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Wide band-response laser-induced thermoelectric voltage in tilted orientation $SrTiO_3$ single-crystal coated by $La_{0.7}Sr_{0.3}CoO_3$ layer

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ABSTRACT

With different wavelengths from the infrared (IR) to ultraviolet (UV) band, laser-induced thermoelectric voltage (LITV) has been observed in the vicinal cut $SrTiO_3$ (STO) single crystals, coated with $La_{0.7}Sr_{0.3}CoO_3$ (LSCO) layer. It is demonstrated that the polarity of voltage signal in the STO substrate is reversed when the STO substrate is illuminated by UV laser rather than by IR or visible laser. The polarity of voltage signal in LSCO film is always consistent with that from the STO substrate no matter 1064 or 355 nm laser irradiate the LSCO film or the STO substrate. A possible interpretation of the phenomenon is proposed.

Recently laser-induced thermoelectric voltage (LITV) was widely studied in high-temperature superconductor thin film, $YBa_2Cu_3O_{7-X}$ films and $Tl_2Ba_2CaCu_2O_8$ films [1–5], in colossal magnetoresistance (CMR) thin film, $La_{1-X}Ca_XMnO_3$ [6–9], and in the *c*-axis-oriented MgB_2 thin films [10]. Based on the Anisotropic Seebeck effect, an atomic layer thermopile [1] was proposed to explain mechanism of the phenomenon and origin of the LITV. Further researches [11–13] have been done to the effect and show a great agreement with the atomic layer thermopile model. Researches demonstrated that this kind of thin film in possess of qualities of wide-wavelength response, fast-time-response, and good linear relationship to laser power in a limited range, can be widely used as laser power/energy meter.

The photoconductivity of insulative $SrTiO_3$ (STO) single-crystal under ultraviolet (UV) light irradiation has been reported for more than 40 years [14–17]. UV LITV signal in commercial vicinal cut STO and $LaAlO_3$ (LAO) single crystals was also reported, however, infrared (IR) or visible LITV signal was not observed [18,19]. In this article, we report IR and visible LITV effect in vicinal cut STO substrate coated by $La_{0.7}Sr_{0.3}CoO_3$ (LSCO) layer.

The LSCO thin film was grown on double-polished STO (1 0 0)-oriented substrate tilted by 10° towards the [0 1 0] direction by chemical solution deposition (CSD) method with thickness of ~80 nm. The preparation of the solution was carried out in air with lanthanum acetate (Alfa Aesar), Strontium acetate (Alfa Aesar), and cobalt acetate (Alfa Aesar). Propionic acid was used as chelating agent and a solution with concentration of 0.2 M was used to prepare the film. A spin coater was used to deposit the layers, the rotation speed was selected as 4000 rpm and the deposition time was 60 s. The deposited layer was dried on a 300 °C preheated hot furnace for 30 min to expel organics, and then the dried layer was annealed at 600 °C for 2 h under flowing oxygen atmosphere at the speed of 0.45 sccm. The size of STO is $5 \times 10 \times 0.5\ mm^3$. Copper electrodes were fabricated on LSCO thin film and STO substrate, respectively, with silver epoxy. The inset of Fig. 1(a) shows the arrangement of four electrodes: A, B, C, and D. Electrodes A and B separated by 8.5 mm were always kept in the dark to prevent the influence of any electrical contact photovoltage, and the same were electrodes C and D. Table 1 shows all specifications of laser light used in this article. The signal was terminated to the digital oscilloscope, Tektronix TDS3054B, with 500 MHz bandwidth and 0.2 ns time resolution. Four times average was taken before we collected the data with the digital oscilloscope.

