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DEPOSITION OF $YBA_2CU_3O_{7-\delta}$ SUPERCONDUCTING THIN FILM BY RF SPUTTERING FOR DEVICE APPLICATION

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Abstract High -Temperature Superconducting (HTS) materials are considered as the attractive replacement of the conventional conductors in many practical applications in future for their unique properties. HTS materials are now preparing to come to the market as practical devices ranging from power storing device to space communication. Different applications of superconductors require different format of the superconducting materials such as bulk, tape, wire, thick film, thin film etc. The communication devices need thin films for different applications such as antenna, filter, beam-forming network (BFN), low noise amplifier (LNA), detector, mixer, transmission lines and so on. High quality and large area thin films are essential for these devices. We have successfully fabricated high quality and moderately large area thin films for the device applications. RF (radio frequency) magnetron sputtering of a stoichiometric $YBa_2Cu_3O_{7-\delta}$ (YBCO) target has been used to deposit the thin films on single crystal magnesium oxide (MgO) substrate with 20 mm x 20 mm size. Experimental results on the successful deposition conditions, characterization techniques and film properties (crystal quality, composition, critical temperature T_c etc.) have been reported in this article.

Keywords: Superconductor, Thin film, Sputtering, YBCO

INTRODUCTION

The high-temperature superconductor is an attractive candidate for different device applications, which is expected to replace the conventional conductors increasing the performance of the devices dramatically. Some superconducting devices are now already in the market for different applications such as SQUID (Superconducting Quantum Interference Device), MRI (Magnetic Resonance Imaging), signal processors etc [Shen, 1994]. The scientists and engineers are now trying to use it in power generating magnet, power-storing device, computer memory device, computer microprocessor, different microwave communication devices, ultra-fast switching device, and in space communication devices. Devices made of HTS materials have many distinctive advantages including low loss (high Q value), low noise, low power consumption, and circuit miniaturization. Among all the new exciting technological breakthroughs based on the superconductor, microwave and millimeter wave active and passive devices are significantly got the most advantages of the extraordinary properties of this new material [Ali *et al.*, 2000 and Ali *et al.*, 1999]

There are different families of HTS materials such as $YBa_2Cu_3O_{7-\delta}$, $Tl_2Ba_2CaCu_2O_8$, $Tl_{.5}Pb_{.5}Ca_2Sr_2Cu_3O_9$, $HgBa_2Ca_2Cu_3O_8$ etc. with transition temperatures ranging from 90K to 150K [Shen, 1994, Chu *et al.* 1993]. Among all these families, YBCO is a stable and highly analyzed family, both theoretically and experimentally and therefore, has been chosen as the main candidate for the device applications. The properties of HTS thin films and their suitability for microwave devices are critically dependent on processing [Newman and Lyons, 1993]. Because of the processing difficulties, some phases with higher T_c (Tl and Hg families) have not been found widespread use for microwave applications. Therefore, almost all the microwave devices have been fabricated using YBCO system. There are some reports on the fabrication of YBCO thin films; however, the successful reports on the large area and high quality film are yet very less. This work is aimed at fabricating the high quality and large area YBCO thin film for high performance microwave devices.

EXPERIMENTAL PROCEDURES

In the present article we present the YBCO thin films deposited by RF magnetron sputtering on single crystal MgO substrate with 20 mm x 20 mm x 0.5 mm size for the fabrication of microwave devices.

Description of the Experimental System

Fig. 1 shows the RF magnetron sputtering system used in the deposition of YBCO thin film on MgO substrate. It is a reactive type deposition system to deposit YBCO thin film from stoichiometrically (1:2:3) produced sintered target of 50 mm diameter and 5 mm thickness with a grounded shield to eliminate the negative ion bombardment which affects the deposition rate as well as film quality. The figure shows the sputtering chamber with two targets on the base inside the chamber. It also shows a RF generator coupled with the matching network to feed the radio frequency (RF- 15.56 MHz) power to the target. The sputtering of the film material requires very low background pressure. Therefore, the pumping system is comprised of rotary and turbo molecular pump to acquire a vacuum level of the order of 10^{-6} Torr. The figure also shows the sputtering (Ar) and reactive (O_2) gas cylinders and a heater attached to the substrate holder. The magnetrons were set below the target as shown in the figure. During the deposition time, water circulation was maintained to the target to keep it cool. Because the target becomes hot due to the bombardment of the positive ions on it.

