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Laser-induced thermoelectric voltage in normal state MgB_2 thin films

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Abstract

Laser-induced voltage has been observed in *c*-axis oriented MgB_2 thin film at room temperature. The amplitude of the signal is approximately proportional to the film thickness. For the film with the thickness of 150 nm, a very fast response has been detected when the film was irradiated by a 308 nm pulsed laser of 20 ns duration. The rise time and full width at half-maximum of the signal are about 3 and 25 ns, respectively. The physical origin of the laser-induced voltage can be attributed to a transverse thermoelectricity due to the anisotropic thermopower in MgB_2.

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Keywords: MgB_2 thin films; Laser-induced voltage; Thermoelectric effect

1. Introduction

Studies of laser-induced voltage for high-T_c superconducting $YBa_2Cu_3O_{7-\delta}$ thin films have attracted considerable attention because of their promising application as fast, broadband photo detectors and mixers [1,2]. Recently, laser-induced photovoltage has also been observed at room temperature in other perovskite oxide films and heterostructures such as $La_{0.67}Ca_{0.33}MnO_3$ [3], $La_{0.9}Sr_{0.1}MnO_3/SrNb_{0.01}Ti_{0.99}O_3$ [4], $La_{0.7}Sr_{0.3}MnO_3/Si$ [5] and $SrTiO_{3-\delta}/Si$ [6], $BaNb_{0.3}Ti_{0.7}O_3/Si$ [7].

MgB_2, a newfound metallic compound superconductor with the T_c of 39 K, has attracted great interest in both fundamental studies and practical applications [8]. Over the past few years, a great deal of physical properties has been investigated about high quality thin film samples of this material. In this paper, we report the optical response of MgB_2 thin films to laser radiation. A transient voltage signal has been observed at room temperature when the films are irradiated by a 308 nm laser with the pulse duration of about 20 ns. The typical signal pulse has a rise time of several nanoseconds, indicating that these MgB_2 thin films have a potential application in fast ultraviolet photo detectors.

2. Experimental

MgB_2 thin films were prepared on mirror double-polished MgO (1 1 1) substrates by chemical vapor deposition (CVD) technique [9]. Amorphous B precursor films were deposited by CVD. The chamber was first purged with purified H_2 gas three times. 1000 ppm B_2H_6 diluted in H_2 was then admitted directly onto the substrates, whereas the system was continuously evacuated by a mechanical pump. Typical conditions in the experiments were as follows: pressure was 5×10^4 Pa, total gas flow rate was 60 sccm and the substrate temperature was 600–700 °C. Then the precursor boron thin film was put into a quartz tube, which was evacuated to 10^{-4} Pa together with high purity magnesium (99.99%) bulk and fast heated to 890 °C in 15 min. After holding at that temperature for 40 min, it was quenched to room temperature in 15 min.

The as-formed MgB_2 thin films had glossy metallic appearance with a very low two-probe resistance of $<1\ \Omega$. The thickness of the film was measured by a DEKTAK-III surface profile meter. The crystalline structure was characterized by X-ray diffraction (XRD) using Ni-filtered Cu Kα radiation.

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Measurements of the laser-induced voltage were performed at room temperature. Electrical point contacts were made with silver dots on the film surface, to which copper wires were attached with indium solder. To prevent the generation of any electrical contact voltage, the contacts were kept in the dark during the measurements. A 308 nm XeCl laser with the pulse duration of about 20 ns was used for film irradiation. The laser energy density was kept at 0.3 mJ/mm^2, and the irradiation area was limited to 5 mm × 5 mm. The voltage signals were recorded with a 500-MHz sampling oscilloscope terminated into 1 MΩ.

3. Results and discussion

Fig. 1 shows a typical XRD θ–2θ scan of the CVD-prepared MgB_2 thin films on MgO (1 1 1) substrates. The scan indicates the presence of highly preferred c-axis oriented MgB_2 thin films. The resistance measurements using a four-probe method reveals that the MgB_2 thin films have a very sharp zero resistance transition temperature T_c of about 38 K, as shown in Fig. 2. The inset of Fig. 2 shows the critical current density J_c of 1.9×10^7 A/cm^2 in zero field and 10 K, which further confirms the high quality of the CVD-prepared MgB_2 thin films.

