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Study of fractal dimension and power spectral density analysis of superconductor/ferromagnetic bilayer

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ABSTRACT

Atomic force microscopy investigations through power spectral density analysis and fractal dimension analysis of crack surface due to swift heavy ion (897.6 MeV Xe) irradiation on $YBa_2Cu_3O_{7-\delta}$ and $YBa_2Cu_3O_{7-\delta}$/$La_{0.67}Sr_{0.33}MnO_3$ PLD thin films have presented. Lattice disorder and suppression of crystallinity of the film has been reported through Ion irradiation. The grain size reduction coupled with development of cracks at higher fluence $\sim 3 \times 10^{12}$ ions/cm^2 has been observed. The width of the cracks has increased with increase of fluences and is more prominent in bilayer films. The grain size decreased with increasing ion fluence, which led to reduced surface roughness. Swift heavy ion irradiation causes surface diffusion, volume diffusion and strain relaxation in nanoparticles thin films which appear to be responsible for the pragmatic particle size reduction. Power spectral density analyses of AFM data followed by fractal model and K-correlation model have been explained. The crack formation in the above thin films due to irradiation is responsible for the above related phenomena along with the tensile stress which causes surface instability.

1. Introduction

A smooth surface of high temperature superconductor is very much crucial for the production of high temperature superconductor (HTSC) thin-film devices, integrated circuits containing multilayer or HTSC multichip modules. For varieties of applications like electric motor, particle detector, transition edge sensor, best of these applications crave $YBa_2Cu_3O_{7-\delta}$ (YBCO) in the form of a thin film and the surface morphology of the films dictates its suitability for a definite purpose. Hence, Scanning probe microscopy (SPM) is a promising dominant tool for analyzing the surface for both fundamental application and nanotechnology point of view.

Swift heavy ion irradiation (SHI) is believed to be a controlling technique for generating variety types of nano-structure. SHI irradiation leads to various interesting phenomena like grain alignment, ripple formation, nano-hillock formation and grain fragmentation etc. Particularly, SHI induced grain fragmentation can be restricted through a wide range of available ion-energy combinations with many diverse and convenient characteristics. Due to swift heavy ion irradiation, the extent of crack formation and property modifications of the thin film depend upon the mass, energy of the fluence and different charge state of the used ions, and more importantly the uniqueness of the target. Whenever a highly energetic ions passes through the film interface, it transfers its energy to a extremely restricted area, in a few short span of time through electronic energy loss (S_e) and nuclear energy loss (S_n). The nuclear energy loss S_n is due to the elastic collisions of the incident ions with the target atoms and it dominates in the low energy regime (energy of few keV/u) of incident ions. On the other hand, the electronic energy loss S_e is because of the inelastic collisions between the impinging ions and the atoms of the target material. The latter prevails in the high energy regime (energy > 1 MeV/u) of the incident ion, where 'u' represents atomic mass unit.

SHI has been developed, as a most advanced proficiency approach towards surface modification like defects, tracks, cracks, self assembled nanostructure etc. Significant number of defects and cracks formed by ion irradiation is very much important to cryogenic industry, particularly in case of superconductors to enhance its critical current density (J_c) without disturbing its coherence length through flux pinning. The crack formation on the high temperature YBCO was initially explained by Bourgault et al. with varying oxygen deficiencies upon GeV ion bombardment [1]. Then Hensel et al. confirms a threshold for crack formation with MeV ion irradiation on high quality $YBa_2Cu_3O_{7-\delta}$ crystals and investigations with GeV ions in (Bi-2223) by Civale et al. [2–5] were few discussed literature. The most important deciding factor for these aspects was grain boundary contribution. It is also seen that the response of nanoparticles to SHI irradiation however, can be very

