Growth of YBCO Superconducting thin Films on CaF_2 Buffered Silicon

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CaF_2 films were grown on $< 100 >$ silicon using the neutral cluster beam deposition technique. These films were highly crystalline and c-axis oriented. Superconducting YBCO thin films were grown on the CaF_2 buffered silicon using the laser ablation technique. These films showed Tc(onset) at 90K and Tc(zero) at 86K. X-ray diffraction analysis showed that the YBCO films were also oriented along the c-axis.

I Introduction

Since the discovery of superconductivity in YBCO much effort has been put to deposit it as thin films on silicon substrates, owing to its potential applications in microelectronics. However, during the annealing process at high temperatures silicon from the substrate is found to diffuse into the YBCO films, severely affecting the superconductivity, transition temperature (T_c) and current density (J_c) [1-3]. To prevent this deleterious diffusion of Si into the superconducting film a suitable buffer layer is found necessary to interpose between Si and YBCO. Calcium fluoride has shown good thermal expansion corresponding to silicon and YBCO films. The lattice mismatch between CaF_2 and Si is 0.6% at room temperature, while for [011]/[001] relationship between YBCO and CaF_2, a mismatch of 0.8% along YBCO a-axis and 1.1% along the b-axis exists [4]. Hence in the present study CaF_2 buffered Si has been used for fabricating YBCO thin films. The aim of the present study is to investigate the minimum thickness of CaF_2 required to stop the migration of Si into the superconducting film. The criterion used for this purpose is the T_c value and the sharpness of the transtion which is displayed by small transition width ΔT_c. The choice of YBCO was however, made on the basis that, it is one of the most stable high T_c superconductor.

II Experimental

Calcium fluoride powder (99.99% purity, Aldrich Chemicals, USA) was used to develop the buffer layer on Si using the neutral cluster beam deposition technique. The powder was charged in a specially designed graphite crucible resistively heated to the required temperature The details of the crucible design and other aspects of neutral cluster beam deposition technique are described elsewhere[5]. The silicon $< 100 >$ substrates were cleaned using the standard cleaning procedure. Prior to the deposition, the silicon wafers were dipped in dilute HNO3 for a few seconds and then thoroughly rinsed in distilled water. These wafers were dried and loaded in the work chamber for deposition. The CaF_2 deposition was carried in the work chamber evacuated to 10^{-6} mbar pressure using an Edwards Co. (U.K.) turbo-molecular pump backed by a rotary pump. During the deposition the thickness of the CaF_2 films was monitored using a Maxtek film deposition controller model FDC 440 and was cross- checked using Dektak thickness profilometer.

A KrF (248 nm) eximer pulsed laser (Lambda Physik model 301i) having a pulse width of 25ns and 1 to 10 Hz repetition rate with maximum energy of 1200mJ was used for the ablation of YBCO on buffered silicon from its sintered pellet. Since the intensity profile of 30mm $\times$ 20mm laser beam has a gaussion distribution along the short axis, only 5 mm of central region of the beam was allowed to pass through an aperture with 5mm height and 10mm width. The beam was focussed onto the target to get 3mm $\times$ 0.8mm spot size with the help of a quartz lens of 200mm focal length. Prior to the YBCO thin film growth the deposition chamber was evacuated to the base pressure of 5×10^{-6} mbar using a Turbo molecular pump (Varian 2000) backed by a mechanical rotary pump. AR grade oxygen was introduced in the chamber, during the deposition, the flow of which was controlled using a rotameter. A gate valve was used to throttle the turbo pump to achieve the required oxygen partial pressure of 220mTorr. The substrate temperature was maintained at 760°C The thickness of the YBCO films was measured using the Dektak thickness profilometer. The superconducting films were characterized using computerized resistivity measurement set-up (comprising of Keithley current source model 220, Keithley multimeter model 199, Lakeshore temperature controller model DRC 91C), Joel X-ray diffractometer model 8030 and Joel scanning electron microscope model 840. The angular resolution of the X-ray diffractometer is close to 0.05°.

