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主编 钱伟长

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（第30集）

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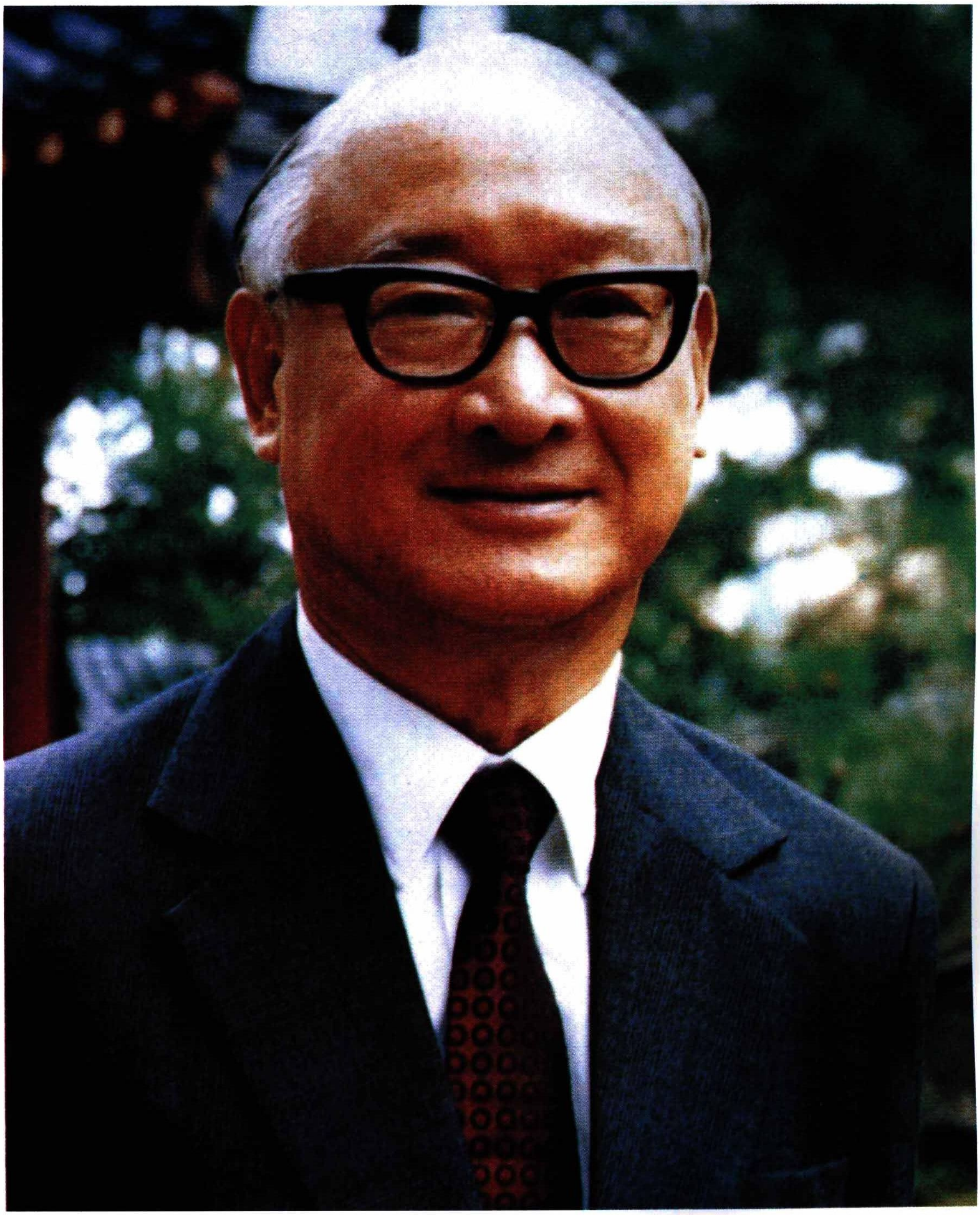

王 宽 诚 先 生

K.C.WONG(1907—1986)

