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Preparation And Characterization of Superconducting YBCO Thin Films Deposited By Magnetron Sputtering Technique

Shailaj Kumar Shrivastava[*1], Chandan Shrivastava[2]
[*1] *Principal, K.L.S.College, Nawada. (A constituent unit of Magadh University, Bodh Gaya), Bihar, 805110, India.*
[2] *B. Tech final, Computer Science Engineering (CSE), International Institute of Information Technology, Hyderabad, Telangana, 500032, India*
Corresponding Author:shailajshri68@yahoo.com

Abstract:In-situ on-axis dc magnetron on-axis sputtering techniques have been used to grow YBCO films on (100) $SrTiO_3$substrates. The single phase stoichiometric YBCO (123) ceramic targets for sputtering are prepared by solid state reaction technique. The experimental setup for deposition of thin films is described.The deposition parameters affecting the in-situ growth and superconducting properties of high quality YBCO thin films on (100) $SrTiO_3$ substrate have been optimized. The YBCO thin films deposited on (100) $SrTiO_3$ substrate are highly c-axis oriented with T_c (R=0) of 91.2 K and J_c(77K) =1.5x $!0^6$ A/cm^2. In this paper, important parts of the sputtering system and step by step optimization of sputtering parameters along with spiral growth mechanism of superconductingYBCO films are described.*

Keywords:YBCO, sputtering parameters, thinfilms, X-ray diffraction, scanning tunnelling microscopy.*

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I. INTRODUCTION

A number of techniques have been developed for deposition of high quality YBCO thin films [1], such as vacuum evaporation, laser ablation, chemical vapour deposition, magnetron sputtering [2,3] etc. The development and understanding of high temperature superconducting film deposition have largely contributed to the application in cryoelectronic devices such as low pass filters, delay lines and antennas for microwave communications and to produce Josephson junctions that are useful in digital circuits and SQUIDs. All the technologies and applications will depend on the success of large-scale inexpensive production of thin films. The growth of cuprate films especially, multilayers has remained a quite complicated matter. The process is complicated due to presence of several inherent material problems like short coherence length, anisotropy, low critical current density, and stoichiometry. Also, in thin films diffusion of elements from substrate to the film and also from adjacent layer is an additional problem in multilayer structures.

The physical properties of high-T_c superconductors vary drastically in different crystallographic directions as atoms in these materials are arranged in layer structure. The deposition conditions of high-T_c thin films also affect their structural, superconducting and surface morphological properties [4]. The post-annealed films have rough surfaces, which are not suitable for device fabrication. The in-situ deposition method is suitable for getting thin films with smooth surfaces. The microstructure of the YBCO thin films varies with grain size, grain orientation and grain boundary weak links, which critically depend upon the complexity of the growth process and the quality of the substrate. The critical current density, J_c, of high-T_c superconducting thin films depends strongly on the microstructure. Hence, in order to reduce the granularity of high-T_c films, it is necessary to increase the grain size and orientation, and also eliminate the impurity phases at the grain boundaries.

Among the various deposition techniques currently being used for YBCO films, on-axis magnetron sputtering offers a clear advantage due to its simplicity and medium to fast deposition rate [5]. However, to avoid re-sputtering of growing films by negatively charged energetic oxygen ions as well as target oxygen depletion, special cares are taken. The deposition process was optimized for deposition of YBCO thin films on $SrTiO_3$ (100) substrate. The sputtering process was optimized by varying the substrate temperature and plasma current. The R-T curvesand XRD data were analysed to achieve the optimum depositions to obtain thin films with high-T_c and high J_c. The X-ray diffraction scan shows that films were almost single phase and fairly well oriented with c-axis perpendicular to the substrate surface. The AFM data on the effect of substrate annealing on the surface morphology of the $SrTiO_3$ substrate indicates that the roughness of the substrate surface is considerably reduced after annealing in flowing oxygen. The YBCO thin films sputtered on $SrTiO_3$ (100) substrates under the optimum conditions and substrate temperature of 740°C were highly c-axis oriented.