Fig. 3(a) exhibits a typical transient voltage for a 150-nm thick MgB_2 thin film to the 308 nm pulsed laser irradiation. The amplitude of the signal is about 27 mV. The pulse shows a rise time of about 3 ns and a full width at half-maximum (FWHM) of about 25 ns. Furthermore, if the film is illuminated through the substrate, rather than at the film surface, the side to which the leads are attached, the signal polarity is reversed as shown in Fig. 3(b). This inversion of the signal may be considered to support the suggestion that this phenomenon is due to a transverse thermoelectric effect due to the anisotropic thermopower in MgB_2, which is similar to those reported for $YBa_2Cu_3O_{7-\delta}$ superconducting thin films. Heating the surface of the MgB_2 thin films by a 308 nm pulsed laser irradiation leads to a temperature difference between film surface and film

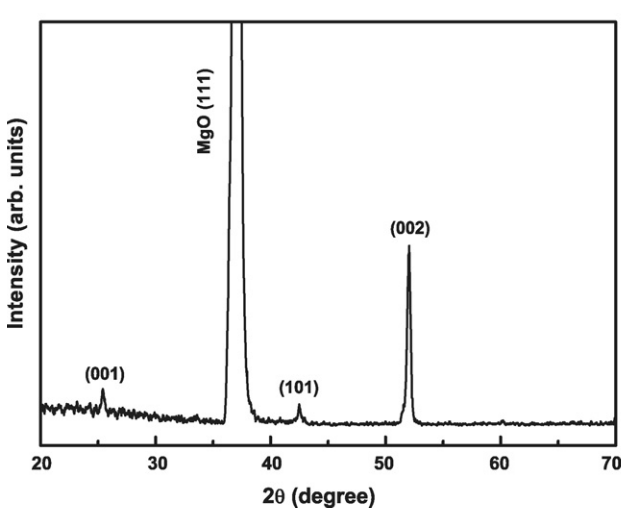

Fig. 1. XRD pattern for the CVD-prepared MgB_2 thin film on MgO (1 1 1) substrate.

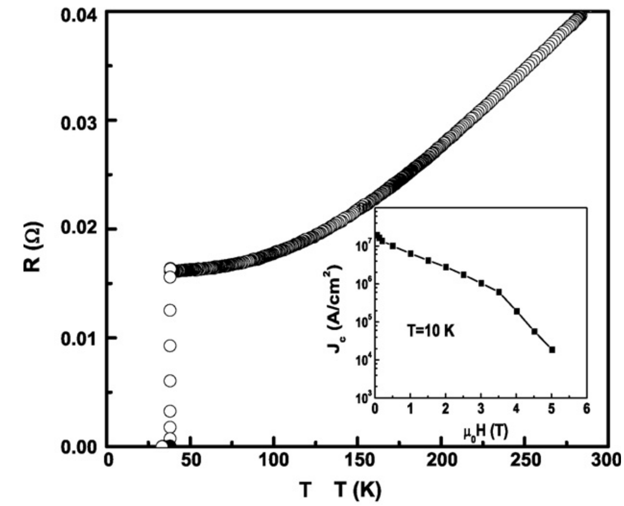

Fig. 2. Resistance vs. temperature for the CVD-prepared MgB_2 thin films on MgO (1 1 1) substrates. The inset shows the field-dependent J_c at 10 K.

bottom. According to the Seebeck effect [10], a thermoelectric voltage,

$$U = \frac{l}{d} \Delta S \Delta T \sin 2\alpha, \quad (1)$$

is generated due to the temperature gradient normal to the film surface. Here $\Delta S = S_{ab} - S_c \sim -8\mu V/K$ is the difference of the absolute thermopowers in the ab plane and along the c-axis of MgB_2 [11], ΔT a temperature difference between MgB_2 film

