Vol 15 No 4, April 2006
1009-1963/2006/15(04)/0839-03

Chinese Physics

© 2006 Chin. Phys. Soc.
and IOP Publishing Ltd

Ultraviolet photovoltaic characteristic of MgB_2 thin film

Zhao Song-Qing(赵嵩卿), Zhou Yue-Liang(周岳亮)†, Zhao Kun(赵 昆),
Wang Shu-Fang(王淑芳), Chen Zheng-Hao(陈正豪), Lü Hui-Bin(吕惠宾),
Jin Kui-Juan(金奎娟), Cheng Bo-Lin(程波林), and Yang Guo-Zhen(杨国桢)

Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China

(Received 17 November 2005; revised manuscript received 26 December 2005)

Fast photoelectric effects have been observed in MgB_2 thin film fabricated by chemical vapour deposition. The rise time was ∼10 ns and the full width at half-maximum was ∼185 ns for the photovoltaic pulse when the film was irradiated by a 308 nm laser pulse of 25 ns in duration. X-ray diffraction and the scanning electron microscope revealed that the film was polycrystalline with preferred c-axis orientation. We propose that nonequilibrium electron–hole pairs are excited in the grains and grain boundary regions for MgB_2 film under ultraviolet laser and then the built-in electric field near the grain boundaries separates carriers, which lead to the appearance of an instant photovoltage.

Keywords: MgB_2, photovoltaic effect, thin film
PACC: 7475, 7430M, 7390

1. Introduction

Since the discovery of the binary metallic MgB_2 superconductor with T_c of 39 K, there have been many efforts to fabricate high-quality thin films of the new material for fundamental studies and electronic device applications.[1−3] To date, MgB_2 thin films have been grown by various deposition techniques,[4−8] including chemical vapour deposition (CVD) technique.[9] Till now, most of the researches on MgB_2 mainly focused on its superconductivity. The same as another famous $YBa_2Cu_3O_{7-\delta}$(YBCO) superconductor which can act as infrared photodetector,[10−13] we report here, for the first time, the observation of ∼5 mV photovoltaic signals in MgB_2 thin films when it was irradiated by a 308 nm laser pulse of 25 ns in duration. This phenomenon indicates that the MgB_2 film may serve as one of the potential fast ultraviolet photodetectors.

2. Experiment

The preparation of MgB_2 thin films on MgO(111) substrates by CVD techniques involved two main steps, which have been reported elsewhere.[9,14] The thickness of the films was measured to be approximately 800 nm by using a DEKTAK-III surface profilometer. The structures of the MgB_2 films were characterized by x-ray diffraction (XRD) using Cu $K\alpha$ radiation. Indium (In) electrodes ($0.5\ mm^2$) were placed on the surface of MgB_2 film for measuring the electrical characteristics. The electrical measurements were performed by using a superconducting quantum interference device (SQUID) magnetometer in the temperature range of 5–200 K and magnetic field of 0–5 T. The surface morphology analysis was performed by the JEOL JSM-6700F field emission-scanning microscope (SEM) equipped with an energy-dispersive x-ray spectroscopy (EDX) system. A typical photovoltage transient of MgB_2 film was monitored and memorized with a 500-MHz sampling oscilloscope terminated into 50 Ω under the irradiation of a pulsed laser of 308 nm and 25 ns in duration. The laser energy density was kept as $0.3\ mJ/mm^2$, and the irradiation area was 5mm×5mm. In particular, the electrodes were always kept in the dark to prevent the generation of any electrical contact photovoltage.

3. Results and discussion

Though the appearance of the MgB_2 (101) peak indicates that the films are polycrystalline, the XRD pattern in Fig.1 shows that MgB_2 films have relative good crystallinity with preferred c-axis orientation.

†E-mail: ylzhou@aphy.iphy.ac.cn

Figure 2 presents the morphology of the MgB_2 thin films obtained by annealing B films in the Mg vapour. Based on the scale on the SEM image, the average grain sizes can be estimated as $\sim$ 400 nm in length and $\sim$150 nm in diameter.

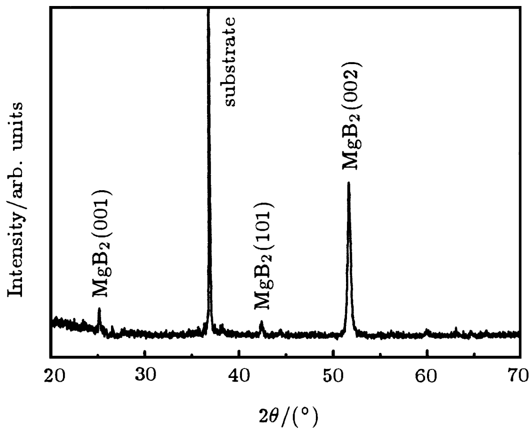


Fig.1. X-ray diffraction pattern for the CVD-prepared MgB_2 thin films on MgO(111) substrates.

