Scientific Journal of Impact Factor (SJIF): 3.134

ISSN (O): 2348-4470
ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2, Issue 12, December -2015

Experimental Study of superconducting properties of HTS Bi-2223superconductors with and without Doping

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ABSTRACT: *In this paper work has been under taken aiming at investigating influence and Effects of chemical doping on the surface morphology and superconducting properties of Bi2223 were studied in detail. Thin films of well-known HTS ($Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) and ($Bi_{1.65-x}Pb_{0.35}$ Nb_x)$Sr_2Ca_2Cu_3O_y$(X =0.00, 0.01, 0.02) series were deposited by electron beam evaporation method. The room temperature resistances of the Bi-2223 films were measured using multimeter and it shows higher values of resistances. Surface reconstruction and remarkable decrease in the normal state resistance were seen after ex-situ annealing. The low temperature resistance measurement for finding the critical temperature (Tc) gave no results up to the LN2 temperature. Surface characterization of the films shows good surface morphology with uniform Nano pillars formation. A clear grain growth with the annealing is evident. The average particle size after annealing in the range ~ 120 -130 nm. Superconducting properties of the samples were investigated. In ($Bi_{1.65-x}Pb_{0.35}$ Nb_x)$Sr_2Ca_2Cu_3O_y$(X =0.00, 0.01, 0.02) series films DC electrical resistivity of all the samples decreased as the wt% of Nb increased. Both the onset critical temperatures Tc (onset) and zero electrical resistivity critical temperatures Tc (R = 0) of the samples were determined from the DC electrical resistivity measurements.*

I. INTRODUCTION

There are several families of cuprate superconductors and they can be categorized by the elements they contain and the number of adjacent copper-oxide layers in each superconducting block. For example, BSCCO can alternatively be referred to as Bi2201/Bi2212/Bi2223 depending on the number of layers in each superconducting block (n). Research has been concentrated in order to grow the Type II BSCCO superconductors, especially the 2212 and 2223 phases in the thin film form. It should be noted that among the HTS families, Bi-2223 phase is difficult to grow in thin film form. Further, the transport properties are greatly improved if the superconductors have the maximum T_C and are composed, as far as possible, of a single phase. Many substitutions have been tried to improve formation and stability of the 2223 phase. Among these, partial substitution of trivalent Bi with Pb has been found to be the most effective one. Substitution of Nb_2O_5 as a high valency cation dopant (i.e. Nb^{+5}, Group V element) was reported to have a similar effect as lead to enhance the formation of high-Tc phase. It was observed that Nb addition enhances the high-Tc 2223 phase formation and improves the critical parameters Tc and Jc.

II EXPERIMENTAL DETAILS

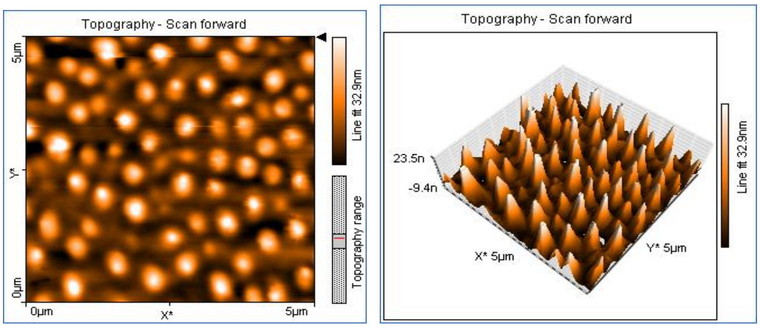
Sample of the $Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) and ($Bi_{1.65-x}Pb_{0.35}$ Nb_x)$Sr_2Ca_2Cu_3O_y$(X =0.00, 0.01, 0.02) series were prepared by solid-state reaction method. The high purity (99.9+ % pure) starting compounds of Bi_2O_3, $SrCO_3$, $CaCO_3$, PbO,Nb_2O_5 and CuO were taken in stoichiometric quantities and ground thoroughly under acetone to form a homogeneous mixture. This mixture was calcinated at 750^o C for 12 hours in powder form .The samples were then palletized and sintered at 800^{0}C for 24 hours with intermediate grindings. Electron beam evaporation method was used for the thin film deposition. The final pellets made by this method having normal state resistances in the range 100 -150 Ω.The structural characterization were done using X-Ray diffraction and electrical characterization were done by low temperature resistance measurements. The thin film of all the samples after annealing now ready for the characterization. The surface and electrical characterization was made.

III RESULTS AND DISCUSSION

(A)Surface Characterization of Thin Film by Atomic Force Microscopy

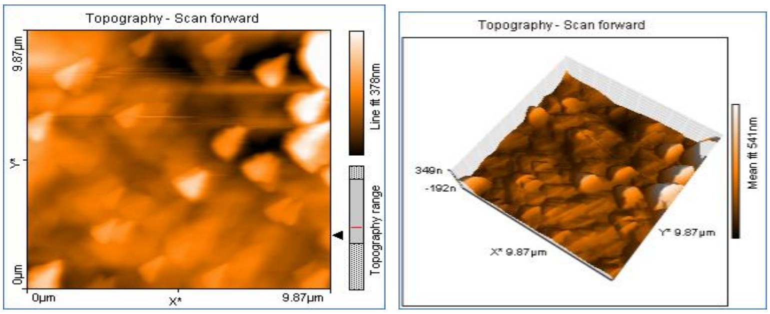
Atomic Force Microscopy (AFM) is an ideal technique to determine the particle size and surface topography profile of thin film nanostructures. The AFM images were taken for the Bi-2223 films. The following two and three dimensional images of AFM taken by Nano surf easy scan at the Physics department, Gujarat University.