Fig. 1(a) shows a typical open-circuit voltage signal measured on electrodes A and B by the oscilloscope with input impedance 1 MΩ, when 1064 nm laser irradiated the LSCO film. The rise time (10–90% of the peak voltage) is 40 ns, the full width at half maximum (FWHM) is 0.6 μs and the peak voltage Vp is 16 mV. The long-time decay of the electrical signal in the system could be explained by the RC effect in the circuit [12]. In order to obtain a fast response of the signal and reduce the long tail of the decay time due to RC effect, we terminated the signal to oscilloscope with 50 Ω input impedance. As shown in Fig. 1(b), the voltage signal is symmetrical, and the rise time reduced to 13 ns and the FWHM reduced to 25 ns, which presents a good agreement with

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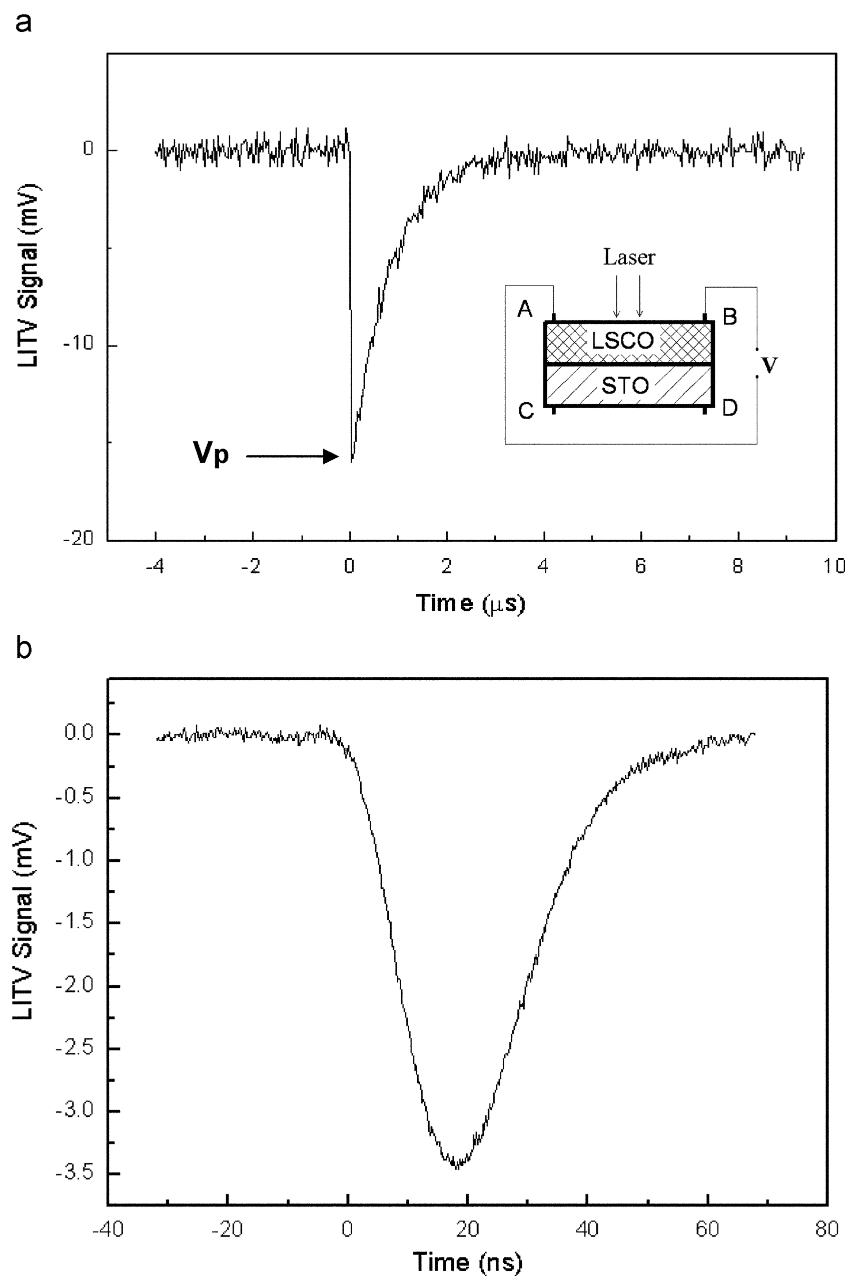

Fig. 1. (a) The inset shows the contact arrangement of the sample and the schematic circuit of the measurement. A typical voltage signal measured on electrodes A and B when the LSCO film was illuminated by 1064 nm laser with 1 MΩ and 50 Ω and (b) input impedance to oscilloscope. Vp is the peak voltage.

Table 1
Parameters of light sources in this article.

