# MODELING OF SUPERCONDUCTING YBCO THIN FILMS BY SHORT PULSE LASER DEPOSITION

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The Short Pulsed Laser Deposition (SPLD) is a sole tool that is used to develop fine quality epitaxial thin films. Depiction and device application aspects of the SPLD on high temperature superconducting epitaxial films have an important role in the field of solid state physics and superconductivity. In the present study, YBCO epitaxial films and buffer layers have been probed numerically with the help of computer simulations. The simulations reveal the structural, magnetic and electrical properties of the deposited YBCO thin films. Moreover, in order to improve the superconducting properties ($T_c$) of the YBCO, we have analyzed the laser plasma dynamics and film structure.

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## 1. Introduction

Thin film deposition techniques involves atoms and molecules and their transportation and deposition. Thin solid films provide the foundation for numerous devices and have an important applications in fields of solid-state physics and emerging technologies. The venders, researchers and practitioners are working over the high temperature superconductivity from many years to fabricate fine quality of superconductors. The SPLD technique [1-4] is a versatile method that is used to deposit the ferromagnetic alloys, multilayers, and thin films; and after deposition it exhibit interesting magnetic and electrical properties [5-10]. The new generation of high temperature superconductors (HTSCs) have been introduced in 1986 when the superconductivity above 30 K of ($T_c$) has been investigated. The experiment performed by Wu et al. [11] found a transition ($T_c$) of 93 K in YBaCuO. This experiment was the first attempt to show HTSCs. YBCO tape which has a multi-layer, where each layer consists of buffer layer on metallic tape satisfies the requirements of practical HTS devices applications. However, these experiments are performed at liquid nitrogen temperature. In order to have a cost effective way to fabricate the coated conductor, the rolling-assisted biaxially textured substrate has been made. In Rolling Assisted Biaxially Textured Substrate (RABiTS), which consists of layers of metal oxide buffers deposited epitaxially with either a cube-on-cube or rotated cube-on-cube orientation on textured Ni or Ni-alloy different substrates [12-15]. However, the epitaxial growth of ceramics in the form of thin film seems to be quite challenging for researchers.

Generally SPLD is considered a very universal method that is used for fabricating thin films of complex, multicomponental materials, especially oxides of different stoichiometry [16]. In

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different HTS superconducting thin film deposition techniques, the SPLD presents several advantages. It can be operated at high gas pressure giving advantages such as a good control of the stoichiometry of the deposited films and also allows comfortable in situ preparation of heteroepitaxial multilayers [17]. As compared to bulk materials HTS thin films exhibits superior properties due to which they have an important role to meet the requirements of fascinating electronic applications. This motivates the researchers to focus on the thin film technology associated with deposition.

In the present article, we have discussed the YBCO epitaxial films and buffer layers which have been probed numerically through computer simulations which represent the structural, electrical and magnetic properties of the deposited YBCO thin films. The research covers theoretical features of pulsed laser deposition and improves the superconducting properties ($T_c$) of the YBCO by analyzing and characterizing the laser plasma dynamics. In order to fulfill the physical conditions of the PLD system containing ND:Yag-laser pulses striking with pellets of pure YBCO targets, plasma formation, transportation of particles to target substrate, deposition conditions such as base temperature and ambient are also discussed.

## 2. Material and method

### 2.1 Short Pulse Laser Deposition (SPLD)

SPLD is a novel technique that is used to prepare the fine quality epitaxial thin films. It is also used to make highly stoichiometric and single crystal films. The high vacuum which is a necessary part of the inner SPLD chamber which affect the quality of films specially for Ceramics deposition to remove the Oxides effecting the quality of films. These Oxides are synthesized at high Oxygen, Nitrogen and their combination pressure for the formation of plume expansion. SPLD is used to prepare different types of thin films including metallic, ferroelectric, YBCO/Ni/YBCO and different oxide superlattices.

