DEPOSITION AND STUDY OF SUPERCONDUCTING BEHAVIOUR OF YBCO THIN FILM BY SPUTTERING

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ABSTRACT:*Superconducting thin film of Yttrium Barium Copper Oxide (*$YBa_3Cu_3O_7$*-YBCO) was fabricated on glass as well as on un-doped Silicon Substrate by Sputtering. Superconducting behavior of YBCO thin film was studied with the help of Liquid Nitrogen Cryo State and Keithley Source Meter. It was found that when the temperature of the chamber lowers from 153 K, there was a sudden decrease in resistance, this temperature could be the critical temperature of the YBCO thin film, and when temperature reached to 93K the resistance was decreased to zero.This showed the superconducting behavior of the YBCO thin film.*

Key Words: Keithley Apparatus, Liquid Nitrogen Cryo State, Superconductor, Thin Film, YBCO.

INTRODUCTION:

The prefix ‘nano’ is very important in Nanotechnology which means one billionth ($1x10^{-9}$)[1]. The term Nanotechnology was first coined by Norio Taniguchi in 1974[2]. He suggested “atomic bit machining”**.** It can also be narrated by more efficient way as, engineering with atomic or atomically precise technology.[3].Nanotechnology interacts with the bio-nanotechnology, economy, environment, health habits, governance, and imaginative futures[4].By reducing dimensions of insulating materials, electric field increases, it means probability of field related effects also increases. Mathematically it can be explained as:

$$E = - V/d$$

Where E is electric field, V is applied voltage and d is thickness of material

The above equation shows when applied voltage is 1 V and thickness is 1 nm then the electric field will be 10^9 V/m,which indicates that surface to volume ratio is very important in nanotechnology.

Sputtering is the process in which atoms are removed from target surface due to the bombardment of highly energetic particles. The upper surface of target material is removed and new surface is deposited in the form of thin film on the substrate [5]. The phenomenon of sputtering was first discovered by Grove in 1852 in dc gas discharge.[6] Process of sputtering is usally characterized by yield of sputtering which is basically the ratio of sputtered atoms to incident ions.[7]**.**

One of the most outstanding and interesting property of solids is that its electrical resistivity disappears completely below a certain temperature. This ‘Zero Resistivity’ or infinite conductivity is called as superconductivity. Superconductivity is applied in many fields to design computer switches, superconducting magnets and many more other technical devices. Engineers are using superconductivity in the field of transportation and transmission of power. The Dutch physicist H. K. Onnes observed Superconductivity in 1911, in the course of his experiment carried out on electrical conductivities of metals. He investigated that at 4.2K when purified mercury was cooled, its resistivity disappeared abruptly[8]. Above that temperature resistivity was small while below that temperature it was essentially zero. The temperature at which that transition occurred was called as Critical Temperature**.**Onnes also studied that superconductivity is a reversible phenomenon. It means that when superconducting sample is heated it recovers its normal resistivity(Fig.1)

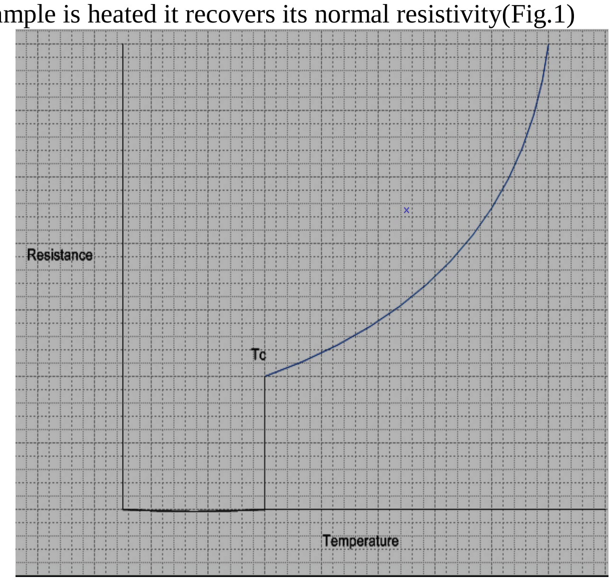

Figure 1:Resistance versus Temperature

In 1986, a new class of ceramics material was discovered that becomes superconductor at temperature as high as 125 [9]. Any superconductor with a critical temperature above 77 K, the boiling point of liquid nitrogen, is referred as a high temperature superconductor. Recently a complex crystalline structure known as Yttrium Barium Copper Oxide ($YBa_3Cu_3O_7$) have been reported to become super conductor at 163 K or −110 ^{0}C.[10].