Wavelength	355 nm	1064 nm
Energy density	$\sim$1 mJ mm^{-2}	$\sim$1.2 mJ mm^{-2}
Pulse duration	4 ns	6 ns
Diaphragm/on-sample energy	2 × 3 mm^2/6 mJ	ϕ2 mm/3.6 mJ

laser pulse duration. We also got analogical result with 532 nm laser irradiation and these experimental results accord with other reports [6–13].

Fig. 2 demonstrates the relation between the peak voltage Vp and the incident laser energy. The very good linear relationship provides the possibility of making use this effect as laser power/energy meter at the wavelength of 1064 nm. Peak voltages Vp in LSCO film on STO substrates with tilted angle 10° and 4° are studied. According to Zhao's theory [18], we get $Vp(\alpha)\propto(\cos\alpha-\sin\alpha)\sin(2\alpha)$ and $Vp(10^\circ)/Vp(4^\circ) = 2.15$. α is the tilted angle of STO substrate. In this case, $Vp(10^\circ)/Vp(4^\circ) = 18.6/9.6\,mV = 1.94$. The result is in good agreement with the theory.

Fig. 3 presents the voltage signal measured on electrodes C and D with irradiation of 1064 and 355 nm, respectively, on the STO substrate. An interesting phenomenon is the inversion of the signal and explanation based on the Seebeck effect was given as the following.

According to the atomic layer thermopile [1,7] and the anisotropic Seebeck effect, the gradient of the electrical potential generated by the STO substrate is a function of the gradient of the lattice temperature as below:

$$\nabla\Psi = S_{il}\nabla_j T \tag{1}$$

where S_{il} is the Seebeck tensor. In this case, the gradient of the electrical potential $\nabla\Psi$ is related with the gradient of the lattice

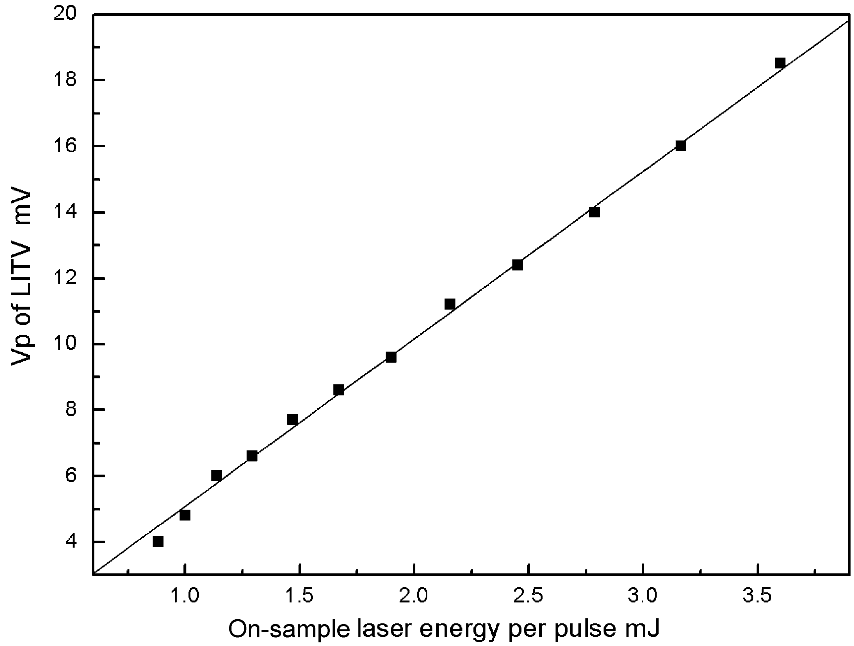

Fig. 2. The linear relationship between peak voltage Vp and the on-sample laser energy per pulse for $\lambda = 1064$ nm. The solid line is a guide for the eye.