II. PREPARATION OF SPUTTERING TARGET

High purity (99.99%) powders of Y_2O_3, $BaCO_3$ and CuO were used as starting materials [6]. Suitable amounts of these powders in the cation ratio Y: Ba: Cu = 1:2:3 was weighed and thoroughly mixed and grounded in a pestle mortar to form a homogeneous mixture. The powder was then cold pressed (3500 Kg/cm^2) into 2.5cm diameter pellets (4 pellets). These pellets were calcined at 820^{0}C for six hours. These pellets were again grounded, repressed into pellets, and calcined at 930 ^{0}C (heating rate 10^{0}C/min) for 30 hours in flowing O_2. The step was repeated twice. The pellets were calcined at a relatively high temperature in order to facilitate the decomposition of the precursors to oxides and to allow diffusional mixing for the formation of the stoichiometric superconducting phase. The calcined pellets were grounded and pressed into two-inch diameter disc target. The compressed target was then sintered in electrical muffle furnace at 940^{0}C for 24 hours in flowing O_2. The orthorhombic superconducting phase of YBCO is unstable at temperature higher than 650°C. At 900-950°C, the oxygen content per formula unit is less than 6.5 and the structure is tetragonal. If quenched in this form the material is non-superconducting. To regain the oxygen to the desired value close to seven, the material should be given a long anneal in O_2 or air in the temperature range of 400°C-500°C to enable the oxygen pickup. Therefore, after sintering, the furnace was cooled slowly at the rate of 1^{0}C/min to 450°C. At this temperature, the target was kept for 72 hours, and then cooled slowly to room temperature. The resultant YBCO target was black in color. The density of the target was 5.6 gm/cm^2. The T_c (R=0) of small pieces of targets were between 89 to 92K. The targets have single (123) phase as shown by XRD. Figure 1 shows the XRD of a small piece of a YBCO target.

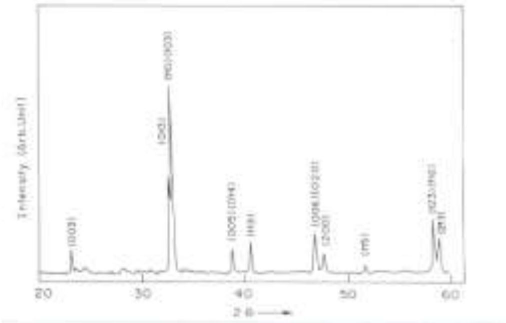


Figure.1 XRD pattern of a small piece of a YBCO target used for dc magnetron sputtering system.

III. DEPOSITION SYSTEM FOR PREPARATION OF YBCO THIN FILM

The thin film deposition was carried out using the conventional dc magnetron sputtering from a single YBCO (123) target. The schematic diagram of our sputtering system is shown in figure 2. The deposition system consists of a high vacuum chamber with a base pressure of 10^{-6} Torr, which was achieved using a diffusion pump. The liquid nitrogen trap has been provided in the vacuum line so as to prevent back streaming of the high vapour pressure fluids used in these pumps. This system includes a dc magnetron-sputtering gun (Ion Tech. B 315, UK), substrate heater (Conductus, USA), a chromel-alumel thermocouple attached near the substrate, a gas assembly and a shutter. The planar magnetron-sputtering gun is mounted on the top flange of the deposition chamber parallel to the base plate. The magnetron gun is provided with permanent magnets directly behind the cathode. The discharge plasma is restricted to an area adjacent to the cathode surface. The target is in the form of a disc having toroidal plasma ring facing the planar substrate holder. In balanced condition the plasma is confined just above the substrate holder. In magnetron sputtering, target erodes only in the transverse magnetic field region. The transverse component of magnetic field in front of target is typically in the range of 500G. The dc magnetron source is operated at low cathode voltage ranging between 100 to 200V using dc power supply (MegaTech Ltd. MDS-1K). The substrate heater, which could be heated up to 900°C, acts as an anode and is grounded. A thermocouple embedded under the surface of the heater close to the substrate position measures the heater temperature.