Superconductivity Phenomenon in YBCO

The Hilbert space of the model is spanned over the Cu 3d, Cu 4s, O 2p and O 2py atomic states of the CuO plane. Superconductivity in this class of materials is confined to the CuO_2-Ba-CuO_2-Ba-CuO_2 layer assembly sandwiched between two layers with particular emphasis on the CuO_{2+x} layers which helps to retain the two dimensionality of CuO_{2+x}layer. Partial oxygen occurs in the center of CuO_{2+x} layers.

High Temperature Superconductivity in YBCO

The ionic semiconductors with very high frequency phonon are the first requirement.

To get this very high frequency phonon light element such as carbon, oxygen or even hydrogen is used.The second important point to get this superlight interside bipolaran which can propagate easily through the lattice we need triangular like or triangular lattices where the building block is just unit triangle.

The third and the last condition is doping level at optimum, i.e.the pairs should be individual pairs not overlapping pair.Kozłowski, and their co workers studied the $YBa_2Cu_3O_6$ films that were attained directly on the polished silver substrates by using the sedimentation process.[11]**.** They observed that the thickness of these films was of the order of several tens micrometers. They measured and analyzed the temperature dependences of the resistance as well as the AC susceptibility of these films and observed the variation of the critical temperatures of these films from 89 K to 91 K .It may also be noted that they did not depend on the annealing temperatures. The Bean's model was used to calculate the critical currents from AC susceptibility measurements. The YBCO thick films properties did not influence strongly by the silver substrate if they were sintered at temperatures of 92K or lower. Their superconducting parameters are considered similar to those of the bulk samples and probably better, depending on the optimal procedure (such as heat treatment, appropriate pressure sand other) [12-19]

MATERIALS AND METHODS:

YBCO was used as a material for the deposition of thin film. There are many methods which can be used to deposit thin films, at the nano level, of YBCO. These methods are characterized as physical which involves, thermal evaporation, sputtering, electron beam evaporation, molecular beam epitaxy, and Chemical that includes chemical vapor deposition, sol-gel, plasma enhanced chemical vapor deposition, solid state reaction and spray. Sputtering is more advantageous technique because of high deposition rate, purity of thin film, contamination free and high sticking coefficient with only drawback of high vacuum requirement within the chamber.

There were different options to use substrate for the fabrication of device but the most important Silicon wafer was used. There were different reasons to take Si and glass as substrate; the most important was not to react with superconducting materials.

In order to avoid contaminations and to remove impurities onto the Silicon wafer, ultra-bath cleaning was used. Silicon wafer was first placed in ultra-bath for ten minutes and acetone was used as cleaning solution. Ultra-cleaning was done for ten minutes in the presence of isopropyl alcohol (IPA) solution.Silicon wafer was placed onto the sample holder. A thin film of YBCO (superconducting material) layer was deposited on un-doped silicon by sputtering. Similarly, a thin layer of the order of nm was deposited onto the glass substrate by sputtering in order to study the behavior of the material with the change in temperature for superconducting material (YBCO) and resistivity measurement of the thin film of YBCO.In case of thin film electrical characterization following formula was used;

$$\rho(T)=\frac{V(T)}{I}\left(\frac{\pi}{\log 2}\right).$$

The resistance was measured by using a standard four – probe method with the help of Cryo-stat (VS 35B). After placing thin film from the sample onto the sample holder, it was placed in the chamber of Cryo-stat. A constant voltage of 1mV was applied across the 2 probes and the current was measured with the help of source meter unit (SMU) model 2400.(The Keithley 2400 source meter available in Centre of Excellence in Solid State Physics, University of the Punjab, Lahore).

