Thin Solid Films 591 (2015) 126–130

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

# Deposition of $Bi_{3.15}Nd_{0.85}Ti_3O_{12}$ ferroelectric thin films on 5-inch diameter Si wafers by a modified pulsed laser deposition method

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ARTICLE INFO

Article history:
Received 18 July 2014
Received in revised form 7 August 2015
Accepted 8 August 2015
Available online 12 August 2015

Keywords:
Bismuth Neodymium Titanate
Pulsed Laser Deposition
Large Area Deposition
Ferroelectric Materials
Thin Films
Film Thickness Distribution

ABSTRACT

5-inch diameter $Bi_{3.15}Nd_{0.85}Ti_3O_{12}$ (BNT) ferroelectric thin films were prepared on Si wafers by a modified pulsed laser deposition method, in which two laser scanning rates and 6-inch diameter target were used. The investigation on the distribution of the film thickness reveals that the laser scanning technique used in conjunction with the large-diameter target can improve the uniformity of film thickness. Especially the reasonable setup of the laser scanning rate ablating the fringe area of the large target has a prominent effect on weakening the edge deviation of thickness distribution. Such phenomenon was fundamentally explained by the simulation results on the ablation tracks of the laser beam on target. Through optimizing the laser scanning rates, BNT thin film with uniform thickness was obtained on 5-inch diameter Si wafer and the maximum variation in film thickness was found to be less than $\pm 2.5\%$. The results of X-ray photoelectron spectroscopy and X-ray diffraction show that the prepared 5-inch BNT thin film has great uniformity in stoichiometry and crystallinity. In addition, the measurements of electrical properties indicated that the prepared BNT thin film exhibits good ferroelectric property and *I–V* characteristic.



## 1. Introduction

Ferroelectric oxide thin films have attracted considerable attentions for their wide range of applications in integrated circuits [1]. Major examples of prototype applications for the ferroelectric thin films include ferroelectric random access memories, dynamic random access memories, frequency filters for mobile communications or sensors, field effect transistors and micro-electromechanical systems [2,3]. In order to increase the integration and uniformity of ferroelectric devices, uniform ferroelectric thin films with high-quality deposited on large-area silicon or silicon-based wafers are required urgently. With the development of film technology, some methods like sputtering, metal-organic chemical vapor deposition and solution-based thin film deposition techniques have been developed to grow large-area ferroelectric thin films [4–6]. As we know, pulsed laser deposition (PLD) is a promising method to deposit complex multi-component films with high-quality and proper stoichiometry [7,8]. However, the conventional PLD is limited to prepare small-size thin film due to the small laser-ablation plume and it's highly directional distribution [9,10], which obviously cannot meet the development of integrated ferroelectric devices although ferroelectric film deposited by PLD has much higher quality than that deposited by other methods [11,12]. To solve the up-scaling problem, a lot of attempts have been tried, such as rotation of the target [8], rotation of the substrate [13], dual-beam PLD source [14], scanning of the laser beam over the target surface [15], using more than one target [16], and matrix shape PLD [17]. With the improvement of large-area PLD technique and the emergence of corresponding commercial equipments [18,19], great progress about the large-area thin film has been achieved. For example, 3-inch high-$T_c$ superconducting $YBa_2Cu_3O_{7-x}$ film [20], 5-inch ionic conducting yttria-stabilized zirconia film [15], 3-inch dielectric $Ba_{1-x}Sr_xTiO_3$ film [21], 2-inch compound semiconducting AlN film [22], and 6-inch piezoelectric Pb(Zr,Ti)$O_3$ film [23] have been prepared. However, the problem of "edge effect" on large substrate, i.e., the thickness of films at edge area is much thinner than that of films at the center, is still difficult to overcome [18,24,25]. In this work, in order to surmount the "edge effect" and further improve the uniformity of large-area film, a modified PLD method is used to fabricate lead-free $Bi_{3.15}Nd_{0.85}Ti_3O_{12}$ (BNT) ferroelectric thin films, which employs a larger target and two laser scanning rates.

## 2. Experiment

Thin film deposition was carried on a prototype machine of the PLD-5000 deposition system produced by PVD Products, Inc. This system includes a constant-focus laser beam scanning package and a programmable procedure as shown in the schematic of Fig. 1(a), which can make the laser beam scan on 6-inch diameter target to deposit 5-inch diameter thin films. The target is 6-inch diameter BNT with the thickness of 6 mm. The substrate is 5-inch diameter heavily doped n-type Si (100)