Optimization Procedure of the System Parameters

YBCO film properties depend on different sputtering parameters. Optimization of these parameters is of vital importance for the best deposition condition to get the best quality YBCO thin film. The parameters are target-substrate distance (d_{ts}), substrate temperature (T_s), system pressure, partial pressure of the gases (Ar and O_2), and sputtering power. The films were fabricated changing these parameters to get the best deposition condition. The substrate temperature was varied from 680 to 720°C. Initially, the d_{ts}, RF power, and total pressure were set to 5 cm, 50 Watt, and 200 mTorr, respectively. The partial pressures of Ar and O_2 were set to 4 ccm and 7.5 ccm, respectively. Once T_s was optimized, then we fixed this optimized T_s and changed the d_{ts} keeping other values constant to get the best value of d_{ts}. In the same manner we had optimized the total pressure, partial pressure and sputtering power to get the final deposition condition.

X-ray Diffraction

The epitaxial YBCO thin films produce higher T_c and lower surface resistance, which is the determinant factor of the improved performance of the YBCO superconducting device [Shen, 1994]. Therefore, films were tried to fabricate with c-axis orientation. The crystallinity of the films was confirmed by the x-ray diffraction (XRD) method with Cu-K_α radiation. The films were analyzed from the XRD data regarding orientation, intensity, lattice constant of the c-axis, and full width of half maximum (FWHM) calculated from the x-ray rocking curve (ω scan).

Film Stoichiometry

The YBCO thin films were fabricated from a composite target. Therefore, the film stoichiometry may be other than 1:2:3 which is the standard composition giving the highest transition temperature [Lee, 1997]. Therefore, it is extremely important to maintain the standard (1:2:3) film stoichiometry. The "Energy Dispersive Analysis by X-ray" (EDAX) was used to check for the stoichiometry of the fabricated films.

Film Thickness

The film thickness is important to fabricate the microwave devices because of its influence on the film properties and consequently, on the device properties [Stork *et al.*, 1997]. The film thickness measurement also gives the deposition rate of the system that defines the efficiency of the system. A stylus-type profilometer (DekTak) was used to measure the thickness of the films.

Critical Temperature (T_c) Measurement

The most important and essential parameter for characterizing the YBCO thin films is to measure the films' critical temperature; T_c. Direct measurement of resistivity is the most often reported method of