谨以此书纪念本会创建人、故董事会主席王宽诚先生

王宽诚教育基金会

DEDICATED TO THE MEMORY OF MR. K. C. WONG, FOUNDER OF THE FOUNDATION AND THE LATE CHAIRMAN OF THE BOARD OF DIRECTORS

K. C. WONG EDUCATION FOUNDATION

王宽诚教育基金会简介

王宽诚先生(1907—1986)为香港著名爱国人士,热心祖国教育事业,生前为故乡宁波的教育事业做出积极贡献。1985 年独立捐巨资创建王宽诚教育基金会,其宗旨在于为国家培养高级技术人才,为祖国四个现代化效力。

王宽诚先生在世时聘请海内外著名学者担任基金会考选委员会和学务委员会委员,共商大计,确定采用“送出去”和“请进来”的方针,为国家培养各科专门人才,提高内地和港澳高等院校的教学水平,资助学术界人士互访以促进中外文化交流。在此方针指导下,1985、1986 两年,基金会在国家教委支持下,选派学生 85 名前往英、美、加拿大、德国、瑞士和澳大利亚各国攻读博士学位,并计划资助内地学者赴港澳讲学,资助港澳学者到内地讲学,资助美国学者来国内讲学。正当基金会事业初具规模、蓬勃发展之时,王宽诚先生一病不起,于 1986 年年底逝世。这是基金会的重大损失,共事同仁,无不深切怀念,不胜惋惜。

1987 年起,王宽诚教育基金会继承王宽诚先生为国家培养高级技术人才的遗愿,继续对中国内地、台湾及港澳学者出国攻读博士学位、博士后研究及学术交流提供资助。委请国家教育部、中国科学院和上海大学校长钱伟长教授等逐年安排资助学术交流的项目。相继与(英国)皇家学会、法国科研中心、德国学术交流中心、法国高等科学研究院等著名欧洲学术机构合作,设立“王宽诚(英国)皇家学会奖学金”、“王宽诚法国科研中心奖学金”、“王宽诚德国学术交流中心奖学金”、“王宽诚法国高等科学研究院奖学金”,资助具有副教授或同等职称以上的中国内地学者前往英国、法国、德国等地的高等学府及科研机构进行为期 2 至 12 个月之博士后研究。

王宽诚教育基金会过去和现在的工作态度一贯以王宽诚先生倡导的“公正”二字为守则,谅今后基金会亦将秉此行事,奉行不辍,借此王宽诚教育基金会《学术讲座汇编》出版之际,特简明介绍如上。王宽诚教育基金会日常工作繁忙,基金会各位董事均不辞劳累,做出积极贡献。

钱 伟 长

二〇〇九年十二月

前　言

王宽诚教育基金会是由已故全国政协常委、香港著名工商企业家王宽诚先生(1907—1986)出于爱国热忱，出资一亿美元于1985年在香港注册登记创立的。

1987年,基金会开设“学术讲座”项目,此项目由当时的全国政协委员、历任第六、七、八、九届全国政协副主席、著名科学家、中国科学院院士、上海大学校长、王宽诚教育基金会贷款留学生考选委员会主任委员兼学务委员会主任委员钱伟长教授主持。由钱伟长教授亲自起草设立“学术讲座”的规定,资助内地学者前往香港、澳门讲学,资助美国学者来中国讲学,资助港澳学者前来内地讲学,用以促进中外学术交流,提高内地及港澳高等院校的教学质量。

本汇编收集的文章,均系各地学者在“学术讲座”活动中的讲稿,文章内容有科学技术,有历史文化,有经济专论,有文学,有宗教和中国古籍研究等。本汇编涉及的学术领域颇为广泛,而每篇文章都有一定的深度和广度,分期分册以《王宽诚教育基金会学术讲座汇编》的名义出版,并无偿分送国内外部分高等院校、科研机构和图书馆,以广流传。

王宽诚教育基金会除资助“学术讲座”学者进行学术交流之外,在钱伟长教授主持的项目下,还资助由国内有关高等院校推荐的学者前往欧、美、亚、澳等参加国际学术会议,出访的学者均向所出席的会议提交论文,这些论文亦颇有水平,本汇编亦将其收入,以供参考。