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http://dx.doi.org/10.1016/j.tsf.2015.08.009
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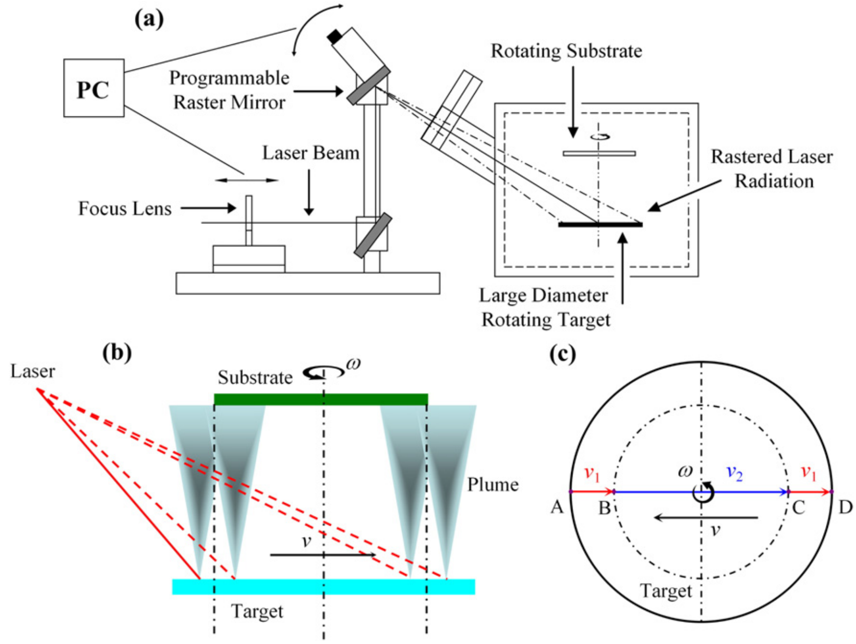


**Fig. 1.** The deposition of the large-area BNT thin films: (a) the schematic of the large-area PLD system, (b) the side-view of the laser scanning technique with large target and (c) the profile of laser beam ablating the 6-inch target with two scanning rates.

wafer, which is also used as back electrode. Substrate and target were located face to face at a distance of 111 mm. A KrF excimer laser (COHERENT COMPEX 205) with a wavelength of 248 nm and a pulsed duration of approximately 25 ns was used. The laser energy and the repetition rate were 350 mJ/pulse and 30 Hz, respectively. The imprint area ablated on the target by one-pulse laser amounted to $2 \times 10$ mm$^2$. The oxygen pressure and the substrate temperature were maintained at 13.33 Pa and 750 °C, respectively. In this deposition experiment, the peculiarities are the pulsed laser scanning technique with two laser scanning rates and the use of a large target, which can be illustrated from Fig. 1. The laser scanning rates in the center part ($|BC|$in Fig. 1(c)) and in the edge part ($|AB|$and$|CD|$ in Fig. 1(c)) were defined as $v_2$ and $v_1$, respectively. During the deposition, the laser beam ablated the target through whole diameter (starting from point A to point D, and then backing, as shown in Fig. 1(c)), and the substrate and target rotated at the speed of 25 rpm simultaneity. Here a focusing lens is mounted on a linear stage driven by a programmable actuator. As the laser beam is walked across the target the focusing lens position

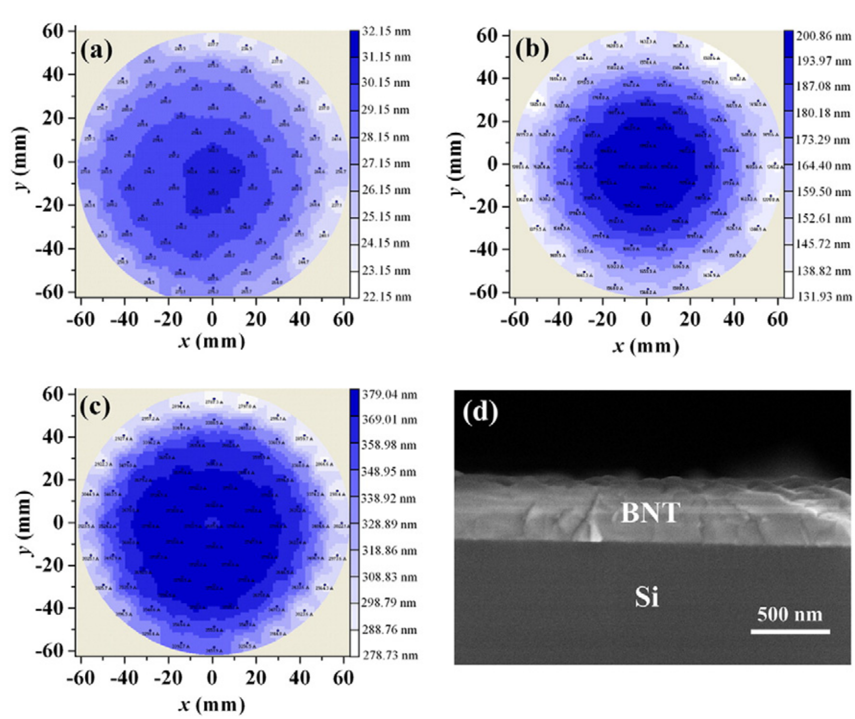


**Fig. 2.** The thickness distribution maps of 5-inch diameter BNT films (a) sample 1 deposited at $v_1 = 0.625$ mm/s, $v_2 = 62.5$ mm/s and $t = 336$ s, (b) sample 2 deposited at $v_1 = 0.625$ mm/s, $v_2 = 41.667$ mm/s and $t = 1806$ s, (c) sample 3 deposited at $v_1 = 0.313$ mm/s, $v_2 = 62.5$ mm/s and $t = 3608$ s, and (d) the cross sectional SEM image of the sample 3.