Research Article

Near Infrared Lateral Photovoltaic Effect in LaTiO_3 Films

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We have reported on the lateral photovoltaic effect of LaTiO_3 films epitaxially grown on (100) SrTiO_3 substrates. Under illumination of continuous 1064 nm laser beam on the LaTiO_3 film through SrTiO_3 substrate, the open-circuit photovoltage depended linearly on the illuminated position. The photosensitivity can be modified by bias current. These results indicated that the LaTiO_3 films give rise to a potentially photoelectronic device for near infrared position-sensitive detection.

1. Introduction

Lateral photovoltaic effect (LPE) discovered by Schottky in 1930 has been widely used as position sensitive detectors (PSDs) in many fields requiring precision measurements, such as robotic vision, remote optical alignment, machine tool alignment, and medical instrumentation, [1, 2]. In order to improve the sensitivity and linearity of PSDs, many researchers have made efforts to study LPE in various kinds of materials systems, such as conventional p-n junctions, hydrogenated amorphous silicon based structures, porous silicon, Ti/Si amorphous superlattices, semiconducting polymer, metal-semiconductor and metal-insulator-semiconductor structures, modulation-doped AlGaAs/GaAs heterostructure, and Cu_2O nanoscale film, [3–11]. Almost all of the reported LPEs were applied in visible or ultraviolet region, while works concerning large LPE in near infrared (NIR) region have been rarely reported [10, 11].

Recently, the strongly correlated electron systems composed of transition-metal oxides have attracted many interests [12, 13]. By the advanced preparation technology of thin film, such as terminate oxide substrates at well-defined ionic planes, pulsed-laser deposition (PLD) and molecular-beam epitaxy (MBE), and high-pressure reflection high-energy electron diffraction, many new physical phenomena have been discovered in oxide interfaces [14, 15]. Ohtomo et al. have studied the Mott insulator LaTiO_3 (LTO) embedded in the band insulator LaTiO_3 (STO) and found interface-specific conducting states between the two different insulators [16–18]. And then the investigations of $\text{LaTiO}_3/\text{SrTiO}_3$

have been focused on their electro-optic properties [19–23]. These results have shown that the different structures among bulk materials, films, and interfaces have generated a large difference in physical properties, even when the same component materials are used.

In this paper, we have grown epitaxial LTO films on STO substrates using PLD technique and presented a near infrared lateral photovoltaic effect by irradiating the structure of LTO/STO. The open-circuit photovoltage of the LTO film depended linearly on illuminated 1064 nm laser beam position. The photosensitivity can be modified with bias current. The results demonstrated that the present film has a great potential application in NIR position-sensitive detector.

2. Experimental

The LTO film with a thickness of about 100 nm was deposited on a 0.5 mm thick single crystalline (100) STO substrate with an area of 5.0 mm $\times$ 5.0 mm using a polycrystalline $\text{La}_2\text{Ti}_2\text{O}_7$ target by pulsed laser deposition. The substrate temperature was kept at 850°C and the oxygen background pressure was 2.38×10^{-6} Torr. After the deposition, the LTO film was then cooled to room temperature with the substrate heater power cutoff. The structure of the sample was characterized by X-ray diffraction (XRD).

The schematic setup for LPE measurement is shown in the inset of Figure 2(b). For photovoltaic measurement, two silver electrodes of 4.0 mm $\times$ 1.0 mm in area, separated by about 3.0 mm, were fabricated on the as-prepared LTO film

FIGURE 1: (a) XRD pattern of LTO/STO sample. (b) The typical I - V characteristics of the LTO/STO at room temperature. The top inset shows the schematic measurement setup. The bottom inset shows the temperature dependence of resistance of LTO/STO film.

FIGURE 2: (a) The typical waveforms recorded by oscilloscope with 1 M Ω input impedance without any bias when laser spot irradiated region from A to B. (b) The steady waveforms' peak voltages depended linearly on the spot positions through the zero point.

surface. A small area of 1 mm diameter was irradiated on the LTO/STO interface by a 1064 nm continuum solid state laser. The lateral photovoltage (LPV) between the Ag electrodes A ($x = 1.5$ mm) and B ($x = -1.5$ mm) on the LTO film surface was measured and recorded by a sampling oscilloscope of 350 MHz terminated into 1 M Ω at ambient temperature.