In SPLD of YBCO thin films, the Substrate is positioned ~ 2.5-4.5 cm from the target and heated at 700-800$^0$C depending upon the system. The chamber is normally pumped for the HTS $1\times10^{-7}$ mbar before the deposition and kept at least $1\times10^{-5}$ mbar under certain ambient during the ablation as shown in Figure 1. The pellets are prepared by the solid state reaction method. The intense pulses with wave length 1064 nm strike the bulk YBCO target material and remove some part of it within certain limits of time. Which headed toward any substrate material fixed at 45$^0$ angle to the bulk YBCO target sample. The required gas flow inside the chamber helps the movement of the atoms and molecule from the bulk to substrate. Moreover the substrate temperature help the compound to stick and improve the quality of deposited film. The deposited film again annealed in the chamber at certain ambient in between 550-400$^0$C during the cooling down the system to room temperature. It has been also found that post annealing in tubular furnace from 800-900$^0$C in air or certain gas ambient also improves the quality of thin film.

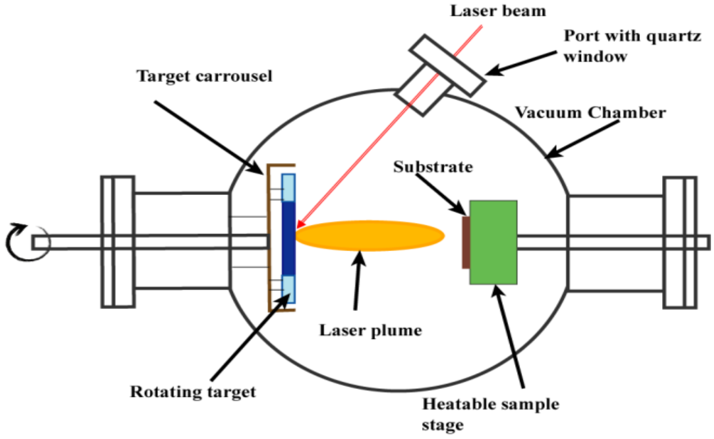


*Fig. 1. PLD setup of the YBCO films*

## 3. Results and discussion

### 3.1 Laser Plasma Dynamics

We have modeled the hot plasma growth of laser plume as supersonic expansion of the particle and solve the theory of supersonic expansion which is finally applied to laser plume dynamics. The similarity is observed due to the laser releases a huge amount of particles (atoms and ions) at the target substrate. The behavior of the escaping atoms and ions is identical to the blasted particles from the supersonic nozzle. The theory discussed in [18,19], the velocity distribution of each atomic species can be represented by the following equation

$$f(v) = Av^3 e\left[\frac{-m(v-v_0)^2}{2kT_S}\right] \quad (1)$$

Where in equation 1 the variable A is used as normalization constant, $v_0$ shows the stream velocity of the blasted particles, m represent atomic mass while $T_s$ stands for the effective temperature for spread velocity.

The mathematical equation for the laser plasma's absorption coefficient [20] can be stated as

$$\alpha_p = 3.69 \times 10^8 \left(Z^3 n_i^2 / T^{0.5} v^3\right)[1 - \exp(-hv/KT)] \quad (2)$$

Where Z represents the average charge of particles, $n_i$ is used for density of ions, T shows temperature of the hot plasma, $v$ represents frequency of the laser light, h Plank constant and K Boltzmann constant.

Following Figs. 2, 3 and 4 reflect that energy of laser is highly absorbed if $\alpha_p X \sim 1$, where X(t) represents the dimension which is at the $90^0$ with target of the expanding hot plasma at time t. The hot plasma absorbs the incident shining laser when the distances is in the range of 2.5-4.5 cm from target material and during the same time densities of the charged particles are slightly high. These results illustrate that laser plume as shown in Figure 1 that headed toward the target in vacuum undergoes free expansion. When there is increase in back ground pressure, the width of the expanded plume is governed by the gas phase collisions. Stream velocity of the hot plasma species scrambled up exponentially with change in temperature. For higher values of temperature, the velocity distribution function have found to be broadened.