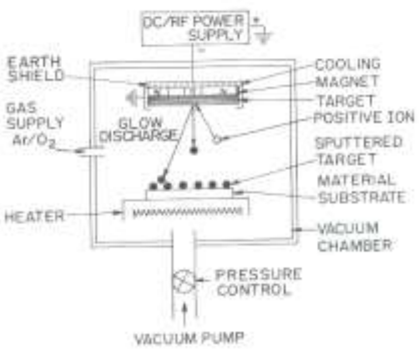


Figure 2 Schematic diagram of dc magnetron sputtering system used for thin film preparation

The substrate temperature was calibrated as a function of heater temperature with an uncertainty of $\pm 1^0$C using microprocessor-controlled temperature indicator-cum-controller (Thermotech, L 2001). Total absolute pressure during the deposition process was measured by a Baratron gauge (MKS Model 220C), which was kept at a constant level, by admitting the gas mixture (Ar: O_2) in close vicinity of the target through a needle valve. Mass flow controller (MKS PDR-C-1C) was used to establish the partial pressure of the sputtering gases.

IV. FABRICATION OF HIGH-T_C SUPERCONDUCTING YBCO THIN FILMS

The on-axis single target magnetron sputtering technique was used for depositing high quality superconducting YBCO thin films. The deposition system consists of a high vacuum chamber. The ultimate vacuum of $1\text{x}10^{-6}$Torr was achieved inside the chamber using a diffusion pump in conjunction with a liquid nitrogen trap. Planar magnetron sputter gun (Ion Tech, UK, Model B-315) was mounted on the top plate of the deposition chamber. The single phase stoichiometric YBCO (123) target (50mm diameter and 3mm thick) was mounted on 2-inch diameter copper plate of planar magnetron cathode using silver paste for good electrical and thermal contact between copper plate and the target. The heater block (Conductus, USA) which acts as anode was held below the cathode in the on-axis configuration. Cleaned substrate with both sides polished was mounted on the heater block with the help of conducting silver paste. The substrate temperature was calibrated as a function of heater temperature. Digital temperature indicator-cum-controller (Thermotech L-2001) was used to measure the substrate temperature using a chromel-alumel (type K) thermocouple attached to the heater block close to the substrate. Pre-sputtering was done for one hour, on the shutter provided between cathode and heater block, at low plasma current, to remove contaminations from the target surface. The shutter was removed only after attaining the desired conditions (temperature, gas pressure, substrate-target distance etc) for thin film deposition. The substrate temperature was maintained between 650-760^{o}C during deposition. The sputtering gas pressure was monitored using a digital capacitance manometer (MKS PDR-1C) and controlled by using piezoelectric control valve. The films were deposited using argon-oxygen mixture (2:1) as sputtering gas. The sputtering pressure of mixture was maintained between 300-1000 mTorr during deposition. The substrate was placed at a distance of 25-35 mm from the target. The films were deposited at plasma current of 175 to 425 mA and the cathode voltage was maintained around -120 V using dc power supply (MegaTech Ltd. MDS-1K). High-T_c superconducting YBCO (123) thin films were deposited in-situ on single crystal substrates $SrTiO_{3.}$ To avoid oxygen depletion from the film surface, the sputtering chamber was evacuated and filled with pure dry oxygen at a pressure of 300 Torr after film deposition. The substrate temperature was slowly reduced to 475^{o}C (2^{o}C/min.). During this process, the YBCO thin film passes through the tetragonal to orthorhombic structural phase transition. The film was kept at this temperature (475°C) for 1 to 2 hours and then slowly cooled to room temperature. The deposition conditions (substrate temperature, gas pressure etc.) were optimized for obtaining films with high-T_c and high J_c deposited on (100) $SrTiO_3$substrate [7]. The as-deposited film was black, smooth and shiny.

In order to prevent major cracks in the target the following procedure was followed. The plasma current was first maintained at 50mA until the plasma got stabilized. The plasma current was then slowly increased to the desired value. Water cooling of the target also saved it from cracking. This procedure enabled the targets to be used for about 60 hours without developing any major cracks. It may, however, be mentioned that prolonged sputtering affects severely the composition of the target and therefore make it unsuitable for depositing stoichiometric YBCO (123) films.

A. Target mounting on the magnetron cathode

The superconducting YBCO (123) ceramic target having 50mm diameter and 3mm thickness was mounted on the cathode with the help of silver paint to ensure low thermal resistance. Water cooling system was used to prevent undue heating of the target during sputtering. Target was pre-sputtered for 8 hours at low plasma current prior to film growth to remove surface contamination.

