Journal of Alloys and Compounds 723 (2017) 311–316

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Ultra-high photocurrent response in a chromia oxide thin film under visible light illumination

Z.C. Wang, J. Miao*, M. Yang, R.H. Zhao, Y. Wu, X.G. Xu, Y. Jiang**

State Key Laboratory for Advanced Metals and Materials, School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing, 100083, China

ARTICLE INFO

Article history:
Received 15 October 2016
Received in revised form
19 March 2017
Accepted 10 June 2017
Available online 12 June 2017

Keywords:
Cr_2O_3 thin films
Photoconductivity
Poole-Frenkel conduction mechanism

ABSTRACT

In this work, the photoconductivity of chromia (Cr_2O_3) thin films, which were configured an in-plane electrode, was investigated under visible laser illumination. The fast and slow response components of photocurrent were originated by its exciting defect level. Surprisingly, a high photoresponsivity up to 1.94×10^3 A/W was obtained when the Cr_2O_3/Pt planar capacitor was applied an incident wavelength of 650 nm at room temperature. Moreover, dielectric characterization implied that the current of channel in Cr_2O_3 film increased with the increasing of its defects concentrations under laser illumination. Our results indicate that the Cr_2O_3 thin films have a potential application in the photoelectric field.

1. Introduction

Recently, the wide-band-gap semiconductors have attracted much attention due to their unique characteristics in electronics and optoelectronics applications. Many materials, such as GaN, ZnO, TiO_2, GaP etc., have been widely used as photodetectors owing to their special properties such as the large band gap value [1–5]. Among them, chromia oxide (Cr_2O_3) is one of the most important wide-band-gap (Eg ~ 3 eV) transition-metal-oxide semiconductors [6]. It belongs to rhombohedral crystal system with lattice parameter a = b = 4.953 Å, c = 13.578 Å and space group *R*-3*c* [7,8]. Furthermore, Cr_2O_3 is a refractory material due to its high melting temperature and oxidative resistance [9], as well as a component of gas sensors for ethanol and ammonia vapor [10–12]. Importantly, bulk Cr_2O_3 is antiferromagnet with the Néel temperature of $T_N = 318$ K [13]. An intrinsic spin Seebeck effect was found in the Cr_2O_3/Pt structure [14] and a pure spin currents was observed in the Pt/Cr_2O_3/YIG structure [15]. Although Cr_2O_3 has been extensively studied, there are a few investigations on the photocurrent response in Cr_2O_3 films.

In this work, the photoresponse of Cr_2O_3 films patterned with inter-digital electrodes was investigated for the first time. Interestingly, the photoresponsivity of a Cr_2O_3/Pt planar structure reached as high as 1.94×10^3 A/W when applied a 650 nm illumination with a power density of 40 mW/cm^2 at low bias (10 V). Accordingly, the photocurrent of Cr_2O_3 films exhibited different time characteristics that were fast and slow respond components, which is mainly caused by its defect level excitations. Moreover, a response of dielectric constant to laser illumination was observed in the Cr_2O_3/Pt planar electrode structure. Rayleigh experiment revealed the concentration of defects of the Cr_2O_3 film increased under laser illumination. Our results suggest that the Cr_2O_3 thin film has a potential application in future photoelectric devices due to its large photo response.

2. Experimental details

Cr_2O_3 thin films were deposited on Si/SiO_2 substrates by radio-frequency magnetron sputtering. The base pressure was lower than 1.0×10^{-5} Pa. Behind the film growth process, a platinum inter-digital electrode was fabricated by electron beam lithography, dc magnetic sputtering and lift-off technology. Finally, the sample was annealed at 500 °C for 1 h. The thicknesses of the Cr_2O_3 layer and Pt electrode were 50 and 80 nm, respectively. The crystal structure of the film was characterized by X-ray diffraction (XRD) with Cu Kα radiation. Atom force microscopy (AFM) measurement was performed by MFP-3D-SA (Asylum Research). UV–vis diffuse reflectance spectrum was recorded by UH4150 (Hitachi) spectrophotometer with an integrating sphere. Magnetic

* Corresponding author.
** Corresponding author.
E-mail addresses: j.miao@ustb.edu.cn (J. Miao), yjiang@ustb.edu.cn (Y. Jiang).

http://dx.doi.org/10.1016/j.jallcom.2017.06.109
0925-8388/

properties were measured by the VersaLab VSM system (Quantum Design, Inc.). The electric measurement was performed on a precision probe station equipped with a commercial laser diode as light source by using a measurement system, which was composed of a GS200 voltage source, an Agilent 34401A and a RS570 amplifier.

3. Results and discussion

Fig. 1(a) shows the scanning electron microscope (SEM) of the sample structure with 50 inter-digital Pt electrodes (finger width of 2 μm, overlap length of 140 μm and finger spacing of 2 μm). Fig. 1(b) shows a XRD θ-2θ pattern of $Si/SiO_2/Cr_2O_3$ structure. The presence of only Cr_2O_3 (1 0 4) and Si (4 0 0) peaks confirms textured growth of the films, which excludes the possibility of other phases. As shown in Fig. 1(c), AFM image of Cr_2O_3 thin film reveals a very smooth surface while the root mean square (RMS) roughness is 0.11 nm. Temperature dependence of the ZFC and FC magnetization of Cr_2O_3 thin films were measured by applying an in-plane magnetic field of 1 kOe, as displayed in Fig. 1(d). From the inset (M-H curve) and M-T curve, the Néel temperature of Cr_2O_3 thin film is around 320 K, close to the bulk Cr_2O_3 ($T_N = 318$ K) [13].