Equipment Used For Resistivity Measurements

The following apparatuses were used for the measurements of resistivity as a function of temperature by four probe method.[20]

1. Cryo-stat.
2. Sample holder.
3. Sample holder cover.
4. Temperature recording instrument.
5. Constant current source (Digital Source-meter Unit (SMU)).

CRYO-STAT

It is an experimental instrument at which the measurement of superconductivity was carried out.

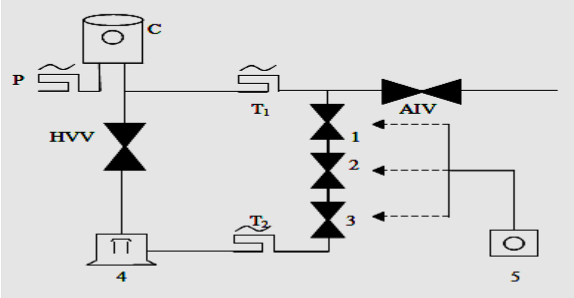

Figure 2: The schematic diagram of High Vacuum Cryostat: 1-Roughing Valve, 2-All Valves Closes, 3-Backing Valve, 4-Diffusion Pump, 5- Rotary Pump, C-Cryostat Chamber, P-Pressure Gauge, T_1, T_2-Thermocouples, HVV-High Vacuum Valve, AIV- air inlet Valve.

Sample Holder

Sample was mounted onto a holder which was attached to the chamber of the cryostat. The holder was heated with the help of a heater which was placed on the opposite side of the holder in order to change the temperature.

Sample Holder Cover

Specimen was covered with the help of an insulating material to reduce the effects of impurity at its surface.

Temperature Recording Arrangements

To measure temperature of surrounding and surface of the specimen, mineral insulated platinum thermocouple of model Pt100 was used. Maxtech model MC-2838 temperature sensor was used. For the measurement of temperature, tip of thermocouple was connected to the chamber of cryostat and then connected to sensor (MC-2838). Before mounting the sample on the sample holder, it was first calibrated. Platinum wire thermocouple was first dipped into liquid nitrogen (which has a temperature of ~77 K). The three outer terminals of the platinum wire thermocouple were connected with sensor and temperature was noted. Second reading was taken at room temperature and then at higher temperature up to 60°C.

CONSTANT CURRENT SOURCE

FARNELL stabilized power supply of model L30AT was used to provide constant current by connecting a resistance in series with output voltage of power supply. Digital Source-meter unit (SMU) of model Keithley 2400 was also used in experiment to get the value of voltage for I-V measurement of superconductivity. We used source meter by connecting it with computer through GPIB connection rather than to operate manually.

Voltage Measurement

Electrical measurements are very important characterizations to prove the authenticity of research work. Current and voltage both parameters are important and should be well accurate for proper experiment. In present case, current was applied whereas voltage was measured through Keithley Source Meter of model 2400.

Function Generator

To establish the electrical behavior of superconducting thin film of YBCO, radio frequency was applied through FARNELL Function Generator of model FG/1. The applied radio frequency worked at constant voltage of 2.5 V. Device was characterized with almost all possible value of frequencies that can be taken from function generator. The range of frequency was from 0.1 Hz to 100 kHz.

Table.1 Operating conditions in sputtering unit.

Serial No.	Parameter Name	Unit
1	Operating Pressure	4.12Pa
2	Base/Residual Pressure	4.14Pa
3	C-Load	517
4	C-Tune	456
5	Voltage	600V
6	Power	50W

Heating Source

The whole process for the measurement of superconductivity took too much time to be completed. This time period was because of liquid nitrogen. In vacuum, the sample holder remained cool for much longer time. Time period may be shortened by connecting a heater onto the holder of substrate.(DC-Power supply of model MCH 305AB).

RESULTS AND DISCUSSION

Thin film of Yttrium Barium Copper Oxide was grown on glass substrate and Silicon Substrate by sputtering(Fig.3). Process of sputtering was carried out after setting initial conditions. Vacuum in sputtering chamber was decreased because of the injection of argon gas and the sputtered atoms. Radio frequency (RF) generator was switched off after acquiring the deposition of required thickness. Many thin films were deposited onto the glass substrate on different conditions. RF Magnetron sputtering of generator model PFG 600 RF was used.