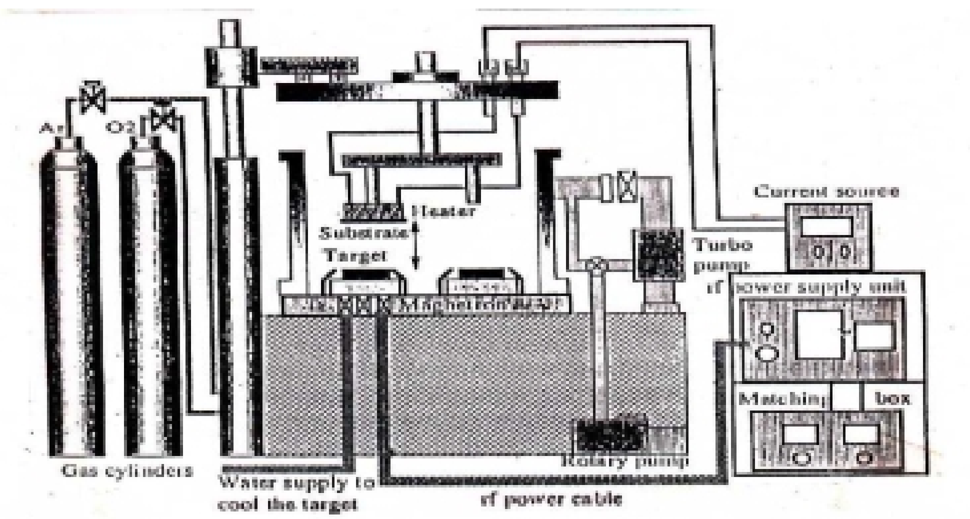

Fig. 1 RF magnetron sputtering system to deposit YBCO thin film

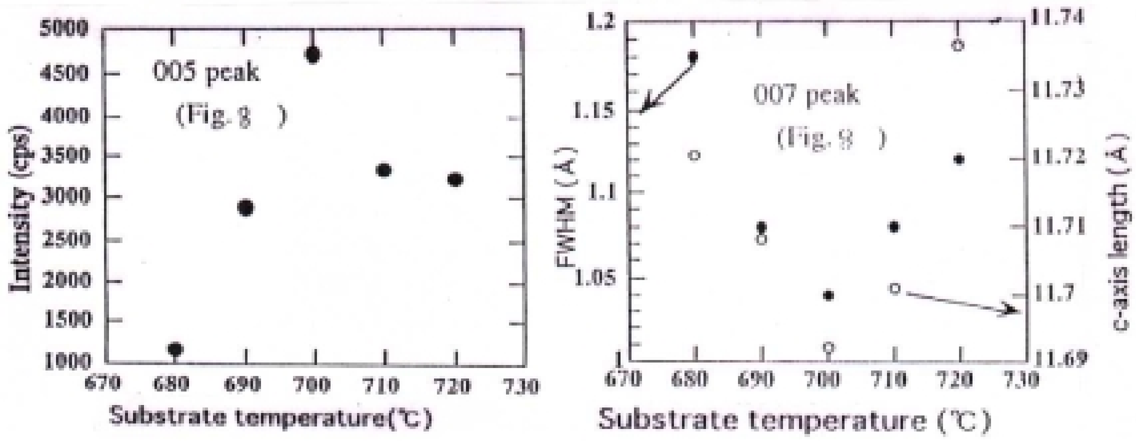

Fig. .2 Film X-ray intensity, c-axis length and FWHM as a function of substrate temperature

determining T_c. The resistivity is measured as a function of temperature and the film T_c is defined as the temperature where the resistivity falls below certain value. We measured films' T_c using standard four-point probe method of measuring the resistivity. Indium contact was coated on the film as the four striplines. The film was then set on the cryohead of the cryocooler. The four striplines were then connected to the voltage and current leads. Resistances were then measured as a function of temperature by computer-controlled automatic measurement system.

RESULTS AND DISCUSSIONS

Crystalline and Superconducting Properties of the Preliminary Films

The sputtering system was optimized to deposit high quality YBCO thin films. Preliminarily, we optimized the system parameters for the best deposition condition. Accordingly, we first optimized the deposition temperature that was varied from 680 °C to 720 °C. Fig. 2 (a) shows the x-ray intensity counts for the 005 peak (Fig. 6) in the films which is found to be highest around 700 °C. The x-ray intensity is a measure of good crystallinity and possible amorphousity in the films. Fig. 2 (b) shows the c-axis length and full width of half maximum (FWHM). These are also found to converge towards 700 °C. 005 peak of the XRD-pattern (Fig. 6) of the films was used as the reference peak for the calculation of the FWHM. 007 peak was used for the intensity count and for the calculation of the c-axis length of the YBCO unit cell. Proper adjustment of c-axis length to the standard value is important for higher film critical temperature T_c. The FWHMalso reveals the crystallinity in the films, i.e., the stacking of the film materials on the substrate and also crystalline distortion in the interface of the films [Roy *et al.* 1994 and Mukaida, *et al.* 1990). Films with good crystalline quality produce very narrow FWHM [Mukaida, *et al.* 1990]. The plot shows that the c-axis length is longer than the standard value that is about 11.69 Å for the YBCO [Izumi *et al.*, 1987]. This indicates the oxygen deficiency in the structure. In the XRD patterns at temperatures other than 700 °C, the film showed mixed orientation. There were two phases, (100) and (110) present in the films. The measurement of T_c of these films are shown in Fig. 3 that shows that the T_c value is higher for the film fabricated at 700 °C. Therefore, we fixed the substrate temperature at 700 °C and then changed the target-substrate distance (d_{ts}).

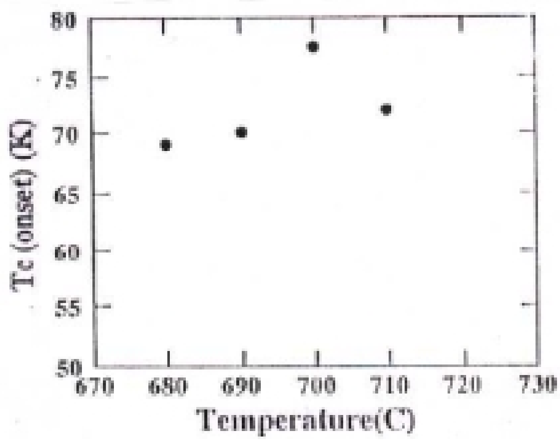

Fig. 3 Critical temperature as a function of substrate temperature

Using the same process above, we optimized the d_{ts} value and found that a target-substrate distance of 5 cm produces good quality film. However, the T_c value was still lower than the standard YBCO system (~90 K) with orthorhombic phase that produces relatively higher value of T_c than other phases as reported by the other researchers [Chew *et al., 1987* and Nishida *et al.*, 1994]. This indicates the necessity of further investigations.

