Conversion of YBCO Pellet into Single Layer Thin Film using Pulse Laser Deposition

Fasih Ud Din¹,², Abdul Halim Shaari¹, Chen Soo Kien¹, Zainal Abidin Talib¹, Amad Ud Din³, and Lim Kean Pah¹

¹Department of Physics, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
²Department of Physics, Government College University, Faisalabad, Sahiwal Campus, 57000 Sahiwal, Pakistan.
³Department of Electronic Engineering, Advanced Electronics System (AES) Lab, Fatima Jinnah Women University (FJWU), The Mall, Rawalpindi-Pakistan.

Email: uddin.fasih@gmail.com

Abstract. The Pulse laser deposition (PLD) is used to convert bulk YBCO Pellet to high-quality YBCO epitaxial film and superconducting transport properties of YBCO single layer has been investigated using surface techniques and four probe method. The present study includes thin film fabrication via PLD, X-ray diffraction (XRD), Scanning electron microscopy and four point probe method. This study reveals the relationship between plume dynamics and quality of the single layer film based on the important parameter, such as background pressure, substrate temperature, plume size and film thickness. The plume dynamics role in fabricating high-quality layer and improving the superconducting properties of the single layer has been analysed.

1. Introduction

The discovery of High-Temperature Superconductors (HTS) motivated the practitioner and vendors to use them for specific practical purposes such as better low cost, usage efficiency and the performance of material that was not achievable in the bulk form of material. Due to this reason, nowadays for practical applications most of the HTS materials prepared in the form of thin films. To progress the quality of HTS Layer’s, widespread efforts have been made since the discovery of high-Tc oxide superconductors. The Low cost HTS materials were prioritized over low-temperature superconductors as they showed critical temperature when cooled down in liquid nitrogen [1-4].

Thin film deposition techniques engage atoms and molecules of the respective compounds, their transportation and deposition. Thin solid films provide the foundation for numerous devices and have important applications in fields of materials sciences and emerging technologies.

In the PLD of layer’s, a transparent Ultra Violet (UV) lens focuses the laser light to solid bulk YBCO pure target sample, melt it and some part of the material is detached in the form of a plume as shown in figure 2. The plume comes in contact with the help of oxygen molecules to close fitted
substrate a few centimetres away at an angle of 45° [5]. The plume generated by the interaction of laser and pure target YBCO can be used to assist the growth of fine quality layers at relatively low processing temperatures.

For the formation of high-\(T_c\) phases, it has been found that the thermal treatment parameters like heating up rate, annealing time and cooling rate play an avital role. The researcher believed that YBCO has regained interest as it retains superconductivity under large magnetic fields as compared to the other class of superconductors [6-8].

![Figure 1. YBCO sample preparation using solid state reaction method.](image)

2. Material and Method

The YBCO bulk sample pellet is prepared by Solid-State Reaction Method as shown in figure 1. PLD a novel film fabrication method is used to make the vastly stoichiometric epitaxial films as shown in figure 2. The ultra-high vacuum is created with turbo molecular pump which assists the deposition cavity to remove oxides and impurities. The oxygen gas has the primary role in all this creation process and the oxygen dependency of YBCO layers. The PLD technique is an economical technique for making the epitaxial superconducting YBCO film layers as shown in figure 2.

During this PLD process, the MgO substrate is placed 3-5 cm away from the pure bulk target prepared with solid state reaction method. The substrate object which is attached to the heater can be heated according to its own range from 0 to 600\(^\circ\)C depending upon the system. In case of low range substrate heating system compel the vendor to prepare the samples ex-situ by use of a tubular furnace to alleviate the prepared YBCO thin films. The most important role of oxygen gas is used to progress the blasted particle of to the substrate fitted at some angle from the YBCO target. The YBCO target is hit by converged intense laser light beam. The size and shape of the glowing plume also depend upon the quality of the film. The whole system can properly manage to improve the quality of epitaxial YBCO films [9, 10].
3. Results and discussion

The pellets were prepared by simple solid-state reaction method the calcination temperature was 940°C and sintering temperature was also 940°C, it was then used as a target and was placed at 4.5 cm distance from the substrate MgO in the vacuumed chamber in presence of oxygen as background gas at pressure 200 m Torr. The deposition time was 40 minutes. The deposition was done at 790°C and a post-annealing was applied in-situ at 550°C for 30 min and flow of oxygen pressure of 300 Torr. Later the system was cooled down to room temperature. In order to obtain the best annealing sequence, the annealing temperature was varied. The heating rate was 3°C/min while the cooling rate was 2°C/min in order to improve the quality of the film [11, 12].
YBCO single crystal material was confirmed by XRD patterns with pointed peaks that portrayed different crystal lattice planes as shown in figure 4 and 5. Those are represented by (hkl) values, which phase appeared and was analyzed and considered appropriately. The XRD analysis was accomplished as per X’pert High score matching with a standard database (ICCD Data).

