

Magnetic field-induced bipolar resistive switching and negative differential resistance in (110)SrTiO₃:Nb/ZnO heterojunctions



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ABSTRACT

(110)SrTiO₃:Nb (NSTO)/ZnO heterojunctions were fabricated by magnetron sputtering. The NSTO/ZnO heterojunctions exhibit a typical rectification characteristic, and two attendant behaviors of bipolar resistive switching and negative differential resistance appear after applying a magnetic field. The ideality factor (n) increases from 3.0 to 8.8 and the density of interface state N_{ss} increases from 8.4×10^{13} to 1.8×10^{14} eV⁻¹.cm⁻² after applying a magnetic field. The variance of interface state density can be used to qualitatively understand the above results.

1. Introduction

Resistance switching (RS) effect attracts considerable attention because of potential applications in nonvolatile resistive memories [1]. Recently, the resistance switching effect has been reported in many systems such as oxide thin films [2,3], two-dimensional transition metal dichalcogenides [4,5], and one-dimensional nanostructures [6]. A lot of interesting phenomena have been reported in this research field, such as control of normal and abnormal bipolar RS by interface junction [7], conversion of switching direction by electroforming process [8], bipolar RS accompanying negative differential resistance (NDR) [9]. Various mechanisms including bulk and interface effect are proposed to understand these phenomena.

In the past decade, zinc oxide (ZnO) has received considerable attentions owing to its outstanding optical and electronic properties [10]. Nb-doped STO (NSTO) is one of the most popular substrates for growing oxide thin films, and also a pioneer material of the emerging field of oxide electronics [11]. Furthermore, there are a few reports dealing with the electrical transport properties of NSTO/ZnO heterojunctions. Zhang et al. observed multi-resistance states by applying voltage pulses with different amplitudes in NSTO/ZnO thin film heterojunctions [12]. Wu et al. found a Schottky behavior in NSTO/ZnO thin film heterojunctions [13]. In our previous report, we have observed a rectification at a small voltage, and bipolar resistive switching with negative differential resistance at a large voltage in (100)NSTO/(110)ZnO epitaxial heterojunctions by pulsed laser deposi-

tion [14]. On the other hand, the magnetic property at the nonmagnetic oxide heterojunction interface between LaAlO₃ and SrTiO₃ has been at the focus of recent intense scientific research [15,16]. Here we would like to explore the magnetic field dependent electrical properties of nonmagnetic oxide NSTO/ZnO heterojunction. For (110)NSTO/(0002) ZnO heterojunction grown by rf sputtering in the present work, a typical rectification characteristic was observed without magnetic field, while two attendant behaviors of bipolar resistive switching and negative differential resistance appear after applying a magnetic field.

2. Experimental procedure

(110)NSTO single crystal was used as substrates since it is easy to grow high quality single-domain epitaxial ZnO film. The commercial (110) Nb-0.7 wt% doped-STO (NSTO) substrates were successively cleaned 15 min with ethanol, acetone, and de-ionized water, then blown dry with air before deposition. Epitaxial ZnO thin films were grown on the (110) NSTO substrates by magnetron sputtering, with a sputtering power of 180 W, a substrate temperature of 500 °C, a total pressure of 5 Pa, and an O₂/Ar flow ratio of 1:20 for 1 h. The crystal structure of heterostructures was investigated by x-ray diffraction (XRD, DX-2700) with CuKα radiation. In order to measure the electrical properties of NSTO/ZnO heterostructure, Au top electrodes with about 80 nm in thickness and 0.2 mm in diameter were sputtered on ZnO thin films through a shadow mask by dc sputtering, and In bottom electrode was pressed onto NSTO substrate. Keithley 2400

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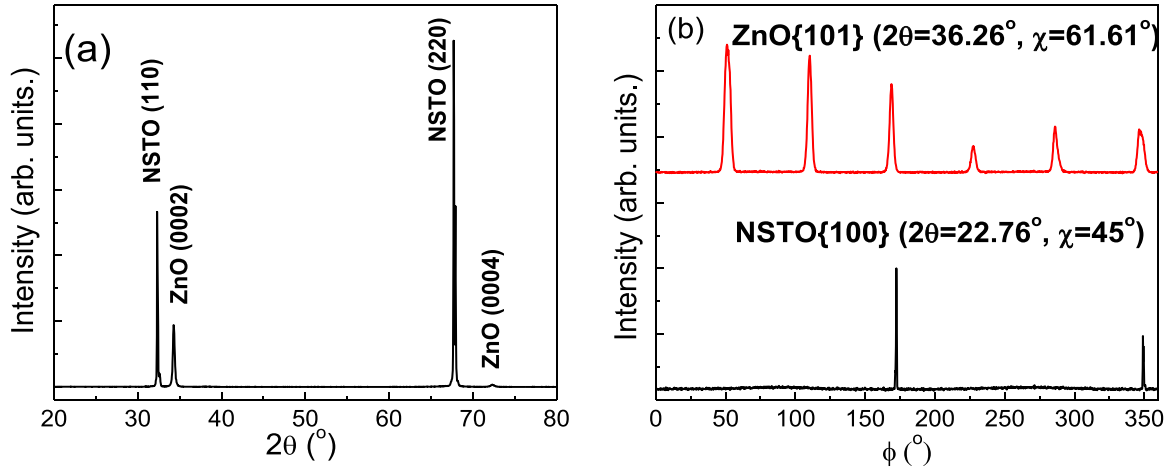


Fig. 1. (a) θ - 2θ and (b) ϕ scanning patterns of NSTO/ZnO heterostructures.