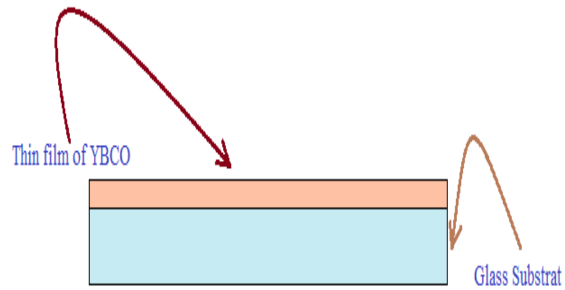

Figure 3.YBCO thin film on glass substrate.

Four Probe Method for Resistivity Measurements

This method is very important and is widely used for the measurements of resistivity[21].

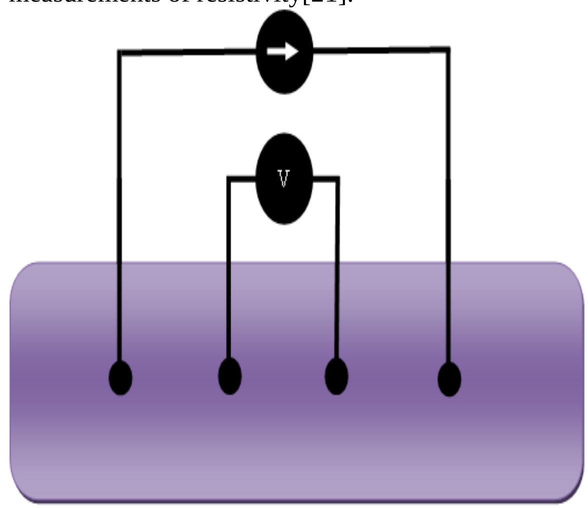

Figure4:Schematic diagram of four probe Method.

The superconducting behavior of YBCO thin film was studied with the help of Liquid Nitrogen Cryo-Stage and Keithley 2400 Source Meter. The XRD results described the supper conducting behavior of YBCO thin film which shows that the critical temperature of YBCO thin film is 153 K. At this temperature resistance of YBCO was started dropping and when it reached at 93 K the resistance of the YBCO thin film became almost zero (Fig.5).

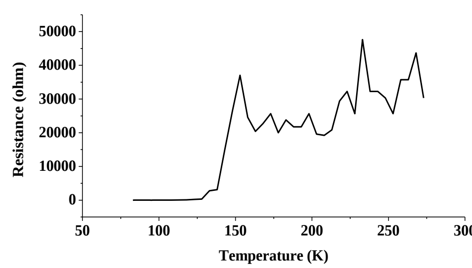

Figure 5: Showing the superconducting behavior of YBCO.

CONCLUSION

An effective nano level superconducting thin film of Yttrium Barium Copper Oxide (YBCO)was fabricated on glass as well as on un-doped Silicon Substrate by sputtering, the operating values of different parameters that were used in sputtering unit were 4.12 Pa (operating pressure), 600V(potential difference) and 50Watt(power). Superconducting behavior of YBCO thin film was studied with the help of Liquid Nitrogen Cryo State and Keithley Source Meter. It was found that when the temperature of chamber was lowered to below 153 K,there was a sudden decrease in resistance and this temperature could be the critical temperature of the YBCO thin film and when temperature reached to 93K the resistance was dropped to zero. This showed the superconducting behavior of the YBCO thin film.This indicates that the fabricated thin films amay be helpful for the use of conducting thin film in electronics and electrical circuits without dissipation of any energy at low temperature.

Our study shows that following factors are important for the high temperature Superconductivity in these oxides.

- The CuO_2-Ba-CuO_{2+x} layer assemblies with emphasis on the CuO_{2+x} layer.
- The quite two dimensional characters of these layers.
- The anti-ferromagnetic interaction in these layers.
- Defect associated with oxygen atoms and atoms in $ABa_2Cu_3O_{6+x}$

In addition the linear dependence of resistance above Tc and the occurrence of superconductivity near the insulator/metal phase boundary should also be considered in any model developments.

Y = Transition Metals
Ba = Alkaline Earth Metals
Cu = Transition Metals
O = Non Metals

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