B. Calibration of substrate temperature as a function of heater temperature

In spite of using silver paste as glue the substrate temperature is usually not the same as the heater block temperature.Hence the temperature at the surface of the substrate was measured as a function of the temperature of the heater block. During this measurement, the pressure of $Ar:O_2$ mixture inside the chamber was maintained at 850mTorr, close to that maintained during sputtering.Prior to mounting, the substrate was cleaned using 1% HCl and then ringed in boiling acetone. Two identical chromel-alumel thermocouples were used for measurement of the temperature of the substrate surface and the heater block respectively. One thermocouple embedded under the surface of the heater close to the substrate position was used to measure the heater temperature while the other was bonded on the substrate surface with the help of air-drying silver paste. The substrate temperature as a function of heater temperature was noted down using microprocessor-controlled temperature controller through a selector switch. Figure 3 shows the substrate temperature as a function of heater temperature. It was found that the substrate temperature was 15°C less than the heater temperature at 750°C and 850mTorr partial pressure of sputtering gas mixture.

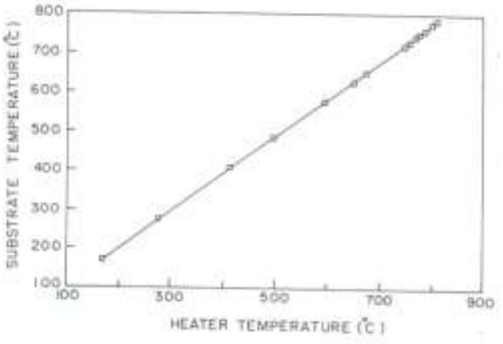


Figure 3 Calibration of substrate-temperature as a function of heater temperature

C. Optimized deposition parameters for growth of YBCO thin films deposited on $SrTiO_3$ substrate

Table 1 shows the optimized deposition condition for the growth of high quality YBCO thin films on single crystal $SrTiO_3$ (100) substrate by dc magnetron sputtering. Three films (S_{11}, S_{12}, and S_{13}) have been deposited under these conditions.

Table 1 Optimized deposition condition for the growth of high quality YBCO thin films on $SrTiO_3$ (100) substrate by dc magnetron sputtering

Target	Superconducting single phase YBaCuO (123)
Substrate	Single crystal (100) $SrTiO_3$
Substrate–target distance	35mm
Sputtering gas pressure (Ar: O_2 =2:1)	850 mTorr
Substrate temperature	740°C
Plasma Current	250mA
Cathode Voltage	~120V
Deposition time	2hours
Hold at 475°C	2 hrs

Figure 4 shows the R-T measurements of these films. The differences in the normal state resistance are due to differences in the distance between the potential probes. The critical temperatures of these films were found to be 90, 91.2 and 90K respectively. All these films show a sharp transition. The transition width ΔT_c being about ~1K. The resistivity ratioR_{250K}/R_{100K} is greater than 3 in these cases. The critical current density of the thin films in ambient field was found to between $1.0x10^6$ and $1.5x10^6 A/cm^2$ at 77K.

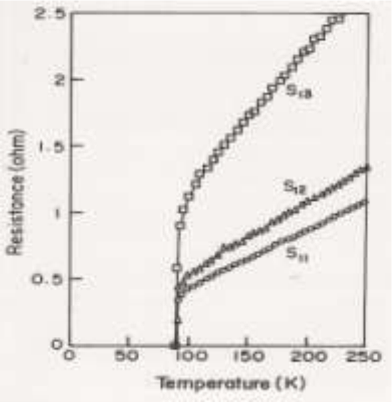


Figure 4 R-T curves of YBCO thin film deposited on $SrTiO_3$ substrate under optimized condition

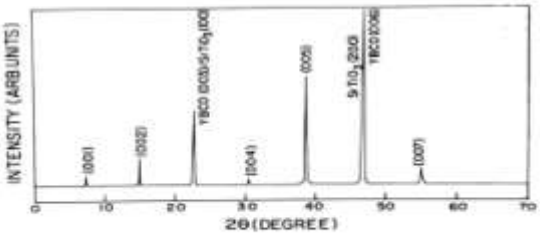


Figure 5 X-ray diffraction pattern of YBCO thin film deposited on $SrTiO_3$ substrate under optimized condition

The XRD diffraction pattern of the film S_{13} is shown in figure 5, which shows the c-axis orientation of the films. No evidence of any other phases was found in the x-ray diffraction scan. Thickness of a typical film, prepared under optimized conditions as measured by stylus was about 360nm. Table 2 summarizes the properties of YBCO thin films deposited on (100) $SrTiO_3$ substrate under optimized condition.