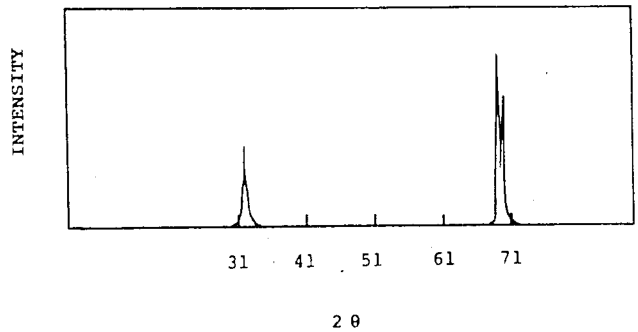

Figure 1. X-ray Diffraction pattern of 165 nm thick CaF_2 buffer layer on < 100 > Silicon.

III Results and discussion

Fig. 1 shows the X-ray diffraction pattern of 165nm thick CaF_2 buffer layer on < 100 > silicon annealed for 1 hour at optimum temperature of 650°C [5]. It is seen that only < 001 > peaks appear which indicates that the buffer layers has C-axis orientation. In addition, a very small magnitude of FWHM, 0.082, corresponding to < 004 > peak suggests the film to be highly crystalline in nature. Fig. 2 shows the x-ray diffraction pattern of the YBCO films deposited on buffered silicon. These YBCO films had a thickness of the order of 450nm. A large number of < 001 > orientations along with a few other random orientations are observed. For example the intensity peak at 21 corresponds to (003) orientation, while the peaks at 30 and 39 are of (004) and (005) orientation respectively. A few unknown peaks which are marked with asterisk in the figure are also seen to be present. The characteristic peak of CaF_2 appears at 70° which corresponds to (004) orientation. Fig. 3 shows the resistance Versus temperature plots of YBCO films grown on CaF_2 layers of different thicknesses. All the YBCO films, deposited on CaF_2 of different thicknesses, were 450nm thick. Curves marked a, b and c correspond to the CaF_2 layers with thickness of 120nm, 150nm, and 165nm respectively. All the films were deposited under identical deposition conditions and were given same annealing treatments. It is seen from the figure that the curve 'a' does not show the presence of superconductivity in YBCO films grown on 120nm CaF_2 buffer. The nature of the curve 'b' shows that the film initially behaves like a semiconductor and then transforms into superconductivity with T_c (onset) at 86K and T_c(zero) at 70K. The nature of the R-T curve in Fig. 2c shows that the YBCO deposited on 165nm thick CaF_2 retains its superconductivity with T_c(onset) 90K and T_c(zero)86K. These values are in good agreement with the reported values. [6]. The R(300, to R(,00) is about 2.8 which is indicative of good metallicity. Also the absolute value of the resistivity of our YBCO film is of the order of 2-3 mΩ-cm at 300K and is in the acceptable range [7]. Thus it can be seen that the minimum thickness of CaF_2 buffer to realize superconducting YBCO on silicon substrate is about 165 nm.

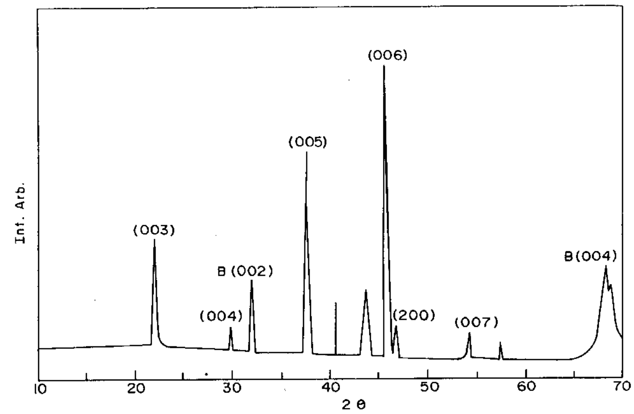

Figure 2. XRD pattern of the YBCO film deposited on buffered silicon.