AFM Images of Bi2223 Film



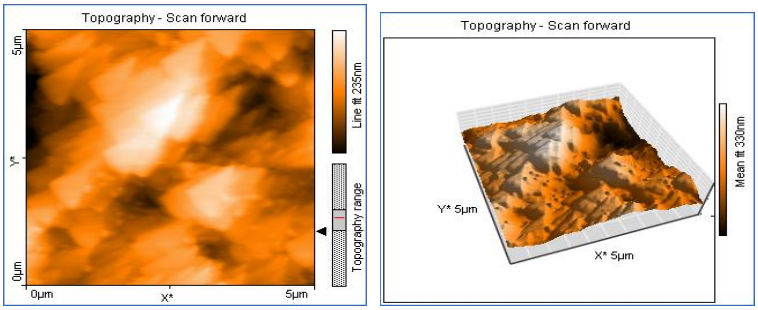
AFM shows good surface morphology with uniform Nano pillars formation. A clear grain growth with the annealing is evident. The average particle size after annealing in the range ~ 120 -130 nm.

AFM Images of (Bi$_{1.65-x}$Pb$_{0.35}$)Sr$_2$Ca$_2$Cu$_3$O$_y$ (Bi2223) Film



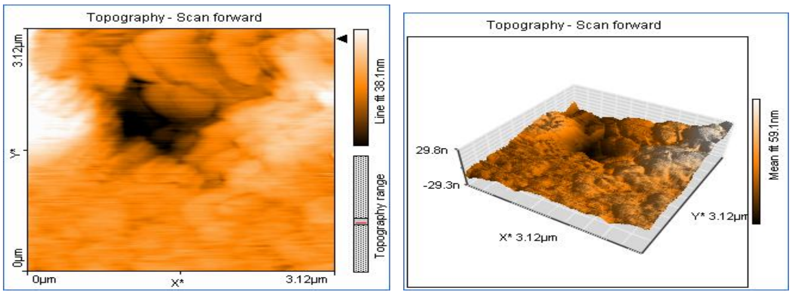
AFM shows good surface morphology with uniform layer formation. It shows good crystallography with particle size range ~ 100-110nm.The RMS roughness of the film in the range of 12-15 nm, which is fairly good.

AFM Images of (Bi$_{1.45}$Pb$_{0.45}$Nb$_{0.1}$)Sr$_2$Ca$_2$Cu$_3$O$_y$(Bi2223) film



AFM shows good surface morphology with uniform layer formation. Topography scan shows average particle size ~ 110 nm. Monodispersed grain distribution with RMS roughness below 25 nm is evident in the AMF scans even with the scan range as high as 5 µm x 5 µm.

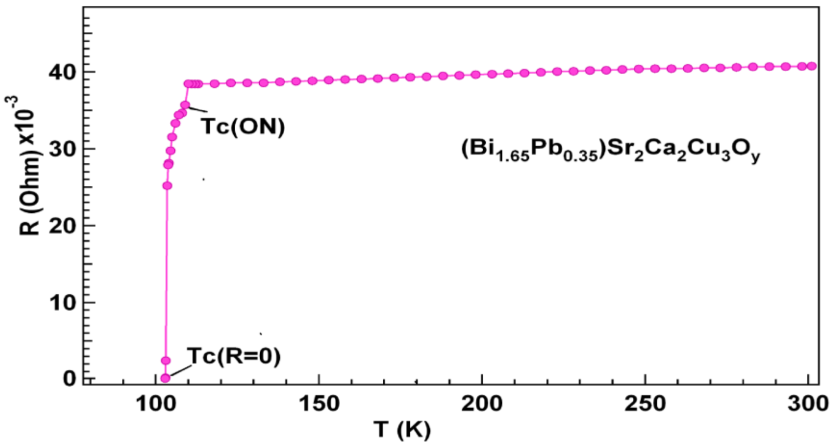
AFM Images of (Bi$_{1.45}$Pb$_{0.35}$Nb$_{0.2}$) Sr$_2$Ca$_2$Cu$_3$O$_y$ (Bi2223) film