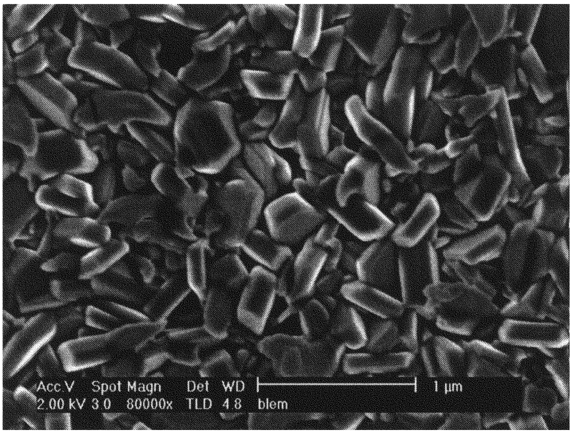
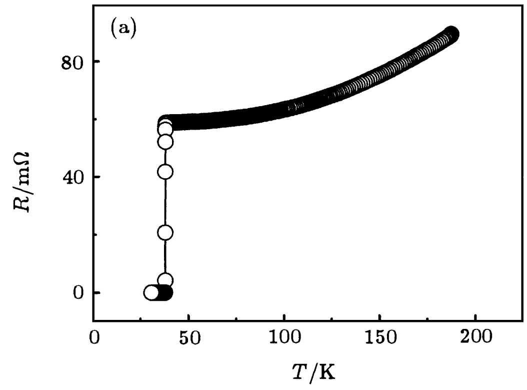


Fig.2. Scanning electron microscopy image for the annealed MgB_2 thin films on MgO (111) substrate.

The superconducting properties of the films were measured by both four-probe DC resistance and DC magnetization measurements. The resistance measurements conducted with a DC current 0.5 mA in zero field revealed that the MgB_2 films on MgO(111) have a sharp zero resistance transition temperature T_c of about 37.56 K (Fig.3(a)), above which the conductivity is metal-like. Figure 3(b) shows the magnetization hysteresis loop of the MgB_2 film with the size of 3.0mm $\times$ 5.0mm $\times$ 0.8μm under the magnetic field applied perpendicular to the film. The magnetization exhibits the symmetry $M(H) = -M(-H)$, which indicates a dominance of the bulk superconducting current.



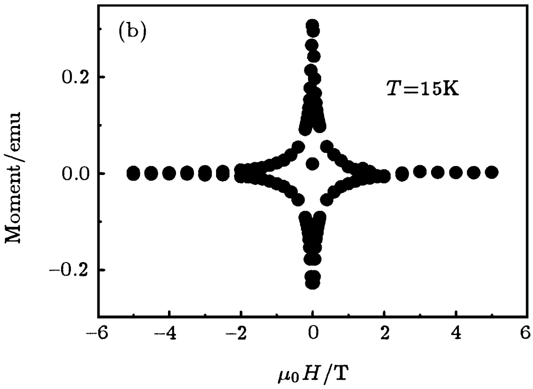


Fig.3. (a) Resistance versus temperature for the CVD-prepared MgB_2 thin films on MgO (111) substrates. (b) The magnetization hysteresis loops (MHL) for a MgB_2 thin film with the size of 3.0mm $\times$ 5.0mm $\times$ 0.8μm at 15 K.

Figure 4 exhibits a typical photovoltage transient of MgB_2 film to a pulsed laser irradiation of 308 nm and 25 ns in duration. The photovoltaic pulse response shows a rise time of 10 ns and a full width for half maximum (FWHM) of $\sim$185 ns, which is a suggestive of the lifetime of $\sim$185 ns for the nonequilibrium photo-induced carriers. Since little band-gap information of MgB_2 at room temperature is available, we propose a possibility to describe the origin of this photovoltaic signal. As the MgB_2 film consists of grains separated by grain boundaries (GBs) shown in Fig.2, there is a chemical potential shift $\Delta\mu$ between the GB region and the grain. Thus it might induce a depletion layer in the GB region, and the build-in voltage V_b (build-in electrical field) is given by $\Delta\mu$, $V_b = \Delta\mu$. Yang *et al* calculated the work function of the MgB_2 surfaces in the state of superconductivity by first principle theory, and gave the work functions of 5.95 and 4.25 eV respectively for B-terminated and Mg-terminated surfaces.[15] As the rising of temperature, the work functions are supposed to be smaller than that in superconductivity state and the ultraviolet (UV) photon energy (4.0 eV for 308 nm). When the laser irradiates the sample, electron-hole pairs can be excited to move out from grains to GB regions. And then the nonequilibrium carriers are separated by the built-in electric field near the GB, eventually, these carriers lead to the appearance of an instant photovoltage.