Table 2 Properties of YBCO thin films deposited under optimized condition.

Critical temperature (T_c)	**90-91.15K**
Critical current density (J_c)	**1.0-1.5x10^6A/cm^2**
Orientation	**Fully c-axis**
Film thickness	**350-370nm**

V. SPUTTERING PARAMETERS AFFECTING GROWTH AND SUPERCONDUCTING PROPERTIES OF YBCO THIN FILM

A. Role of oxygen

Oxygen plays a crucial role in YBCO thin film deposited on $SrTiO_3$[8]. It oxidizes the sputtered species as they arrive on the substrate and condense to form the required phase of the material. In addition, it prevents oxygen depletion from the target surface during sputtering. A mixture of argon and oxygen in the ratio 2:1 and pressure 800mTorr was used during sputtering. After deposition, the sputtering chamber was evacuated and the chamber was filled with pure dry oxygen (IOLAR-I) at 300Torr.

B. Effect of power

Since the normal glow discharge region of dc plasma (constant voltage region) is used in this method, plasma characteristic cannot be controlled by cathode voltage. It has been found that the film properties heavily depend on the cathode current. The sputtering rate of the YBCO target is a function of the plasma current. In magnetron sputtering, the supply of YBCO from the plasma has to be matched to the optimum growth rate determined by the surface kinetics at a given temperature. The cathode voltage, which depends on the conductivity of the target, is one of the most important parameters for making high quality film. The lower cathode voltage decreases the energies of ions to a few hundred eV ranges. When the oxygen deficient target is used, the resulting increased cathode voltage leads to the degraded quality of the film. However, surface roughness increases with the increase in plasma current.

Thin films of YBCO deposited under optimized sputtering conditions for three hours at different plasma current show changes in surface morphology. It was observed that surface roughness increases as the plasma current is increased. The surface roughness is more due to spiral growth. However, excessive surface roughness must be avoided in achieving planar or multilayer tunnel junction devices based on grain boundary alignment. The SEM photographs of YBCO thin films deposited on $SrTiO_3$ substrate at different plasma currents shows smooth surface morphology. Some particles of the target materials are also seen on the surface of film grown at high plasma currents (>350mA). Figure 6 shows the SEM picture of a typical YBCO thin film deposited at high plasma current ~350mA. The SEM pictures shows that YBCO films (deposited on $SrTiO_3$ substrate under optimized conditions) have relatively smooth surfaces free from surface defects like mechanical cracks, voids, surface outgrowth and precipitates.

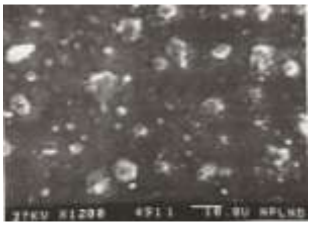


Figure 6 SEM picture of a typical YBCO thin film deposited at high plasma current ~350mA.

C. Effect of substrate temperature

The substrate temperature showed marked dependence on growth direction and superconducting properties of thin film. At lower temperature the mobility of the cations might not be high enough to make them reach their regular positions. With increasing growth temperature, the mobility of the atoms increases exponentially, leading to a rapid decrease in the degree of disorder. At higher growth temperatures, there is enough mobility of atoms to form a completely ordered structure. The substrate temperature is perhaps the most important single parameter as it determines the surface energies and thus relaxation and surface self-diffusion of adatoms and ad molecules as well as their sticking probability.

At low substrate temperatures, the mobility of the constituent atoms is not perhaps large enough to ensure epitaxial growth. With the increase in substrate temperature, the mobility becomes sufficiently high to form films in a nearly completely ordered structure. The critical current density J_c also has been found to depend on the substrate temperature [9]. J_c (at 77K) for films deposited at substrate temperature of 650°C was found to be about $10^4 A/cm^2$. For films deposited at substrate temperature of about 750°C, the J_c (T=77K) was about $10^6 A/cm^2$. The grain size of the YBCO films was measured using a scanning tunnelling microscope (STM). The grain size was found to improve as the substrate temperature was increased from 700°C to 740°C. Table 3 shows the dependence of grain size on substrate temperature.