The Surface topology with ripples, ridges and cones is clearly shown for the bulk YBCO pellet by SEM micrographs for a smooth bulk pellet surface under different magnifications are shown in figure 5. The magnification was 20,000 times. The voids averaging ≈1µm in width with a non-homogeneous and non-uniform microstructure were observed.

The SEM micrographs of the YBCO smooth surface on MgO under different magnifications showing surface topology of the thin film sample with voids of ≈1µm in width with a non-
homogeneous, non-uniform microstructure. The magnification was 20,000 times as shown in figure 6. These microstructure properties of bulk pellets and the thin film sample stand in good agreement [13].

![Figure 6. FESEM image of the thin film with 20,000 times magnification.](image)

The resistance vs temperature curve of the pure bulk was also measured by four point probe method showing the quality of pure YBCO bulk achieving onset resistivity $T_c \sim 80^\circ$ (K) as shown in figure 7(a).

![Figure 7. (a) R - T curve showing resistance of pure YBCO pellet (b) R - T curve showing the resistance of pure YBCO thin film.](figures)

A typical R-T curve of a pure YBCO thin film deposited on (100) MgO annealed inside the PLD vacuum chamber as shown in figure 7(b). Similarly in order to improve the quality of the deposited film which may be due to the deficiency of low oxygen absorbed during the deposition that effects the superconducting behaviour to some extent. It has been subjected to post annealing under oxygen flow.
for 2h at 850° (C) inside the tubular furnace which has the 3° (C/min) increasing rate while 2° (C/min) cooling rate. It plays a critical role during the synthesis of YBCO thin films. It has been observed that the electrical properties of high-T_c are also dependent upon the charge carriers in the CuO_2 planes. The doping under oxygen ambient affects the T_c and pushes it toward the highest value. Similarly, in our present case 1.6 holes per CuO_2 planes push the improved T_c value near to 94° (K).

4. Conclusion

This study leads to the successful conversion of pure YBCO bulk into the thin film form under normal pressure. During this study, the method of preparation YBCO bulk and their conversion into a thin film and superconducting electrical properties has been discussed. The laser sintered pellets target interaction includes the role of laser wavelength and pulse rate. The effect of background pressure during the deposition is not superconducting and subjected to high-temperature post-annealing treatment experiments under O_2 for the recovery of superconducting properties during the epitaxial growth. Stream velocity of the hot plasma species scrambled up exponentially with a change in temperature. This conversion from the bulk YBCO to thin films at normal pressure is a very successful effort leading the normal pressure synthesis of pure YBCO layer films possible. The normal pressure synthesis of this compound subjected the limitations on the versatility of this compound for commercial device fabrication.

References

[1] Jannah A N, Halim S A, and Abdullah H 2009 European Journal of Scientific Research 29 438
[2] Jannah A N, Halim S A, Younus W M M, Zulkifli A, Pah L K, Masrianis A, and Walter C P 2004 Journal of Solid State Science and Technology Letter 11 215
[3] Roas B, Schultz L, and Endres G 1988 Journal of Applied Physics Letters 53 15 57
[4] Viret M, Lawler J F, and Lunney J G 1993 Journal of Superconductor Science and Technology 6 490
[5] Shahid M, Bidin N, Daud Y M, and Ashiq G B 2011 Journal of Intense Pulsed Lasers and Applications in Advanced Physics 1 35
[6] Shahid M, Bidin N, Daud Y M, and Ullah M I 2011 Journal of Intense Pulsed Lasers and Applications in Advanced Physics 1 65
[7] Din F U, Shari A H B, Kamalianfar A, Pah L K, Kien C S, Talib Z A B, Shahid M, and Ashiq G B 2012 Journal of Ovonic Research 8 9
[8] Liu L, Zhao Z, Liu H, and Li Y 2010 Journal of IEEE Transaction on Applied Superconductivity 20 1553
[9] Augieri A, Galluzzo V, Celentano G, Angrisani A A, Rufoloni A M A, Vannozzi A, Silva E, Pompeo N, Petrisor T, Cionte A, Gallandella U, and Rubanov S 2009 IEEE Transaction on Applied Superconductivity 19 3399
[10] Huhtinen H, Laiho R, Lahderanta E, Paturi P, Raittila J, and Stepano Yu 2000 Physica C 341 2377
[11] Khan N A, Din F U, and Khurram A A 2005 Physica C 415 119
[12] Al-Hada N M, Saion E, Talib Z A and Halim S A 2016 Polymers 8 113
[13] Dihom M M, Shaari A H, Baqiah H, Al-Hada N M, Talib Z A, Kien C S, and Abd-Shukor R 2017 Ceramics International 7 707