Nanosecond photoelectric effects in all-oxide p-n junction of $La_{0.9}Sr_{0.1}MnO_3/SrNb_{0.01}Ti_{0.99}O_3$

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Received December 23, 2004

Abstract Nanosecond (ns) photoelectric effects have been observed in all-oxide p-n junctions of $La_{0.9}Sr_{0.1}MnO_3/SrNb_{0.01}Ti_{0.99}O_3$ for the first time. The rise time was about 23 ns and the full width at half maximum was about 125 ns for the open-circuit photovoltaic pulse when the $La_{0.9}Sr_{0.1}MnO_3$ thin film in the p-n junction was irradiated by a laser of ~20 ns pulse duration and 308 nm wavelength. The photovoltaic sensitivity was 80 mV/mJ for a 308 nm laser pulse.

Keywords: perovskite oxide, p-n junction, photoelectric effect.

DOI: 10.1360/04yw0180

Since the discoveries of high T_c superconductors and colossal magnetoresistance, enormous efforts have been devoted to investigating the perovskite oxide materials. The fabrication of artificial crystalline materials through layer-by-layer epitaxial growth with full control over the composition and structure at the atomic level has become one of the most exciting areas of research in condensed matter physics and materials science. In related research, much attention has been paid to the new device concepts on oxide materials. Tanaka et al. reported the electrical modulation of double exchange ferromagnetism in $La_{0.9}Ba_{0.1}MnO_3$/Nb-doped $SrTiO_3$ p-n junction[1]. Mitra et al. observed a large positive magnetoresistance (MR) in $La_{0.7}Ca_{0.3}MnO_3/SrTiO_3/La_{0.7}Ce_{0.3}MnO_3$ tunnel junction[2]. We have discovered the modulation effect of current and voltage as well as large positive MR effect in systems of Sr-doped $LaMnO_3$ and Nb-doped $SrTiO_3$ p-n junctions as well as multilayer p-n heterostructure[3−5]. However, little on the optical effects in the manganese oxides has been reported so far. Kawai et al. observed the photocarrier injection effect in (La, Sr) $MnO_3/SrTiO_3$ heterostructure under illumination of light at a wavelength below 400 nm[6]. Zhang et al. found laser-induced thermoelectric voltages in $La_{1-x}Ca_xMnO_3$ films with a photovoltaic pulse of ~2 μs full width at half maximum (FWHM) when the film was irradiated by a 1064 nm laser pulse of 15 ns duration[7]. Sun et al.[8] reported photovoltaic effect in $La_{0.29}Pr_{0.38}Ca_{0.33}MnO_3/SrNb_{0.005}Ti_{0.995}O_3$ p-n junc-

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tion with a photovoltaic pulse of ~7 ms FWHM with the p-n junction irradiated by a 532 nm laser pulse of 10 ns pulse duration. In this letter, we report on the nanosecond (ns) order photoelectric effect in $La_{0.9}Sr_{0.1}MnO_3/SrNb_{0.01}Ti_{0.99}O_3$ (LSMO/SNTO) p-n junctions. We observed the photovoltaic pulse with a rise time of 23 ns and FWHM of about 125 ns when the LSMO film in the junction was irradiated by a laser of 20 ns pulse duration and 308 nm wavelength. The experimental results have proved that the photovoltaic phenomenon is an ultrafast photoelectric effect.

The sample of LSMO/SNTO p-n junction for studying the optical effect was cut from the same sample in ref. [3] and the sample size is 5×6 mm^2. To obtain the best p-n interface, a computer-controlled laser molecular-beam epitaxy (MBE) was used to fabricate the p-n junction. The LSMO film was epitaxially grown on SNTO substrate and has a high crystal structure and smooth surface. The indium (In) electrodes were placed on a corner of the LSMO film surface and SNTO surface. The photoelectric effects of the p-n junction were excited using a 308 nm XeCl excimer laser pulse (width 20 ns) and a CO_2 pulsed laser of 10.6 μm wavelength and measured by a 500 MHz oscilloscope (Tektronix TDS3052B) at ambient temperature.