Table 3 Dependence of grain size of thin films on substrate temperature:

Sample No.	**Substrate Temperature (°C)**	**Grain Size (nm)***
1	**700**	**327x523**
2	**720**	**964x910**
3	**740**	**7179x7170**

*Standard deviation

D. Effect of substrate- target distance

High quality superconducting thin films were obtained, if the substrate was placed just below the negative glow of the discharge (d_{S-T}= 25 mm to 35 mm). It was observed that the deposited films were non-uniform when the substrate-target distance d_{S-T} was less than 25mm. For smalld_{S-T}, the film during growth was also exposed to bombardment with excited neutrals and negatively charged ions, which results in nonuniformity.

E. Effect of sputtering gas pressure

The use of a relatively high gas pressure increases the collision frequency and thus reduces the energy of the negative oxygen ions before they reach the substrate. High quality YBCO films were obtained using on-axis configuration when the pressure of sputtering gas was greater than 400mTorr and there was no re-sputtering effect.

The thin films deposited at a high gas pressure of 800mTorr (because the harmful ions have been thermalised due to large number of collisions by the time, they reach the substrate) were found to have high-T_c (=91K) and smooth surface morphology. Films deposited at pressure less than 300mTorr showed wide spread re-sputtering of the film materials. The deposited films show poor electrical conductivity at room temperatures. For sputtering gas pressure between 600 mTorr and 1000 mTorr, the T_c was found to be between 86 and 91K. The film deposited at gas pressure of 600mTorr has T_c = 86K. The critical temperature (T_c) increases from 86 to 91K as the pressure is increased to 850 mTorr. The critical temperature does not further increase if the gas pressure is increased beyond 850mTorr and its value is stabilized at 90K. At high pressures, the negative oxygen ions responsible for resputtering effects get thermalized due to increased number of collisions between gaseous ions. The high-energy ions loose most of their energies before striking at the substrates.

F. *Effect of substrate material*

The important parameters for substrate selection are cost, lattice matching, reaction between film and substrate and the matching of thermal expansion coefficients of the thin film and substrate. The thin film deposited on (100) $SrTiO_3$ substrate had least resistivity at room temperature. This is expected as there is a close matching of the film and substrate crystallographic lattices, which minimizes the internal stresses in the thin film. The resistivity ratio R_{300K}/R_{100K} was found to be maximum (~3) for films deposited on (100) $SrTiO_3$ substrate.

Table 4: Properties of substrate material $SrTiO_3$used for high-T_c superconductors

Substrate material	Crystal system	Lattice constant(nm)	Thermal expansion coeff.10^{-6} C^{-1}	loss tangent ($x10^{-4}$)77K	dielectric constant	melting temp.(°C)	%age mismatch with YBCO a=0.386nm.
$SrTiO_3$	Cubic	a=0.3905	9.4	>200	300	2080	-1.15

G. *Effect of surface quality of substrates*

The smoothness of the surface of the substrate is crucial for depositing high quality epitaxial thin films. Thin films deposited on such degraded substrates generally have rough surfaces. This roughness may result from out of plane c-axis growth, pronounced surface outgrowth and isolated clusters of a-b axis crystallites. Similarly, if the substrate is not well polished, step edge Josephson weak links could be formed in films deposited on rough surface. This results in considerable reduction in J_c of the film.

The substrates were cleaned ultrasonically using tri-chloroethylene and acetone and annealed in flowing O_2 at temperature between 900°C to 1000°C for two hours in tubular furnace (Tempress, Model 201) before mounting on the heater block. Table 5 shows the atomic force microscopy (AFM) data on the surface morphology of the $SrTiO_3$ substrate. The roughness of the substrate surface was considerably reduced after annealing in flowing oxygen.

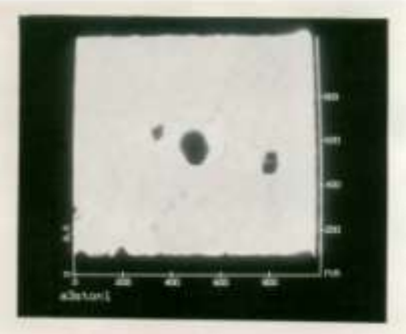
Table 5 Atomic Force Microscopy (AFM) data on the surface morphology of the $SrTiO_3$ substrate.