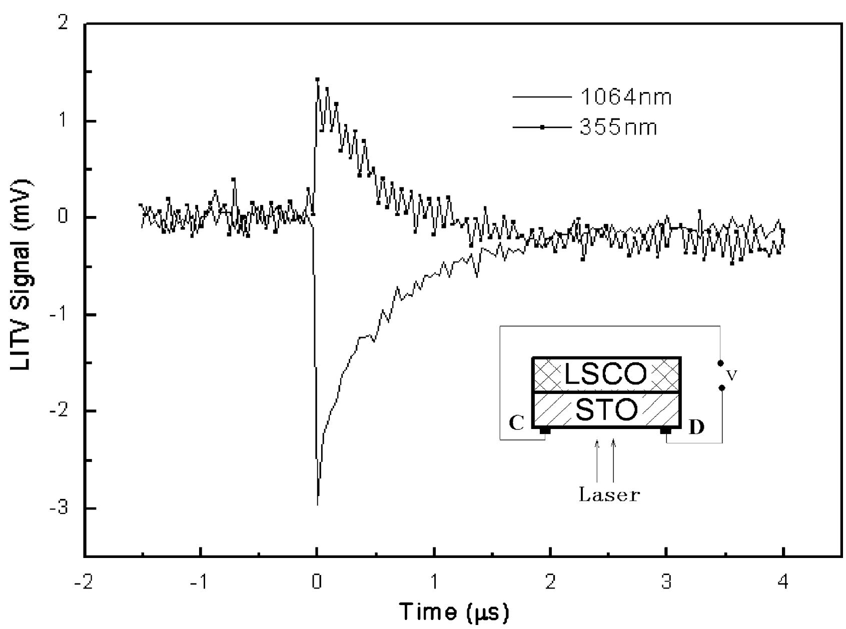

Fig. 3. Voltage signal as a function of time under irradiation of 355 and 1064 nm laser, respectively, on the STO substrate. The inset shows the schematic circuit of the measurement and irradiation direction.

temperature $\nabla_j T$. The direction of $\nabla \Psi$ changes as the direction of $\nabla_j T$ is changed.

The inversion of the signal is caused by the reversed temperature gradient. Illuminated by 355 nm laser, the STO substrate absorbs laser energy and cause a temperature gradient with a direction from the free STO substrate surface to the interface. When the sample was illuminated by 1064 nm laser, the STO substrate is transparent, and the LSCO thin film or the interface absorbs the laser energy, the interface becomes a heat source and a temperature gradient was produced from the interface to the free STO substrate surface. As the direction of the temperature gradient is reversed, the electrical potential is reversed also.

When 532 nm laser replaces 1064 nm, respectively, the result is the same and our experiments have a good agreement with other reports [18,20], that STO absorbs lights with a wavelength of less than 390 nm, and presents a high transparency in the visible and infrared wavelength range.

The magnitude of the signal is by one or two orders smaller than other reports [5–8,11,12], which may be due to improper use and arrangement of copper electrodes, depend on absorption coefficient of the LSCO film, low peak power of irradiation laser or fast thermal diffusion of STO substrate.

Sample potential measurement under illumination from the STO substrate to the LSCO film by 1064 nm laser: $V_{CA} \sim 0$; $V_{DB} \sim 0$; $V_{DA} > 0$; $V_{DC} > 0$; $V_{BA} > 0$; and $V_{BC} > 0$. The polarity of voltage signal in LSCO film and in STO substrate kept invariable no matter 1064 nm laser irradiated the STO substrate or the LSCO films.

Polarity of voltage signal in LSCO film is reversed when the illumination direction of 355 nm laser is reversed, and is in good agreement with that in the STO substrate. Based on our experiments, we make an interpretation: the origin of the signal is from the STO substrate, and LSCO film works as a coating of conductive, absorbing-laser, and heat-source. The mechanism of LITV effect in this article is proposed as the combination of anisotropic Seebeck effect and photoelectric effect. LITV signal in LSCO film is either naught or so weak that can be ignored compared with that in the STO substrate.

In summary, we prepared the LSCO film with CSD method, the first time used to study the Seebeck effect with advantage of simple process and low cost, and analyzed voltage signals on the STO substrate and LSCO film. Polarity of voltage signal in LSCO film and tilting STO substrate was always consistent when UV, visible, and IR laser was used from both sides. Laser power/energy meter and wide-wavelength photo-detectors could be potential applications of our sample. Again our interpretation is effective in our experiments, and further investigations of this phenomenon should be done to elucidate the mechanism.

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