Fig. 2(a) shows the UV–visible diffuse reflectance spectrum of Cr_2O_3 thin films. The energy band gap of Cr_2O_3 thin film is estimated from the tangent line in the plot of the square root of Kubelka–Munk functions F(R) against photon energy [16]. As shown in Fig. 2(b), the tangent line was extrapolated to $(F(R))^{1/2} = 0$, which indicates the energy band gap of Cr_2O_3 thin film is 2.8 eV. However, such energy band gap is smaller when compared with the reported range of 3.08–3.38 eV [17] of Cr_2O_3 thin films fabricated by other different methods.

Fig. 3(a) presents the time dependence of the current of the Cr_2O_3 film with the inter-digital electrodes at incident light intensity of 40 $mWcm^{-2}$ and 10 V voltage bias. As demonstrated by the on/off behavior of the current, an instantaneous current response with a period of 60 s in the $Pt/Cr_2O_3/Pt$ structure is exhibited under light illumination. Interestingly, as revealed in Fig. 3(b), the current-electric field (J-E) characteristic of the $Pt/Cr_2O_3/Pt$ structure presented in logarithmic scales shows a typical photoconductivity response. The excited photocurrent (the blue curve) of the $Pt/Cr_2O_3/Pt$ structure is obtained by subtracting the dark current from the illuminated current. Quantitatively, the photoresponsivity is estimated to be 1.94×10^3 A/W at 10 V voltage bias with incident wavelength of 650 nm. Moreover, the internal photogain of 3.7×10^3 is also estimated from the figure. Surprisingly, both the values of photoresponsivity and photogain in our $Pt/Cr_2O_3/Pt$ structure are higher than other reported photodetectors (1.66 A/W @ZnMgO [18], 1–10 A/W @ZnO [19], 1616 A/W @ZnO [20]).

As known, the concentration of photo charge carriers during the growth process is equal to the generation rate minus the recombination rate which is proportional to the photoexcited carriers. Correspondingly, in the case of decay, the concentration of photo charge carriers is equal to the negative recombination rate. Those

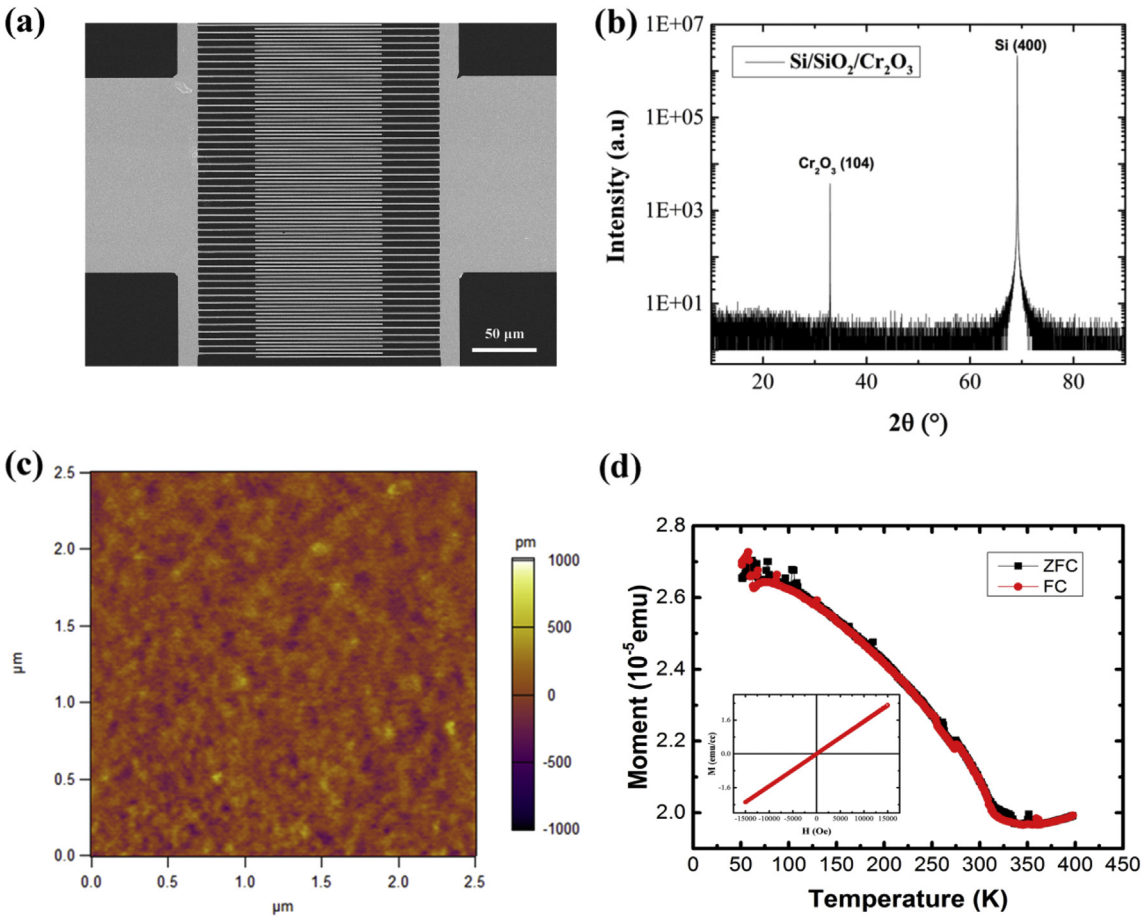

Fig. 1. (a) SEM of sample structure with inter-digital electrodes. (b) XRD θ-2θ pattern of $Si/SiO_2/Cr_2O_3$ structure. (c) AFM scan of Cr_2O_3 thin films. (d) Temperature dependence of the ZFC and FC magnetization measured with an applied field of H = 1T. Inset shows the M-H curve at 300 K.