Sample No.	Substrate	Annealing Condition	RMS Roughness * (nm)
1	$SrTiO_3$(100)	Unannealed	1.00
2	$SrTiO_3$(100)	900°C for 2 hr. in flowing O_2	0.10
3	$SrTiO_3$(100)	1000°C for 2 hr. in flowing O_2	0.02

* Standard deviation

VI. SURFACE GROWTH MORPHOLOGY

Figure 7shows the AFM picture of $SrTiO_3$ substrate used for depositing thin film. The AFM data on surface morphology of the $SrTiO_3$ substrate shows the rms roughness of substrate surface = 0.02nm.



The scanning Tunnelling Microscopy (STM) has been used to investigate the growth mechanism of YBCO thin films deposited on $SrTiO_3$ under optimized sputtering conditions [10]. The film was investigated by nanoscope II STM at room temperature in air using Pt-Ir scanning tip in the constant current mode. In the constant current topography, the probe tip height is continuously adjusted to maintain a constant tunnel current. The set point tunnelling current was set between 0.2 and 1nA and the sample bias voltage were set above 500mV. Figure 8 shows the 200x200nm STM image of a YBCO thin film deposited on $SrTiO_3$ substrate. The bright and dark regions correspond to higher and lower surface regions respectively. The nano-structure of sputtered c-axis oriented films consisting of terraces and growth spirals is observed. This seems to be formed by the two-dimensional nucleation and layer growth mechanism. Large atomically flat terraces, growth spirals and growth steps with a typical height of c and 2c (c: lattice parameter) of the YBCO crystalline structure are seen.

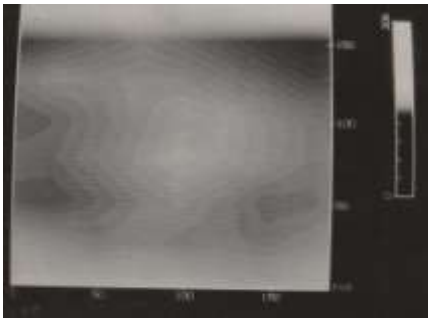
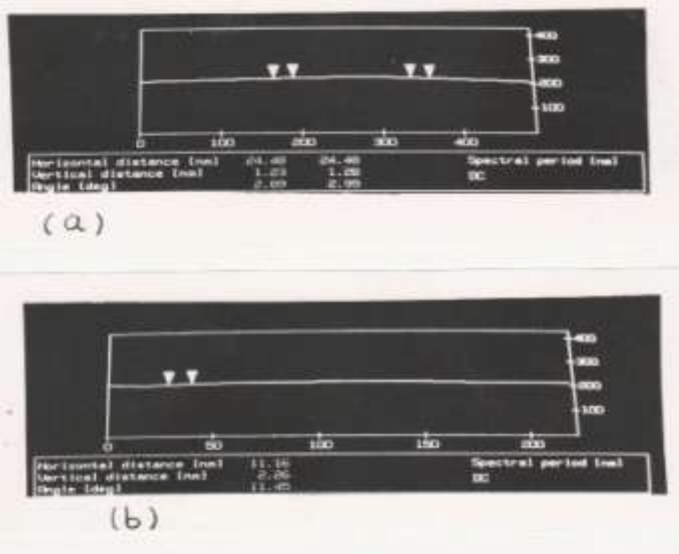


Figure 8. The 200x200nm STM image of YBCO thin film deposited on $SrTiO_3$ substrate

The STM images show the growth morphology and adequate resolution for imaging unit cell growth steps on the surfaces of the grain. Figure 9(a) and 9(b) show line scans across the spirals in the selection mode showing the sequence of heights (vertical distances along the c-direction. The step to step horizontal and vertical distances within a grain were reproduced. The vertical height difference between terraces is often one unit cell, about 1.2nm, although there are also seems to be evidence or c-axis periodicity in some grains. The horizontal distances between the arrows are 24, 48 nm and 11.16 nm in (a) and (b) respectively. The choice of sputtering parameters was found to significantly influence the surface morphology and superconducting properties of the thin films.