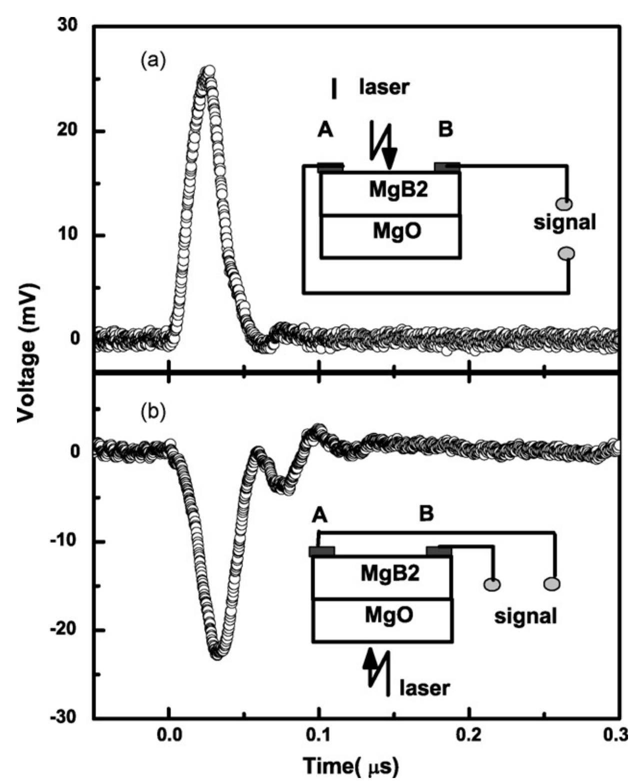

Fig. 3. The laser-induced voltage in MgB_2 (150 nm) thin films when (a) the film surface and (b) the substrate were illuminated. The insets show the schematic circuits of the sample measurements, here, A and B denote the electrodes.

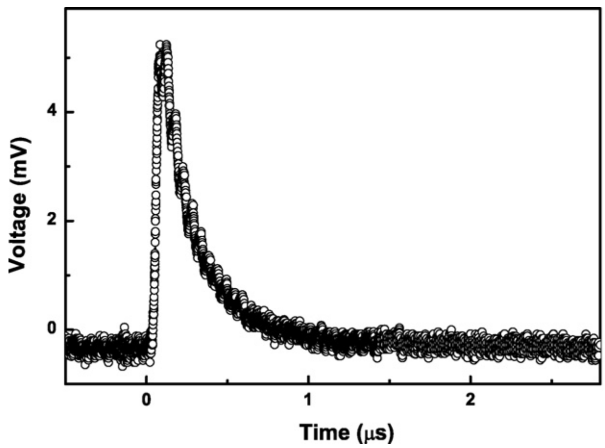

Fig. 4. The laser-induced voltage in MgB_2 (800 nm) thin films when the film surface was illuminated.

surface and film bottom, l the diameter of the radiation spot on the MgB_2 film surface, d the thickness of MgB_2 thin film and α the tilting angle of the film orientation. In this study, the small angles α between the c-axis of the MgB_2 thin films and the surface normal of the MgO substrates may be induced by imprecisely cut substrates.

According to the Eq. (1), the amplitude of the laser induced voltage signal should be proportional to $1/d$. Fig. 4 shows the photovoltaic response of an 800-nm thick MgB_2 film to the 308 nm pulsed laser irradiation. A lower signal of about 5 mV was detected, which is compatible with Eq. (1) and confirm our reasonable suggestion. Besides, it is found that the FWHM dependent on the film thickness and the thicker film exhibit slower response, which was also observed in $YBa_2Cu_3O_{7-\delta}$ films [10,12].

The explanation is, of course, only tentative. For a full understanding, a detailed investigation including the dependence of the laser-induced voltage on the tilting angle of the MgO substrates will be performed in future work.

4. Conclusion

In summary, a laser-induced thermoelectric voltage was observed in MgB_2 thin film when it was irradiated by a 308 nm laser pulse. It is demonstrated that the signal polarity is reversed when the films are illuminated through the substrate rather than the film surface. The amplitude of the voltage signal is approximately proportional to the thickness of the films. The mechanism for this phenomenon should be related to a transverse thermoelectric effect due to the anisotropy of the thermopowers in MgB_2.

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