3. Results and Discussion

The XRD scan curve of the LTO/STO is presented in Figure 1(a). Except for the diffraction peaks of STO (100) and LTO (001), there are no diffraction peaks from impurity phases or randomly oriented grains, indicating that the LTO

film is a single phase and (001) oriented. Figure 1(b) shows the typical current-voltage (I - V) curve of the LTO film measured by tuning the applied voltage with a pulse-modulated voltage source at room temperature, and the resistance of the sample increases with the temperature range from 20 to 300 K as shown in the inset. These results were consistent with the metallic behavior and also confirmed the ohmic contacts between electrodes and LTO surface.

Figure 2(a) shows the typical waveforms recorded by oscilloscope when the 1064 nm laser irradiated the LTO film through the STO substrate at different positions x (from A to B shown in the inset of Figure 2(b)). The on-sample laser power is 98 mW. When the laser irradiated the sample, the LPV rises fast at the beginning of about 3 s and then

FIGURE 3: (a) The typical waveforms with different on-sample laser power from 7.8 to 98 mW at $x = -1.4$ mm. (b) The LPV dependence on the on-sample laser power.

FIGURE 4: (a) The typical waveforms with bias currents applied from 0 to 500 μA at $x = 1.5$ mm. (b) The photoinduced LPV defined by $(V_P - V_R)$ dependence on the bias current.

gets stable. The LPVs at $x = 1.5$ mm and $x = -1.3$ mm were 5.52 mV and -4.52 mV, respectively. The LPV was dramatically changed when the laser irradiated at different positions, and Figure 2(b) shows the LPV as a function of laser spot position. It is clear that the photovoltage shows good linear relationship with the illuminated position. The position sensitivity of LPV in the sample is about 3.7 mV/mm.

In addition we also measured the photovoltaic responses at -1.4 mm with the laser power increasing from 7.8 to 98 mW (see Figure 3(a)). Figure 3(b) shows the photovoltaic response dependence on laser power. It is clear that the LPV is linear to the light power as the power is increased, which means that the position sensitivities of LPV are stable.

To improve the laser position photovoltaic sensitivity, a bias current was applied to the sample. LPVs were measured

by gradually increasing the bias current from 0 to 500 μA under 1064 nm laser illumination at $x = 1.5$ mm. The on-sample power was kept at 98 mW. The V_B in Figure 4(a) denotes the baseline recorded by the oscilloscope for laser-off state, which was caused by the external bias and the input impedance, and shifts from 0.3 to 325 mV for bias current from 0 to 500 μA . The photoinduced LPV defined by $(V_P - V_R)$ is plotted in Figure 4(b) as a function of the applied bias and increases from ~ 5 to 22 mV with bias increasing from 0 to 500 μA .

In our case the band gap of LTO and STO is ~ 0.2 eV and ~ 3.2 eV, respectively. When we used 1064 nm laser to scan the back STO side of sample, the photon can pass through the STO substrate without being absorbed. Under the illumination in LTO, electrons were excited from valance

band to conduction band by absorbing the photon energy and generated nonequilibrium carriers. The light-induced nonequilibrium electrons in LTO will thus generate a gradient laterally between the illuminated and nonilluminated zones, resulting in excess electrons diffusing laterally along the film away from the illuminated spot toward two sides (at anode and cathode). When the lateral distance of the laser spot from each contact is different, the electron density impacting in built-in electric field is different. Thus a lateral photovoltage is generated to be proportional to the difference of electron density between two lateral electrodes and strongly dependent on laser spot position.

Previously the PSDs based on LPE were mainly concentrated in the visible or ultraviolet region. The large IR LPE has been a challenge for a long time because the light in this region is hard to be absorbed. Recently a lateral photovoltage position sensitivity of 16.4 mV/mm/mW was observed at 832 nm light wavelength in nanoscale Co/Si structures [10]. Under pulsed IR laser irradiation the position sensitivity of $\text{Cu}_2\text{O/Si}$ thin film PSD reached 15.3 mV/mm [11]. Different from the reported IR PSD [10, 11], the present NIR PSD is composed of LTO film and STO substrate, named as all-perovskite-oxide (APO) PSD. The waveform of the present detector shows that the rising time of LPV is about 3 seconds. To meet the challenges of applying APO in NIR PSD, we will improve the position sensitivity and resolve the slow response time in the future.

4. Conclusions

In summary, lateral photovoltaic effect was investigated in LTO film. The LPVs were observed by chopping mechanically 1064 nm continuous laser beam, which showed a linear relationship with irradiated position, suggesting a potential application for position sensitive detectors at room temperature. The strong dependence on the laser intensity and bias current implied that LTO film may be of great use in light power measurement.

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