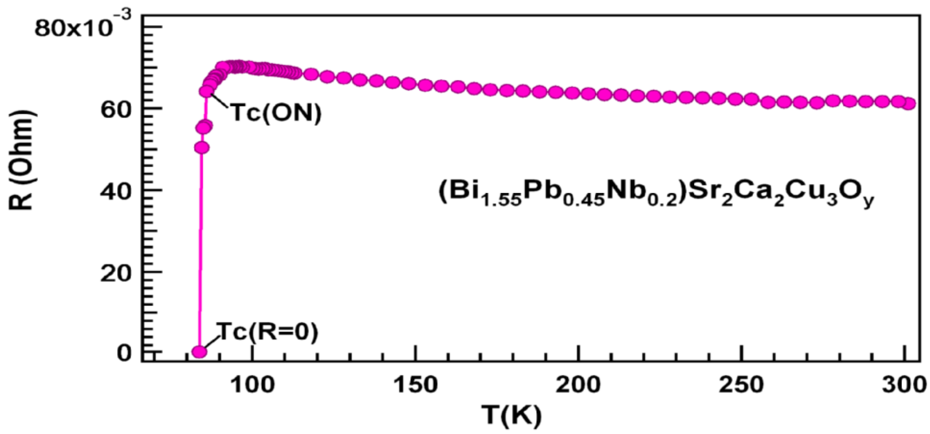


AFM shows good surface morphology with uniform layer formation.Topography scan sows the average particle size ~ 110 nm.The RMS roughness of the film in the range of 22-26 nm, which shows low value of the roughness.

(B) Electrical Characterization

In $Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) films the resistance was increasing after the annealing. The room temperature resistances of the films were measured using multimeter and The low temperature resistance measurement for finding the critical temperature (Tc) gave no results upto the LN2 temperature. The standard method of determination of the superconductor critical temperature Tc comprises a conventional four point technique of measurement of R vs. T dependency, where R is the electrical resistivity and T is the temperature of the sample. This method requires a making of electrical contacts on the sample surface by soldering, vacuum deposition, pressuring etc. For the critical temperature measurement, four probe method was used. For the current and voltage measurement Keithley instruments were used.Keithley nanovoltmeter (2182A) was used for voltage measurement and Keithley constant current source meter (6221 DC and AC) used for supplying the constant current. These instruments are very precise and sensitive. Cryostat was used for maintaining low temperature so that we can find out the Tc of samples. The figure shows the resistance measurement data of $(Bi_{1.65-x}Pb_{0.35}\ Nb_x)Sr_2Ca_2Cu_3O_y$(X =0.00, 0.01, 0.02) films at low temperature for the critical temperature measurement.





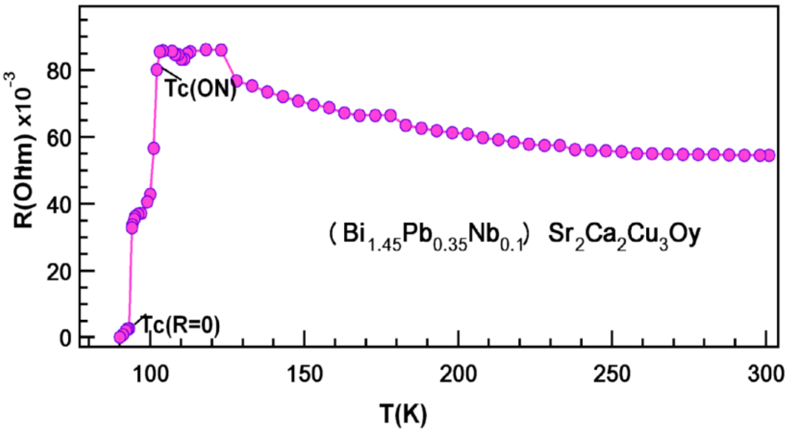


Figure: Temperature dependence of electrical resistance of $(Bi_{1.65-x}Pb_{0.35}Nb_x)Sr_2Ca_2Cu_3O_y$(X =0.00, 0.01, 0.02)

The critical temperature measurement data shows that the value of Tc-off(R=0) of $(Bi_{1.65-x}Pb_{0.35}Nb_x)$ $Sr_2Ca_2Cu_3O_y$ (X =0.00, 0.01, 0.02) are 102.8 K, 90K, and 83.8 K respectively.It shows that the critical temperature of the samples decreases by increasing the doping amount.

IV CONCLUSION

Thin films of $Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) and $(Bi_{1.65-x}Pb_{0.35}Nb_x)Sr_2Ca_2Cu_3O_y$ with Nb concentrations varying from *x* = 0.00 to 0.20 superconductor were deposited by electron beam evaporation method. The AFM of Bi-2223 film show excellent surface morphology with nanopillars formation and uniform grain distribution for the films grown by e-beam evaporation. The average crystallite size 100 nm The room temperature resistances of the films were measured using multimeter and it shows higher values of resistances. The low temperature resistance measurement for finding the critical temperature (Tc) gave no results upto the LN2 temperature. The AFM of Nb and Pb co-doped Bi-2223 films shows good surface morphology with average crystallite size 120 nm. The critical temperature measurement data shows that the value of Tc of $(Bi_{1.65-x}Pb_{0.35}Nb_x)$ $Sr_2Ca_2Cu_3O_y$ (X =0.00, 0.01, 0.02) are 102.8 K, 90K, and 83.8 K respectively. It shows that the critical temperature of the samples decreases by increasing the doping amount.

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