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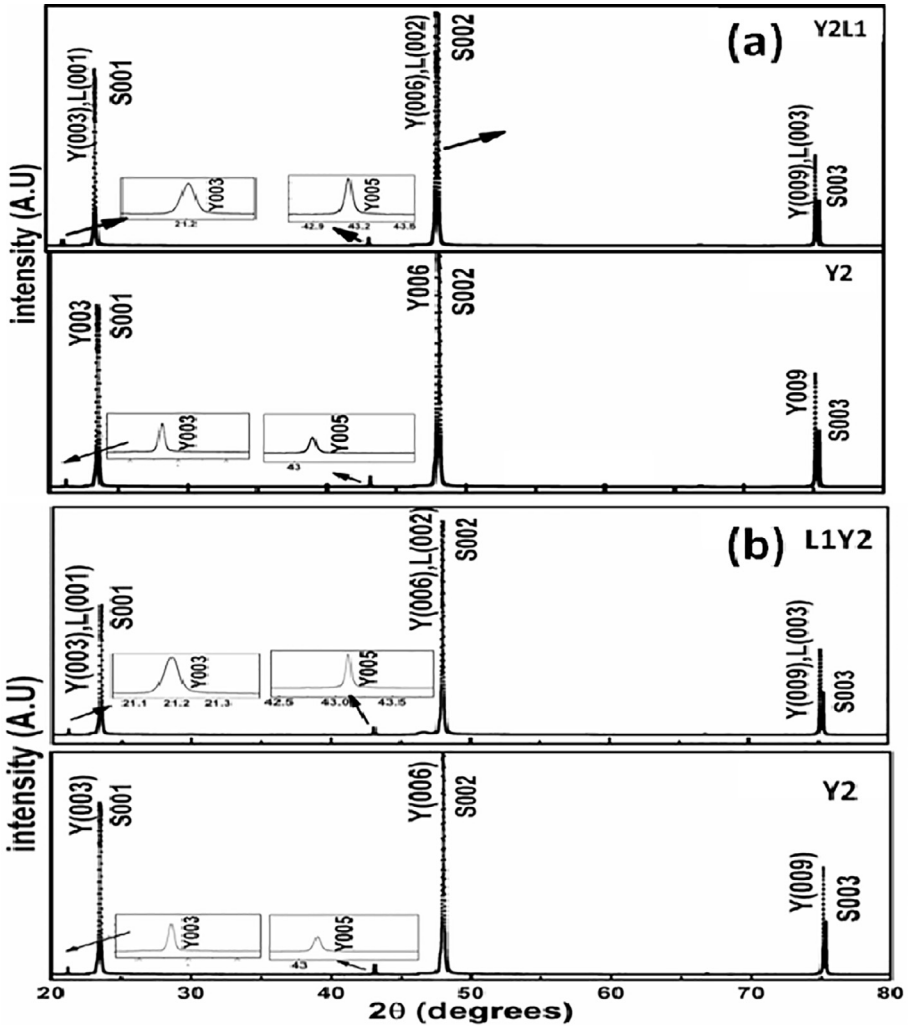

Fig. A.1. Compared XRD analysis of Y2 with Y2L1 (a) & Y2 with L1Y2 (b).

much unusual as compared the bulk. Since many literatures are presented on modified surface topology of $YBa_2Cu_3O_{7-\delta}$ thin film on the basis of ion irradiation but very few literatures are available on the effect of swift heavy ion irradiation on YBCO thin films [6–8].

In this article, we present the effect of Xe (897.6 MeV) ion irradiation on the surface topology of the $YBa_2Cu_3O_{7-\delta}$ & $YBa_2Cu_3O_{7-\delta}$/$La_{0.67}Sr_{0.33}MnO_3$ (YBCO/LSMO) bilayer thin films and gives an idea about formation of cracks beyond threshold fluence with required AFM study. The main interest of this article is to observe the applicability of various models (fractal and K- correlation model, discussed in the text) for interaction of ions with YBCO/LSMO thin films.

2. Experimental details

On c-axis oriented $LaAlO_3$ (LAO) single crystal substrate, $YBa_2Cu_3O_{7-\delta}$/$La_{0.67}Sr_{0.33}MnO_3$ bilayer was grown using Pulse laser deposition technique. $YBa_2Cu_3O_{7-\delta}$ and $La_{0.7}Sr_{0.3}MnO_3$ targets are prepared by solid state reaction route and sol-gel technique respectively. A KrF (248 nm) laser was used to ablate the respective target with chamber evacuated to a respective base pressure of 1×10^{-6} Torr. Total deposition was carried out with oxygen partial pressure of 300 m Torr [8]. Using a multi-target PLD chamber the whole deposition was performed with keeping substrate temperature at 820 °C. At the time of deposition, the repetition rate and laser energy were kept at 10 Hz and 220 mJ respectively. With the presence of oxygen environment the respective films were cool down to the room temperature. All films were grown under identical conditions. The bottom LSMO layer (thickness: 100 nm) was grown on LAO substrate. Next, on LSMO layer, YBCO layer (thickness: 200 nm) was grown. Then the bottom YBCO layer (thickness: 200 nm) grown on LAO substrate. Next, on YBCO layer, LSMO layer of (thickness: 100 nm) was grown. Also single YBCO layer of (thickness: 200 nm) was grown in same respective conditions. The prepared thin films were irradiated with GANIL accelerator at Large National Heavy Ion Accelerator, Research center in Caen, France at room temperature with 897.6 MeV Xe ions. At the time of irradiation all films were fixed to a target holder, which was placed inside the high vacuum compartment. Ion beams focused to a spot of 1.00 mm diameter, was scanned over the entire area (1.0 cm^2 = area of the thin film) of the film to achieve uniform irradiation throughout the thin film. For ion- energy combination, the projected range of ion was much large than that of the thin film's thickness, which confirms that no ion implementation took place during the irradiation. It is also important to note that $S_e > S_n$ for ion-energy beam combination used in the present investigation, such that the incident ions transferred their energy to the target films primarily through electronic energy loss. Sample surface kept nearly perpendicular to the beam line during irradiation. To avoid the sample from the heating effect during irradiation, the samples were placed over a thick copper target using silver paste. During irradiation of samples the increase in temperature of sample estimated by Fourier heat conduction equation.

$$j = \lambda \frac{dT}{dZ} \tag{A.1}$$