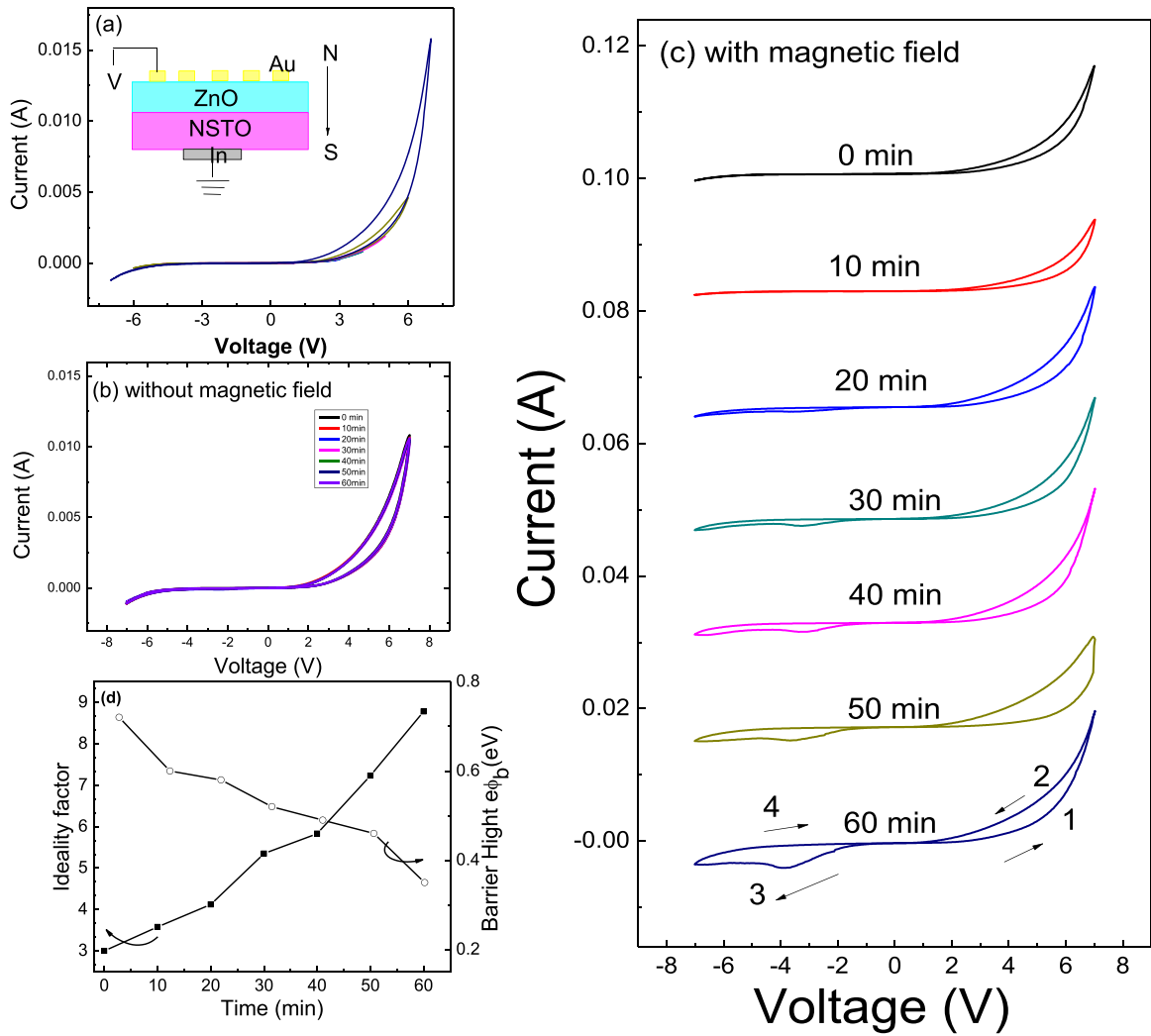


Fig. 2. (a) The current-voltage curves of In/NSTO/ZnO/Au system. Inset is the device structure and the direction of magnetic field. (b) The time dependent current-voltage curves without applying magnetic field. (c) The magnetic field application time dependent current-voltage curves. (d) Magnetic field effect time dependent n and $e\phi_b$, subtracted from fitting to the ideal thermoionic emission mechanism.

sourcemeter was used to conduct the electrical transport measurements. Agilent 4294A was used to measure the capacitance-voltage curves in a frequency range from 100 Hz to 10 kHz with a fixed oscillating voltage of 500 mV. A forward (positive) bias applied to the device is defined as the current flowing from the ZnO film into the

NSTO substrate, as shown in the inset of Fig. 2(a). A magnetic field of 0.55 T was applied perpendicular to the sample surface by a permanent magnet, and removed during current-voltage and capacitance-voltage measurements. All the characterizations and measurements were performed at room temperature.

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