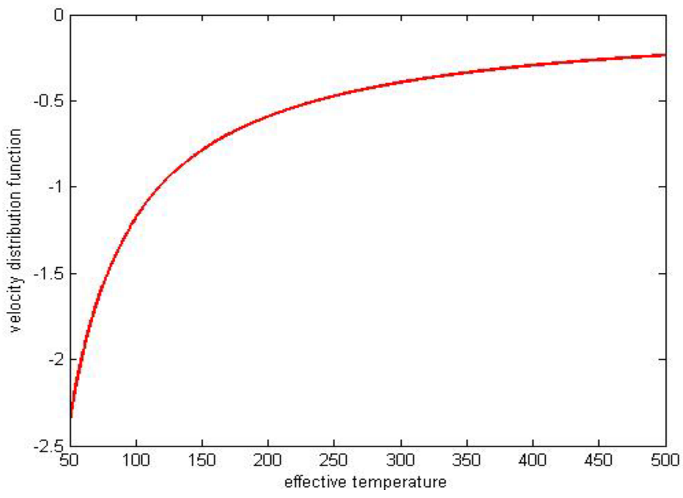


*Fig. 2. Velocity distribution as a function of effective temperature*

The energy of the plasma species was of the shape

$$E = \frac{1}{2}kT \quad (3)$$

where k is Boltzmann constant and T is effective temperature.

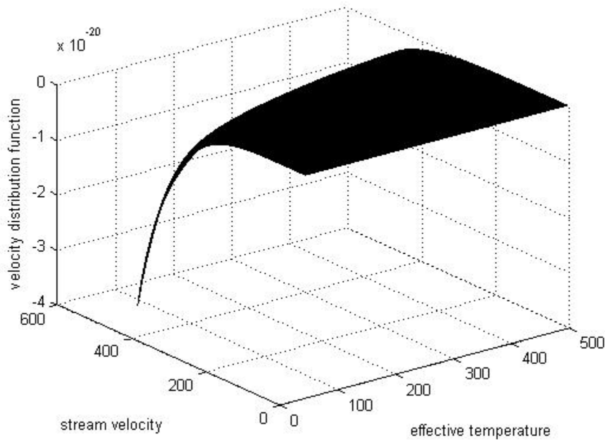


*Fig. 3. Velocity distribution function as a function of stream velocity and effective temperature*

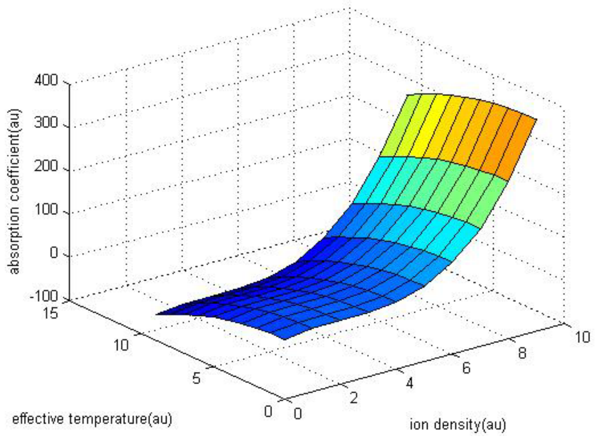


*Fig. 4. A curve of absorption coefficient as a function of ion density and effective temperature.*

### 3.2 Thickness of the Film

Thickness of the film was estimated by the equation [21,22]

$$d = \lambda \sin\theta \ln\left(1 + \frac{I}{\beta}\right) \quad (4)$$

Where $\lambda$ is the attenuation coefficient of the 2p photoelectrons, $\beta$ is the relative intensity of the known film , I is the ratio of intensities of unknown film and $\theta$ is the angle of incident laser beam and sample surface. The Figures 5 and 6, portray that the for large values of relative intensity the corresponding thickness of the film decreased. At the same environs for angle $\theta$>0$^o$ the thickness varies directly towards a high value. It is because for small angle the laser fluence transpire a large and high temperature profile of the surface. Initially, when relative intensity was 1.02, the corresponding thickness of the film was nearly 20.5 nm. As relative intensity decreased, subsequently thickness of the film increased. It is because of the binding energy of the surface atoms of the film. When relative intensity increases the binding energy decreases and vice versa.

