is given. As shown in this table, the heterostructure is expected to cover very wide applications of the HTSCs. This view could be acceptable only by recalling the fact that the heterojunctions of GaAs/AlGaAs, InP/InGaAsP and so on offered a number of new functional devices like a injection laser diode and high speed field effect transistor (MODFET) to the semiconductor electronics which could not be realized by a simple film structure. Even in the Si technology, the $Si/Si_{1-x}Ge_x$ heterostructure is now building up.

Table I. HTSC applications and thin film technology

Polycrystal film	Grain boundary Josephson junction
Epitaxial film	Interconnection
	Transmission line
Heteroepitaxial film	Interconnection of semiconductor devices
	Injection transistor
	MOS transistor
Double-hetero structure	SIS tunneling Josephson junction
	Single electron tunneling device
Semicon./Supercon. hetero	SUPER-HET*
	Future ULSI

* Superconductor-base Hot Electron Transistor[1)]

Particularly, in the formation of the SIS tunneling Josephson junction, the importance of the double-hetero epitaxial growth technology is growing. The primary point we should keep in minds is placement of the surface constituent atoms at such regular positions as those inside the bulk. Otherwise, due both to the natural displacement of the surface atoms (reconstruction) and short coherence length peculiar to the HTSCs, the sound superconductivity will be missing from the surface or interface region. Moreover, the two-dimensionally localized current planes ($Cu-O_2$ plane) in the HTSC base-counter electrodes should be aligned in one line at the both sides of the thin tunneling insulator. Under only this configuration, the efficient coupling of the superconductive wave functions (Josephson coupling) may be obtained. These two requirements, the surface atom arrangement and lattice alignment, can be satisfactorily met by the double-hetero epitaxial technology.[2)]

The surface atom placement at the regurated position plays roles not only in getting the surface (or interface) superconductivity but also in reducing the density of the surface state. The surface state, being out of favor for the Metal-Insulator-Semiconductor (Super-

conductor) field effect devices, is arising from the dangling bond of the surface atoms which, in turn, forces the displacement of the atom location.[3] If the reduced surface state is established at the HTSC-insulator interface by the heteroepitaxy, it will open an application of HTSCs to the field effect devices as have been long done in the semiconductor electronic field.[4]

In the present work, we first demonstrate the feasibility in making the $Y_1Ba_2Cu_3O_y$/MgO/$Y_1Ba_2Cu_3O_y$ double-heterostructures[5] and the micro-observation of their interface structure by the transmission electron microscope (TEM). In the second topic, we discuss how to get a high quality thin epitaxial film by the simple manner.

2. DOUBLE-HETEROEPITAXIAL GROWTH

Throughout the present work, the reactive rf magnetron sputtering technique was employed for the thin film formation. Used sputtering

Table II. Sputtering conditions of $YBa_2Cu_3O_y$ and MgO films.

(a) $Y_1Ba_2Cu_3O_y$

Discharge Gas	Ar + O_2 (50%)
Total Gas Pressure	4 Pa
Substrate Temperature	650 ℃
Target Composition	$Y_1Ba_2Cu_4O_y$
Discharge Power	50 W
Growth Rate	4 nm/min
Film thickness	100 ~ 120 nm

(b) MgO

Discharge Gas	Ar
Gas Pressure	1 Pa
Substrate Temperature	350 ℃
Target	MgO
Discharge Power	20 W
Growth Rate	0.75 nm/min

system equipped three targets inside the chamber, and therefore, by rotating the target, the multiple heteroepitaxial growth was carried out successively without breaking the vacuum (in-situ growth). After the deposition of the YBaCuO layer, the sputtering chamber was filled with O_2 gas and then the substrate was cooled down in order to restore the oxygen atom at sites of Cu-O chain. No post-annealing was done

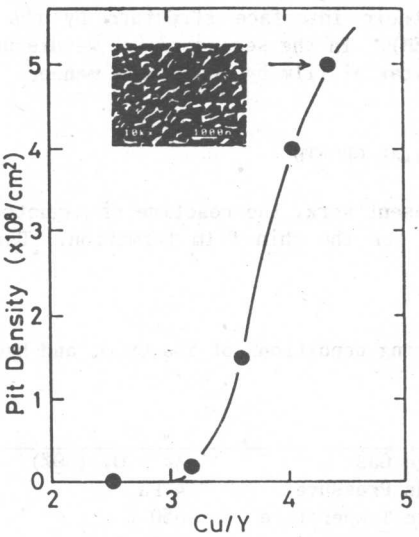


Fig.1 Number density of precipitations as a function of the Cu molar fraction in the film. Ba/Y=2.

First we checked the surface morphology of the grown YBaCuO film. In Fig.1, the change of the number density of surface precipitations is shown as a function of Cu molar fraction in the film. The amount of Cu in the film was measured by the ICP technique. The smooth surface was obtained for the stoichiometric or Cu-deficient film. Otherwise, the morphology significantly degraded with increse in Cu content as shown by the inset which was taken from $Y_1Ba_2Cu_{4.4}O_y$ film.