王宽诚教育基金会学务委员会

凡　例

（一）编排次序

本书所收集的王宽诚教育基金会学术讲座的讲稿及由王宽诚教育基金会资助学者赴欧、美、亚、澳等参加国际学术会议的论文均按照文稿日期先后或文稿内容编排刊列，不分类别。

（二）分期分册出版并作简明介绍

因文稿较多，为求便于携带，有利阅读与检索，故分期分册出版，每册约150页至220页不等。为便于读者查考，每篇学术讲座的讲稿均注明作者姓名、学位、职务、讲学日期、地点、访问院校名称。内地及港、澳学者到欧、美、澳及亚洲的国家和地区参加国际学术会议的论文均注明学者姓名、参加会议的名称、时间、地点和推荐的单位。上述两类文章均注明由王宽诚教育基金会资助字样。

（三）文字种类

本书为学术性文章汇编，均以学术讲座学者之讲稿原稿或参加国际学术会议者向会议提交的论文原稿文字为准，原讲稿或论文是中文的，即以中文刊出，原讲稿或论文是外文的，仍以外文刊出。

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编 后 记

本书前29集出版后，分赠国内外各地图书馆及高等院校和科研机构，引起广泛注意。先后收到内地和港、澳各有关院校，各省、市、地区图书馆暨欧、美各国大学来信，迭有好评。表示愿意今后和我们保持联系，希望继续赠阅。不少单位反映，认为内容很好，专业性强，有一定深度和广度，学术水平很高，对学校的教学与科研有一定的参考价值。

我们受到国内外有关院校及各地图书馆来函鼓励，倍感亲切，益觉力薄，诚恐失误。若有失当之处，尚请海内外广大读者批评指正。

本书内容广泛，科技方面涉及的领域尤多，承蒙上海大学出版社为本书的出版工作给予了大力支持，上海大学上下一心多方协力，使本书出版、发行工作得以顺利进行，谨此一并致谢！

王宽诚教育基金会学务委员会

二〇〇九年十二月

目　录 CONTENTS

王宽诚教育基金会
《学术讲座汇编》第30集,1~7(2009)

Magneto-transport Characteristics of Superconducting $R\mathrm{Ba_2Cu_3O_{7-\delta}}$ Multilayers and Quasi-multilayers

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Abstract: To study flux pinning modulation due to intentional adjustments of rare earth cations, layer sequences and island-like secondary phases, we built up a series of artificial multilayers consisting of binary rare earth *R*123 as well as quasi-multilayers consisting of Y123/*M* (*M* = oxides such as Yttria Stabilized Zirconia) on single crystalline $SrTiO_3$ by pulsed laser deposition. The field dependence of transport critical current density J_c was measured at various temperatures and directions of the applied magnetic field. Comparing with pure Y123 films, almost all present multilayers and quasi-multilayers showed a crossover behaviour of flux pinning, evidenced by an existing medium field (H_{cro}) below which J_c is lower than of pure Y123 films, whereas above J_c is higher. Furthermore, a strong temperature dependence of such a crossover field was observed. The higher the temperature, the higer H_{cro}, implying that an artificial tailoring of flux pinning may appear in a narrow range of fields as the mixed vortex state moves towards to the region of weak vortex glass and vortex liquid. However, the improvement of flux pinning is hardly observed in the state of strong vortex glass.

Key words: superconducting thin films, flux pinning, quasi-multilayers

1 Introduction

In the last years, great effort had been made to overcome the weak linking at grain-boundary networks of coated conductors based on epitaxial $R\mathrm{Ba_2Cu_3O_{7-\delta}}$ (*R*123, *R*: Y and Nd, *etc.*, rare earth) films. The weak linking now, however, appears no longer a major obstacle to

* 蔡传兵,教授,上海大学理学院。由王宽诚教育基金会资助,于2007年9月赴比利时布鲁塞尔参加"2007欧洲应用超导大会",此为其向大会递交的论文。

achieve high in-field critical current density (J_c). It is reported that J_c in high magnetic fields is mainly limited by the intragrain properties, rather than of grain boundaries[1]. Improving flux pinning within the R123 grains is therefore becoming significant issue for the development of conductor technology[2-8].

Columnar defects produced by irradiation and antiphase boundaries produced by miscut substrates provide extended linear defects as strong artificial pinning centers[9-10]. Recently several other artificial routes to increase flux pinning have been realized for R123 films, including chemical doping (*e. g.*, to change the initial compositions of PVD targets)[2-5], growth control (*e. g.*, to build up multilayers or incomplete multilayers)[6-8], and substrate decoration (*e. g.* to introduce nano-scale islands of a second phase onto the substrate)[11-13]. Among them, the growth controlling route is very attractive as it can achieve a high density of second-phase defects up to 10^{11} cm^{-2}[8]. By building up quasi-multilayers of Y123/M(M = single element metal such as Ir and Hf, or oxides), we also achieved the pronounced increase of J_c in high fields[14-15].