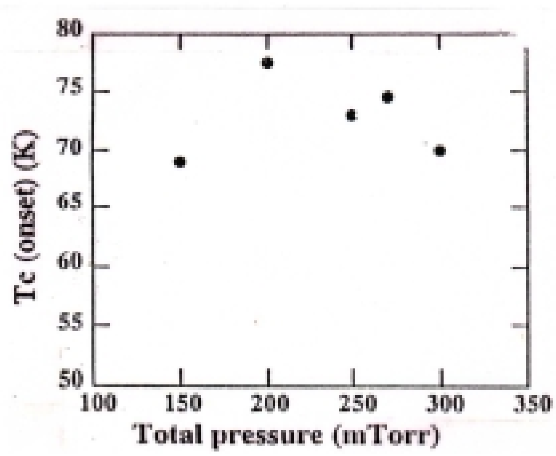

Fig. 4 Critical temperature vs. total pressure

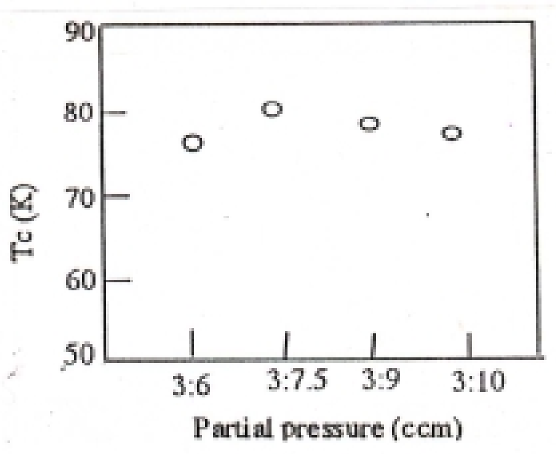

Fig. 5 Critical temperature vs. partial pressure

Up to this point, we got two parameters optimized, substrate temperature and target-substrate distance. For the further improvement of the film T_c, we tried with other parameters. Therefore, we changed the total system pressure. The total pressure was changed from 150 mTorr to 300 mTorr. Fig. 4 shows the T_c measurement results of the films fabricated for different total system pressures. The plot shows that a total system pressure of 200 mTorr produces the films with higher critical temperature. We also changed the partial pressure of the reactive gases to improve the film T_c. We changed the partial pressures of O_2 and Ar. It was thought that the oxygen deficiency of in the film may affect the film structure [Nishida *et al.*, 1994], causing longer c-axis length and thereby, lowering the T_c. Therefore, we increased the oxygen partial pressure with respect to argon. The FWHM of these films decreased significantly and c-axis length was also found to be nearly the standard value of the YBCO system and the film T_c was also increased. Partial pressures of Ar and O_2 of about 3 ccm and 7.5 ccm, respectively, were found to give the best critical temperature that is shown in Fig. 5. In an attempt to increase the film T_c further, we changed the input power to see its effect on the film quality. We checked three values 40W, 50W and 60W. Among all these values, 50W have been found to be the best value. The thickness measurement showed that a 4-hour deposition gave a film of 4000 Å thick, showing good deposition rate of the system.

Crystalline and Superconducting Properties of the Final Films

The optimized deposition condition has been summarized in Table 1. Using this optimized deposition condition; we finally deposited the YBCO thin films. The XRD patterns of the film deposited using this condition is shown in Fig. 6. The pattern shows that the film has been grown only with c-axis perpendicular to the substrate. The FWHM (from the rocking curve by ω-scan) of this film was found to be 0.68 degrees. The measurement of the composition of the film materials shows that Ba and Cu phase are a little less than the

Table-1 Optimized deposition parameters

Parameters	Values
Power (W)	50
Substrate temperature (C)	700
Target-substrate distance (cm)	5
Total pressure (mTorr)	200
Ar : O2 (ccm)	3:7.5

standard composition. Fig.7 shows the composition of this film compared with that of standard YBCO film [Nakamura *et al.*, 1996]. The critical temperature measurement of this film gave a T_c (onset) value as high as 84.5 K and zero critical temperature $T_c(0)$, of about 80 K with a transition width of 4.5 K as shown in Fig.8.

CONCLUSIONS

Fabrication of YBCO thin films by RF sputtering for the device application is reported. The film has been fabricated on single crystal MgO substrate of 20 mm x 20 mm size with 0.5 mm thickness. The fabricated films showed good crystalline quality, good composition and high critical temperature. Therefore, these films may be used to fabricate the devices for practical applications.