We next checked if the film was grown epitaxially by our simple growth technique. The results are given in Fig.2 where you can find

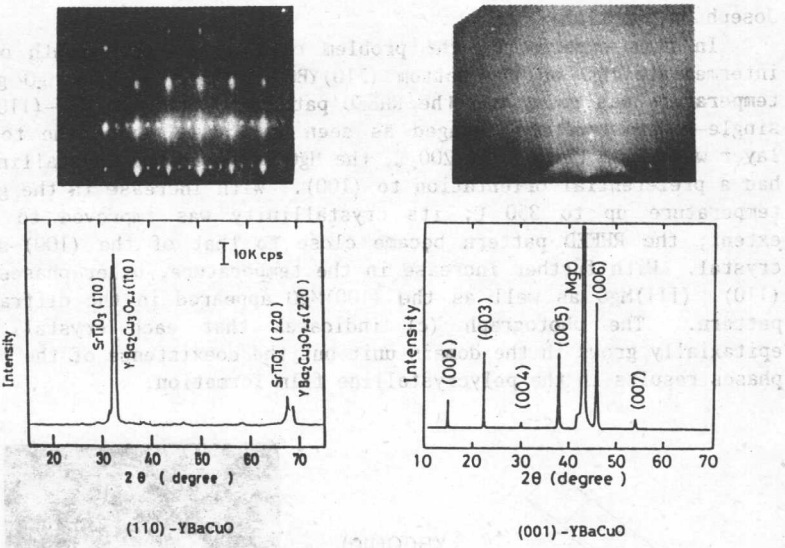


Fig.2 RHEED and XRD patterns of epitaxially grown (110) and (001)-$Y_1Ba_2Cu_3O_y$ films.

the fine RHEED patterns from the epitaxially grown films. Differed from the X-ray diffraction measurement, the RHEED pattern can bring us more direct indication of the epitaxy. According to this figure, the films grew epitaxially with the crystal orientation to (110) and (001) on (110)-$SrTiO_3$ and (100)-MgO substrates, respectively. However, as is discussed later, it must be kept in mind that this orientational relation changes depending on the substrate temperature.

2.1 (110)YBaCuO-MgO-(110)YBaCuO double-heterostructure

Our first attemp was done in preparing the most important hetero-structure such as (110)YBCO-MgO-(110)YBCO where the $Cu-O_2$ conducting plane is normal to the interface. The schematic drawing is given in Fig.3. This structure can be regarded as the idealized SIS tunneling

Josephson junction.

In this experiment, the problem came up in the growth of the intermediate MgO on the bottom (110)YBCO layer. As the MgO growth temperature was going up, the RHEED patterns taken for MgO-(110)YBCO single-heterostructure changed as seen in Fig.4, where the top MgO layer was 20 nm thick. At 200 ℃, the MgO film was polycrystalline but had a preferential orientation to (100). With increase in the growth temperature up to 350 ℃, its crystallinity was improved to large extent; the RHEED pattern became close to that of the (100)-single crystal. With further increase in the temperature, other phases like (110), (111)MgO as well as the (100)MgO appeared in the diffraction pattern. The photograph (c) indicates that each crystal phase epitaxially grows in the domain unit but the coexistence of the plural phases results in the polycrystalline film formation.

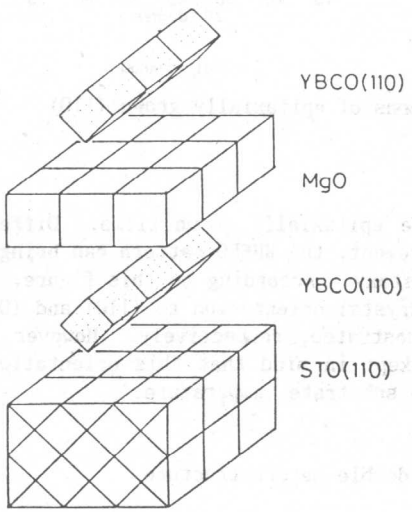


Fig.3 Schematic illustration of a double-hetero structure. (110)YBaCuO-(100)MgO-(110)YBaCuO.

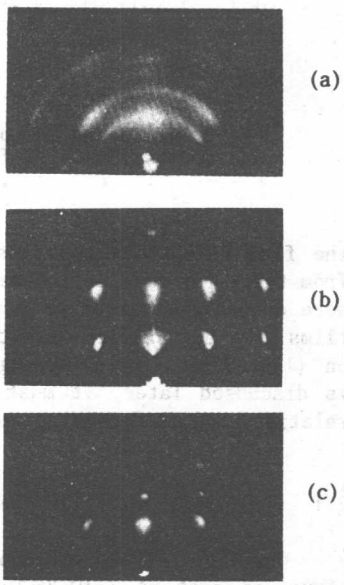
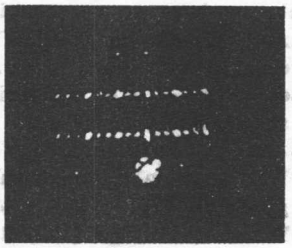
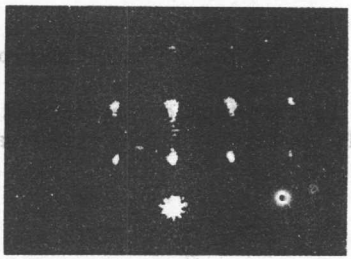


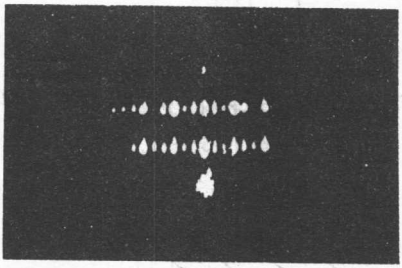
Fig.4 RHEED pattern of MgO-(110)YBaCuO. MgO was grown at (a) 200℃, (b) 350℃ and (c) 550℃.



(c)



(b)



(a)

Fig.5 RHEED patterns of (110)YBaCuO-(~100)MgO-(110)YBaCuO double-hetero structure. Patterns (a), (b) and (c) are, respectively, taken for the bottom (110)YBaCuO, intermediate (~100)MgO and top (110)YBaCuO layers.