In the present work, artificial quasi-multilayers consisting of Y123/M (M is Y_2O_3 and Yttria Stabilized Zirconia, YSZ) as well as the multilayers consisting of binary R123 are prepared for the investigation into flux pinning modulation due to intentional adjustments of rare earth cations, layer sequences and island-like secondary phases. The structural and flux pinning properties are investigated in comparison with that of pure Y123 thin films.

2 Experimental

The samples were prepared on (100) $SrTiO_3$ single crystal using pulsed laser deposition with a KrF excimer laser of λ = 248 nm, and a repetition rate of 5 Hz. For quasi-multilayers of Y123/M(M = YSZ and Y_2O_3), YSZ or Y_2O_3 target was set into position and a certain number of pulses, n (equals to 2 and 10) were done after every m pulses on the Y123 target (m is fixed at 40 for the present study). Other deposition conditions can be found in Ref. [14]. This was repeated 70 times. Multilayers of Nd123/Y123 are prepared as well by a similar processing with the target alternations of two targets. The bilayers and superlattices of Nd123/Y123 are named with NY1 and NdY2, respectively. Corresponding laser pulses and repetition for them are done as typical as 2x(750/750) and 30x(75/25). The growth rates for Nd123 and Y123 are around 1×10^{-9} per pulse, higher than the 0.4×10^{-9} per pulse for YSZ and Y_2O_3. Hence, 40 pulses of YBCO give roughly 3.4 unit cells while 2 - 10 pulses of YSZ and Y_2O_3 are assumed as incomplete layers of 0.075 - 0.370 unit cells. The total thickness of superconducting layers is around 280 - 300 nm for all the present samples.

Microstructure, texture, surface morphology and superconducting transition temperatures are checked by four-circle X-ray diffraction (XRD), atomic force microscopy (AFM) and inductive measurements, respectively. Resistivity and critical current density were measured in various magnetic fields up to 9 T with a Quantum Design PPMS system by standard four-probe method on a bridge of 0.8 mm length and 50 μm width, patterned by photolithography. The current flowing and external magnetic field were applied always normal to *c*-axis of the samples. The critical current density was determined by using an electric field criterion of $E_c = 1$ μV/cm.

3 Results and Discussion

3.1 Structural characterization and heterogeneous phases

As shown in Fig.1, X-ray $\theta - 2\theta$ diffraction patterns indicate the *c*-axis orientation of Y123, not only for two types of quasi-mulitilayers, but also for the bilayers of Nd123/Y123. In the case of Y123/YSZ, a heterogenous perovskite $BaZrO_3$ is present instead of the original doping phase due to a solid state reaction. This is similar to the case of metallic Ir doped Y123 films, where a heterogeneous $BaIrO_3$ appears[15]. With increasing YSZ pulse number, the intensity of $BaZrO_3$ is obviously enhanced while the *c*-axis texture of Y123 degrades. The quasi-multilayer of Y123/Y_2O_3, however, has no additional phase emerged except for the original secondary phase of Y_2O_3. This together with good epitaxial growth and lattice matching, allow Y123 textures hardly affected by Y_2O_3 doping. For NY2, the XRD patterns show satellite peaks aside the main (001) peaks, which clearly demonstrates the superlattice features in the sample.

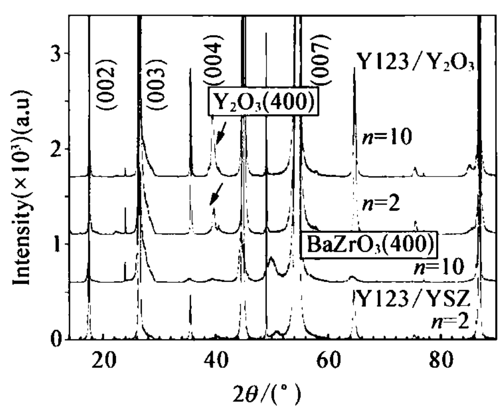

Fig. 1 XRD (CoKα) patterns for the studied quasi-multilayers of Y123/YSZ and Y123/Y_2O_3. The *c*-axis orientation for both YBCO and precipitates $BaZrO_3$ or Y_2O_3 is evidenced by (001) reflections