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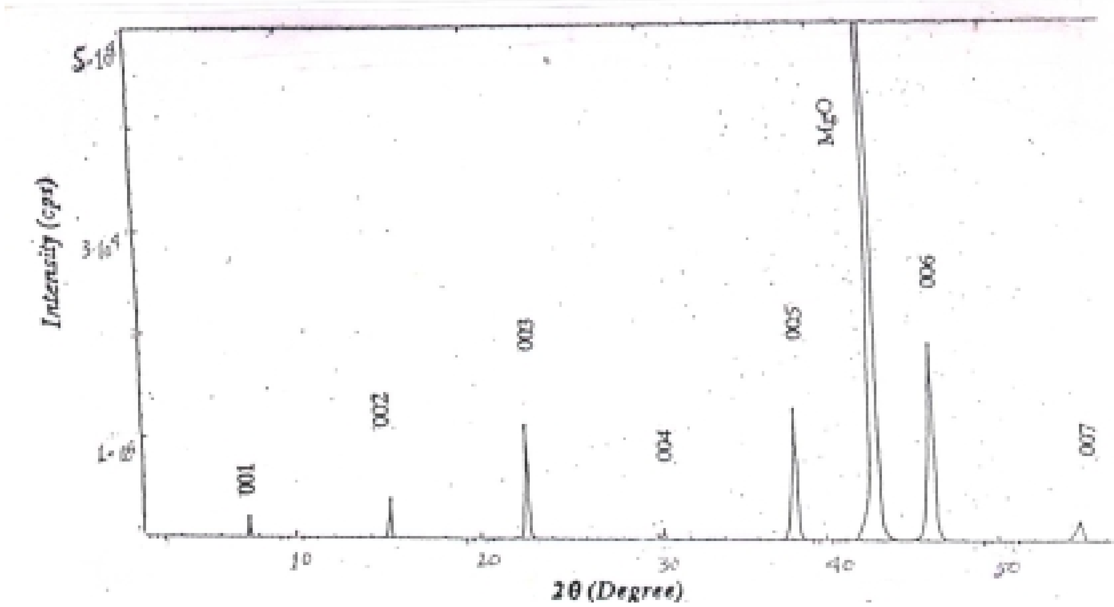

Fig. 6 X-ray diffraction pattern of the film fabricated with optimized conditions, The 005 peak was used as the reference peak for calculating the FWHM while 007 peak was used for intensity count and to calculate the c-axis length of the YBCO unit cell.

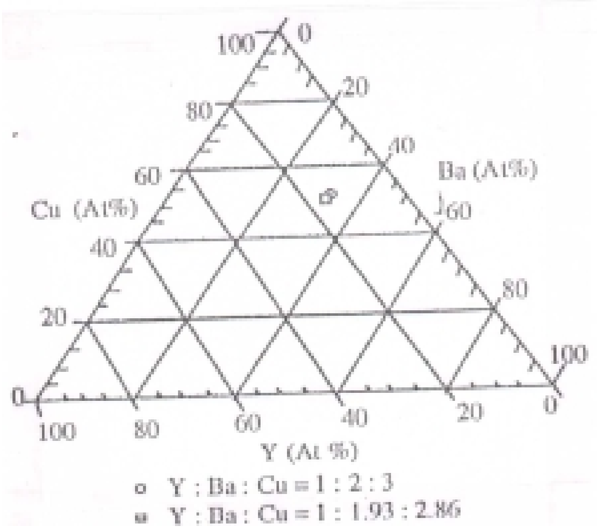

Fig. 7 Composition of the YBCO films deposited with optimized conditions

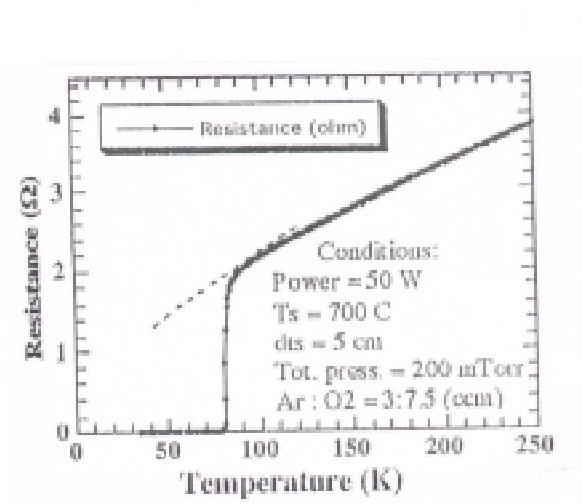

Fig. 8 Resistance vs. temperature graph of the final film deposited with optimized conditions

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