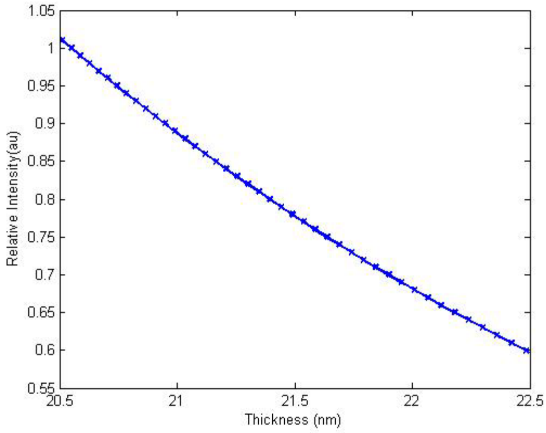


*Fig. 5. Measurement of  thickness versus relative intensity of the film.*

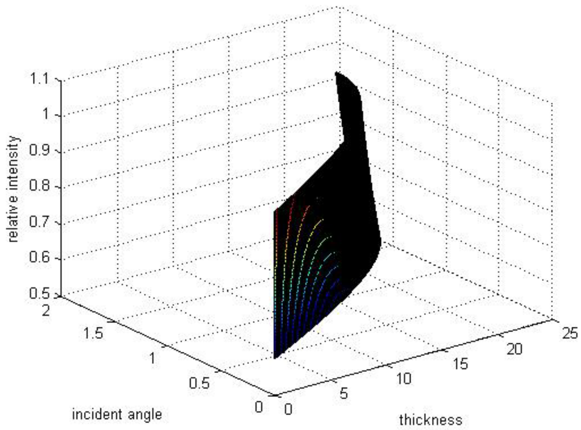


*Fig. 6. Thickness of the curve as a function of irradiation  angle and relative intensity.*

### 3.3 Superconducting Properties

The superconducting behavior of the deposited YBCO is shown in figure 7. A normal metal often has a linear response of resistance with temperature. A superconductor undergoes a deviation from this at its superconducting temperature. Results depicted that deposited thin film show the conducting behavior above the critical temperature $T_c$ of 77K which is the boiling temperature of liquid nitrogen. The transition for YBCO should occur at ≈ 92K. However, inefficient coupling between adjacent grains, the inclusion of impurity phases, or the loss of oxygen from the lattice can cause both a drop in this temperature and a broadening of the transition region.

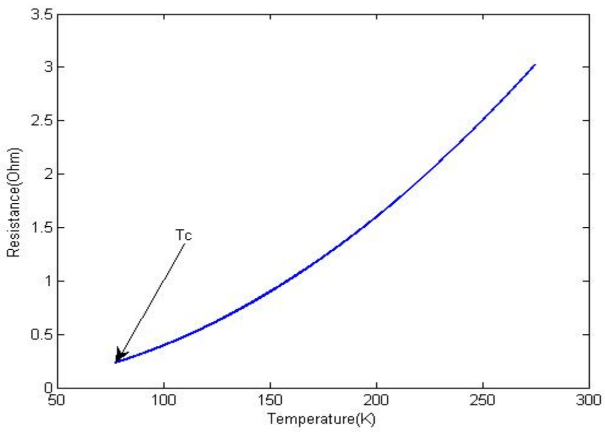


*Fig. 7. R-T measurement of the YBCO films.*

## 4. Conclusions

Numerical study successfully conducted to describe the pure YBCO thin films using PLD. In this research study, YBCO thin films and buffer layers investigated numerically with the help of simulations. Result predicts that the hot plasma absorbs the incident shining laser when the distances is in the range of 2.5-4.5 cm from target material and during the same time densities of the charged particles are slightly high. When there is increase in back ground pressure, the width of the expanded plume is governed by the gas phase collisions. Stream velocity of the hot plasma species scrambled up exponentially with change in temperature. For large values of relative intensity the corresponding thickness of the film decreased. Results depicted that deposited thin film show the conducting behavior above the critical temperature $T_c$ of 77K which is the boiling temperature of liquid nitrogen.

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