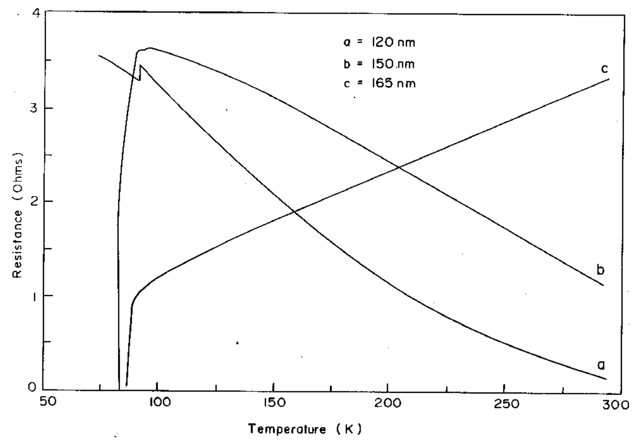

Figure 3. Resistance Vs Temperature plots of YBCO films grown on CaF_2 layers of different thickness.

It is known that [8] CaF_2 tends to loose fluorine during the high temperature annealing to form CaSiO4. This oxidation of silicon and formation of calcium silicate begins at the Si/CaF_2 interface and proceed towards CaF_2 surface where YBCO is deposited. Hence depending on the annealing temperature a part of CaF_2 layer near to silicon will be converted to $CaSiO_4$ owing to the migration of Si. We have seen that YBCO grown on 120nm CaF_2 layer does not superconduct while for

150nm CaF_2 it displays superconductivity with broad transition width. This may be attributed to migration of Si impurity into the YBCO film resulting into incomplete buffer effect. Indeed as revealed by scanning electron micrograph shown in Fig.4 a sizeable number of microcracks and voids, together with outgrowths at the junctions of the coalescent grains are apparent. Thus the transition temperature of the YBCO film reduced with the increase in transition width.

The R-T curve shown in Fig. 2(c) reveals that the film is metallic in nature and transforms into superconductivity with T_c(onset) at 90K and T_c(zero) at 86K. It was found that YBCO films grown on CaF_2 layer having thickness more than 165nm showed more or less identical R-T curves and T_c value as that obtained for films grown on 165 nm CaF_2 layer.

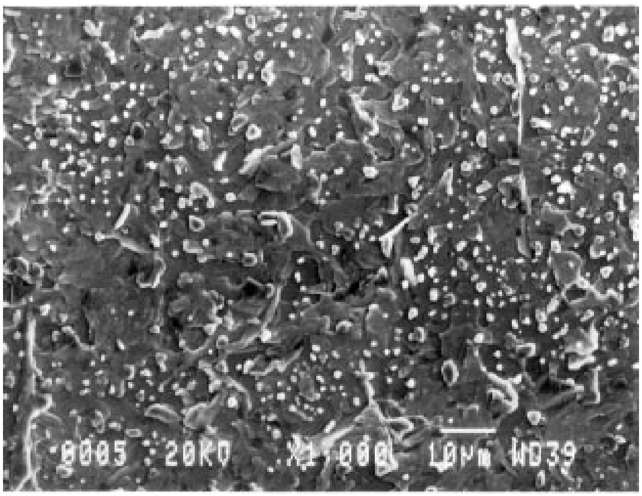

Figure 4. SEM photograph of YBCO film grown on 150 nm CaF_2 Buffer.

IV Conclusion

It is possible to grow highly crystalline c-axis oriented buffers on silicon using Neutral Cluster beam (NCB) deposition technique. The YBCO films deposited on buffered silicon showed T_c(Zero) at 86K, which is in good agreement with those reported for YBCO on CaF_2. It is also seen that the minimum thickness of CaF_2 buffer layer to effectively stop the migration of Si into the films is about 165nm.

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