An open-circuit photovoltage to the p-n junction was observed between the two electrodes when the surface of LSMO film was irradiated by a 308 nm excimer laser (energy density 0.4 mJ/mm^2, illumination area Ø 3 mm). Fig. 1 shows a photovoltage pulse as a function of time. The inset in Fig. 1 shows the zoom of the sharp rise. As shown in Fig. 1 and the inset, the FWHM is about 1.2 μs and the maximum photovoltaic sensitivity is 80 mV/mJ. It should be note that there is a sharp rise of the pulse in the very beginning but then the photovoltage gradually decreases. The signal gradually decreases corresponding to a ~2 ms decay process. Generally, there is a junction capacitance in the LSMO/SNTO p-n junction as well as the impedance in the measurement system. In our case, the junction capacitance is about 1.2 nF at 500 MHz for the sample, and the input impedance

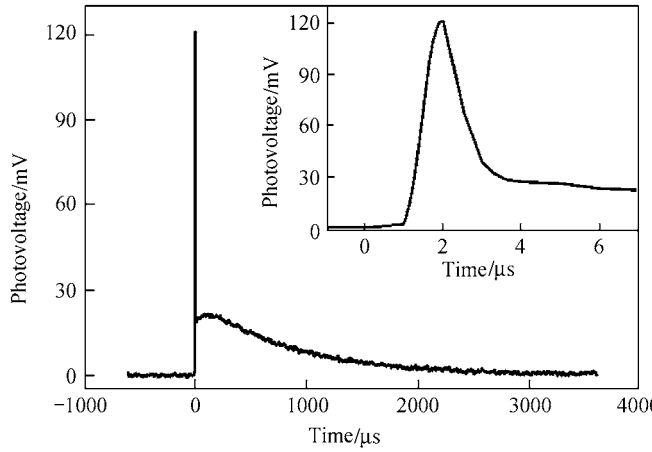

Fig. 1. Variation of the open-circuit photovoltage with time excited by a 308 nm laser pulse on the LSMO/SNTO p-n junction. The zoom of the sharp rise is shown in the inset.

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of the oscilloscope is 1 MΩ. So the discharge time constant coming from the measurement system is about ms order, which is comparable with the ~2 ms photovoltaic pulse in Fig. 1. In order to reduce the effects from the measurement system, a 2 Ω resistance was connected in parallel with the p-n junction, the rise time was dramatically reduced to 23 ns and the FWTH was also reduced to 125 ns as shown in Fig. 2. The FWHM in Fig. 2 is about four orders of magnitude narrower than that of 7 ms observed in ref. [8]. The experimental result is a more realistic process of photoelectric emission in the p-n junction.

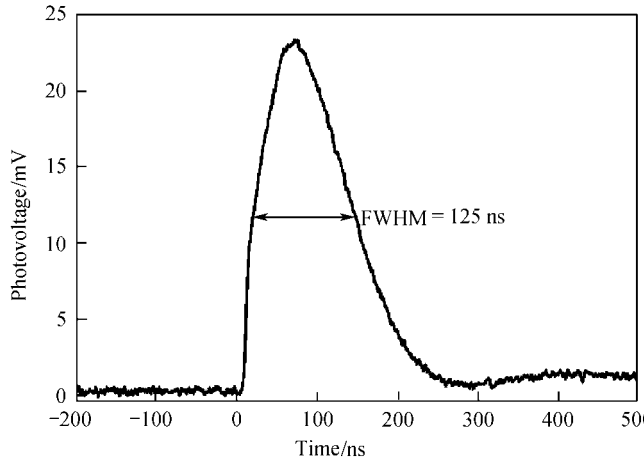

Fig. 2. Variation of the photovoltage with time under the same condition as in Fig. 1, but with a 2 Ω resistance connected in parallel across the p-n junction.

In order to understand the mechanism of photovoltaic effect, the p-n junction was also irradiated by a CO_2 pulsed laser of 10.6 μm wavelength and did not observe any photoelectric signal. SNTO bandgap is about 3.2 eV[8] and LSMO bandgap is about 0.9—1.3 eV[9]. The results reveal that the nonequilibrium charge carriers, i.e. electrons and holes, were created in the LSMO/SNTO p-n junction when the surface was irradiated by photons with an energy larger than the bandgap of the system because the photon energy of 308 nm wavelength is larger and the photon energy of 10.6 μm wavelength is smaller than the bandgaps of LSMO/SNTO system. The results also clearly demonstrate that the nanosecond photovoltage we observed was a photoelectric effect and not a thermoelectric effect.

In summary, we have observed the nanosecond photoelectric effect in all-oxide p-n junctions of LSMO/SNTO for the first time. We have also reported the rectifying I-V characteristics and the positive magnetoresistance effects for LSMO/SNTO p-n systems in our earlier work[3—5]. So the LSMO/SNTO p-n structures are possessed of multifunctional properties of electricity and optics and magnetics. We expect that the investigation and understanding of all-oxide p-n junctions should open up new possibilities in device development and application.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 10334070).

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