(a)
Horizontal distance [nm] 24.48 24.48 Spectral period [nm]
Vertical distance [nm] 1.23 1.28 DC
Angle [deg] 2.89 2.99

(b)
Horizontal distance [nm] 11.16 Spectral period [nm]
Vertical distance [nm] 2.26 DC
Angle [deg] 11.45

Figure 9(a) &9(b). The line scans across the spirals in the selection mode showing the sequence of step heights (vertical distances) along the c-direction.

VII. ISSUES AND CHALLENGES

Few areas that need further attention and efforts are summarized below.

[1] One of the main topics of thin film deposition is the preferred orientation of the films. For making films for device application, the grain of the film must not only be aligned in the growth direction (typically the c-axis) but also in the plane of the film (the a/b plane).

[2] Atomic–level control of film nucleation and growth has to be achieved especially at film interfaces. The ultimate goal is to reproducibly produce clean interfaces in heterostructures where the electronic properties are preserved up to the interface (e.g. in Josephson contacts). A growth method is needed in which the composition can be controlled in-situ with increasing precision.

[3] There is great need of development of system for double sided and large area film deposition, in particular a heater is required that allows the substrate to be uniformly heated at higher fixed temperatures. These films are required for band pass filters resonators and delay line.

[4] It is important to use the rich chemistry of doping and substitution allowed in 123 family to further optimize film properties and performance.

[5] Polycrystalline films generally consist of large angle ($\geq 20^o$) grain boundaries. These grain boundaries acts as weak link and contribute to undesirable and unacceptable microwave losses. It is therefore, mandatory to eliminate high angle grain boundaries in these films by innovative deposition scheme. The attention should be given to the properties of low angle grain boundaries in high quality films.
[6] The thermal contact of substrate with heater is made with silver paste, which is not practical beyond 5cm diameter.
[7] Another issue is the oxygen concentration; it is desirable to investigate which oxygen concentration optimizes the device performance.
[8] There is large impact of defects and growth morphology on physical properties such as microwave surface resistance, critical current, critical thickness and interface resistance. Subsequently, technological processes have to be developed to control the morphology and creation of adequate defects in order to tune the physical properties of the films according to the requirements.
[9] Substrates remain a serious obstacle to commercialization of the technology, for reasons both of performance and cost. It is fair to say that the field is still waiting for the ideal substrate materials.

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AUTHOR PROFILE

DR. SHAILAJ KUMAR SHRIVASTAVA holds first class Master Degree (second topper) in Physics (Advance Electronics) from Patna University. He has worked as Research fellow at National Physical Laboratory, New Delhi and obtained his Ph.D. degree in Physical Science from Delhi University in 2002. His research interest is directed towards superconductivity, thin films and devices. Having a distinguished teaching career over more than 25 years he has to his credit around more than seventy research papers published in leading journals and conferences. He participated in several national and international conferences and seminars and presented papers in the areas of superconductivity and issues related to higher education. Three research Scholar has been awarded Ph.D degree under his supervision. Besides being member of several academic bodies of the university, he has more than 12 years of experience as a Principal in constituent colleges. Currently he is Principal at K.L.S. College, Nawada, Bihar (A constituent unit of Magadh University, Bodh Gaya) and OSD Vocational Courses, Magadh University, Bodh Gaya. His profile available on web search engine like Google Scholar, Orchid, Academia and Vidwan etc. He got several awards including 'Young Research Award' at IUMRS-ICA-98 held at IISc Bangalore. Despite the busy schedule of administrative responsibilities Dr. Shrivastava is still active in his academic pursuit.

Chandan Shrivastava is B.Tech final student of computer science engineering department at International Institute of Information Technology (IIIT), Hyderabad interested in software development and technology. He has experience of various software development and application development intern at different organisations. He possesses skills of C, C++, Python, SQL, JavaScript, Dart, HTML/CSS, GraphQL languages along with expertise in React JS, React native, Node JS, Express JS, Flutter, Redux frameworks. He is using developer tools like Git, Docker, Bash, Firebase etc. His journey in technology has been a dynamic blend of learning, innovation and impactful projects. He has successfully completed various projects assigned to him individually and in group. He published three research papers in reputed Journals. He got ‘Technology Innovation Award-2022’ at 22nd Global Leadership Summit-2022at Goa (India) by Global Leaders Foundation, New Delhi.