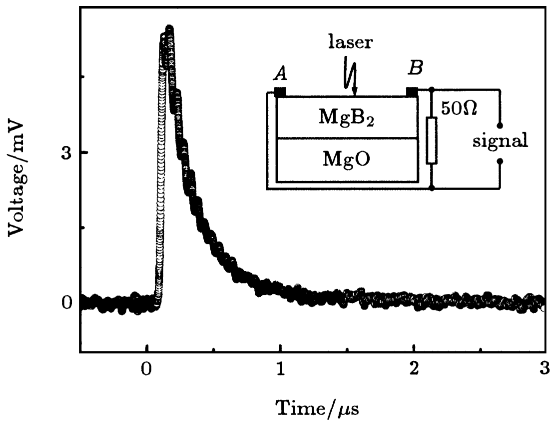


Fig.4. The photovoltaic signal of the MgB_2 film with high c-axis orientation irradiated by a 308 nm laser pulse of 25 ns duration. The inset shows a schematic circuit of the sample measurement, here, A and B denote the electrodes.

Since the sample is polycrystalline, there should be an equal number of grains with photogenerated carriers shifting in one direction as in the opposite direction; hence there should be no net current flow and no photovoltaic signal. This is not being the case. In fact, it is uncertain why there is an overall preferred direction for the flow of the photogenerated current. This behaviour may be due to the asymmetry (e.g. preferred c-axis orientation) of the lattice which induces an asymmetric moving of the excited carriers in a preferred direction. But the mechanism of this moving is still not clear at the present time. Further study on the nature of the photovoltaic properties of such a system is under way.

4. Conclusion

In summary, a photovoltaic effect was observed in the MgB_2 thin film when the film was irradiated by a 308 nm laser pulse of 25 ns in duration. The rise time was $\sim$10 ns and the FWHM was $\sim$185 ns for the photovoltaic pulse. We proposed a possible origin of this phenomenon that the photogenerated nonequilibrium carriers are separated by the built-in electric field near the grain boundaries, eventually, these carriers lead to an instant photovoltage.

References

[1] Nagamatsu Jun, Nakagawa Norimasa, Muranaka Takahiro, Zenitani Yuji and Akimitsu 2001 *Nature* **410** 63

[2] Bud'ko S L, Lapertot G, Petrovic C, Cunningham C E, Anderson N and Canfield P C 2001 *Phys. Rev. Lett.* **86** 1877

[3] Kang W N, Kim Hyeong-Jin, Choi Eun-Mi, Jung C U and Lee Sung-Ik 2001 *Science* **292** 1521

[4] Wang S F, Dai S Y, Zhou Y L, Chen Z H, Cui D F, Xu J D, He M and Lu H B 2001 *Supercond. Sci. Technol.* **14** 885

[5] Ueda K and Natito M 2003 *J. Appl. Phys.* **93** 2113

[6] Zhai H Y, Christen H M, Zhang L, Paranthaman M, Cantoni C, Sales B C, Fleming P H, Christen D K and Lowndes D H 2001 *J. Mater. Res.* **16** 2759

[7] Peng N H, Shao G, Jeynes C, Webb R P, Gwilliam R M, Boudreault G, Astill D M and Liang W Y 2003 *Appl. Phys. Lett.* **82** 236

[8] Bu S D, Kim D M, Choi J H, Giencke J, Hellstrom E E, Larbalestier D C, Patnaik S, Cooley L and Eom C B 2002 *Appl. Phys. Lett.* **81** 1851

[9] Wang S F, Zhou Y L, Zhu Y B, Liu Z, Zhang Q, Chen Z H, Lu H B, Dai S Y and Yang G Z 2003 *Supercond. Sci. Technol.* **16** 748

[10] Kwok H S, Zheng J P, Ying Q Y and Rao R 1989 *Appl. Phys. Lett.* **54** 2473

[11] Leung M, Broussard P R, Claassen J H, Osofsky M, Wolf S A and Storm U 1987 *Appl. Phys. Lett.* **51** 2046

[12] Enomoto Y, Murakami T and Suzuki M 1988 *Physica* C **153-155** 1592

[13] Frosrester M G, Gottlieb M,Gavaler J R and Braginski A I 1988 *Appl. Phys. Lett.* **53** 1332

[14] Wang S F, Liu Z, Zhu Y B, Zhou Y L, Liu Z, Chen Z H, Lu H B and Yang G Z 2004 *Chin. Phys.* **13** 1120

[15] Li Z Y, Yang J L, Hou J G and Zhu Q S 2002 *Phys. Rev.* B **65** 100507(R)