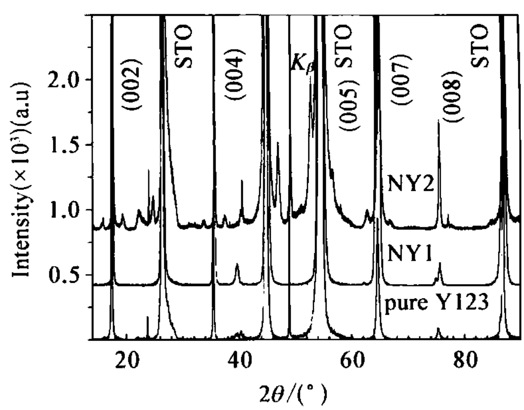

Fig. 2 XRD (CoKα) patterns for the bilayer (NY1) and multilayers (NY2) of Nd123/Y123. Clearly, satellite peaks aside the main (001) peaks demonstrate the superlattice features in NY2

As shown in Fig. 2, surface morphology for both pure Y123 films and quasi-multilayers is characterized by scattered large particles with the size over than 50 nm. These large particles are identified as CuO_x by EDX analysis in SEM, consistent with previous observation done by other groups. In contrast, finer particles as small as 10 nm only appear in the quasi-multilayers. They are presumed to be the precipitates of homogeneous Y_2O_3 or heterogeneous $BaZrO_3$ due to their absence in pure YBCO films. This is further evidenced by the direct observation into $SrTiO_3$ substrate decorated with 2 - 50 pulses of Y_2O_3 or YSZ, where finer particles are visible in the size range of 10 nm, nearly same as in the right images of Fig. 3. This is similar to the case of Ir doped multilayers, in which the second-phase $BaIrO_3$ particles have the size of around 13 nm given by a Scherrer estimation[15].

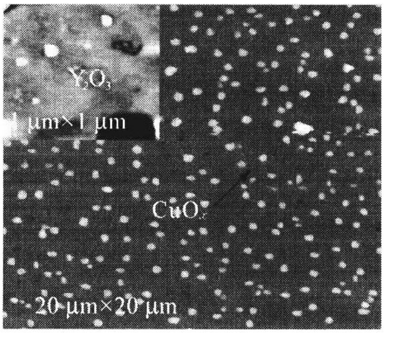

Fig. 3 AFM images of surface morphology of a typical $Y123/Y_2O_3$ multilayers in two scanning scales. The large particles with the size of more than 50 nm appear in both multilayers and pure Y123 films. They are identified by EDX as CuO_x precipitates. Whereas, those finer nano-scale particles are presumed to be doping precipitates because they are invisible in the pure Y123 films

3.2 Superconducting and magneto-transport performance

There are significant different in T_c variation between Y123/YSZ and $Y123/Y_2O_3$. T_c slightly changes with Y_2O_3 doping content, while it decreases greatly with the doping content in the case of Y123/YSZ. As well, the transition width for Y123/YSZ is broadened from 1.5 K to 2.7 K when the pulse number increases to 700, unlike the case of $Y123/Y_2O_3$ where the ΔT_c ($\leqslant 1.5$ K) nearly remains as narrow as in pure Y123 films, even for the sample with the highest amount of Y_2O_3 (*i. e.* the sample with total pulse number of 1 400). Bilayers of Nd123/Y123 show a $T_c \approx 87.2$ K, $\Delta T_c \approx 1.5$ K, 1 - 2 K lower than that of multilayers (NY2), but both have a quite better T_c than the pure Nd123 film prepared with the same conditions. This may result from the degradation of T_c in Nd123 sequence of the bilayers due to the elemental exchange between Nd and Ba sites, which seem to be suppressed in the present multilayers, but emerges in the present pure Nd123. This is obviously interesting, and worthy being further investigated.

Figure 4 shows the field dependence of critical current density J_c for the Y_2O_3 and YSZ doped films as well as a pure Y123 film ($n = 0$) at three temperatures, 50 K, 70 K, and 77 K. The sample of $n = 2$ is selected due to its less decrease in T_c compared with the pure