Available online at www.sciencedirect.com
ScienceDirect
Materials Letters 61 (2007) 4238–4241
materials letters
www.elsevier.com/locate/matlet

Effects of the polarity of bias voltage on the electrical performance of the diamond film detectors

Linjun Wang *, Jianmin Liu, Yanyan Lou, Qingfeng Su, Weimin Shi, Yiben Xia

School of Materials Science and Engineering, Shanghai University, Shanghai 200072, China

Received 21 August 2006; accepted 25 January 2007
Available online 6 February 2007

Abstract

The effect of the polarity of the applied bias voltage on the electrical response and the charge collection efficiency of sandwich structural diamond film detectors under 5.5 MeV ^{241}Am alpha-particle irradiation is investigated. Results show that, under the alpha irradiation the detector applied with a negative bias voltage has a higher response current and a better signal-to-noise ratio than that applied with a positive bias voltage. A better energy resolution of about 25.0% is obtained for the detector applied with a negative bias voltage, and however 38.4% for that with a positive bias voltage. Raman scattering studies demonstrate that these changes with the polarity of the bias voltage may be attributed to the different structural imperfection distributions along the thickness direction of the diamond film.

PACS: 81.05.Uw; 68.55.-a; 81.15.Gh; 29.40.-n; 73.61.-r
Keywords: Thin films; Electrical properties; Chemical vapor deposition; Diamond; Radiation detector

1. Introduction

CVD diamond film is expected to be an ideal material for radiation detectors, because it has many excellent features [1,2]. The potential applications of CVD diamond detectors are being developed in harsh environments [3,4]. RD42 collaboration, comprised of experts from many countries and sponsored by European Laboratory for Particle Physics (CERN), has conducted the research in CVD diamond detectors since 1994. The properties of CVD diamond detectors have been investigated under the irradiation by electron, γ-rays, pions, protons, α particles, and neutrons. Particularly, CVD diamond detectors can be applied in harsh environments, such as the experimental system of ATLAS and CMS included in the Large Hadron Collider (LHC) where conventional detectors cannot be eligible.

It is reported that the charge collection efficiency and the detection sensitivity of CVD diamond detectors are closely related to the quality of the diamond films [5–7]. The defects and the grain boundaries contained in the films which are thought as the trapping and recombination centers for the charge carriers, are the main factors influencing the electrical properties of the detectors. Diamond films with large grains, [100]-orientation or big thickness are believed to be more appropriate for the fabrication of the detectors with good performance [8]. In this work, we study systematically the effects of the polarity of the applied bias voltage on the electrical response and the charge collection efficiency of sandwich structural diamond film detectors. The diamond films we used in our experiments have large grains with [100]-orientation. The goal of this work is to establish the relationship between the operating conditions of the detectors, the film quality and the detector performance, and to provide fundamental basis for CVD diamond alpha-particle detectors with good performances.

2. Experimental

Diamond films are deposited on single-crystalline (100) p-type silicon substrates with a resistivity of 4–7 Ω cm using a hydrogen–acetone precursor mixture in a hot-filament chemical vapor deposition (HFCVD) system. The deposition parameters and the following surface treatments in detail can be found in Refs. [2,9]. The diamond film is then sequentially thermally

* Corresponding author. Tel.: +86 21 56333514; fax: +86 21 56332694.
E-mail address: ljwang@staff.shu.edu.cn (L. Wang).

0167-577X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.matlet.2007.01.104

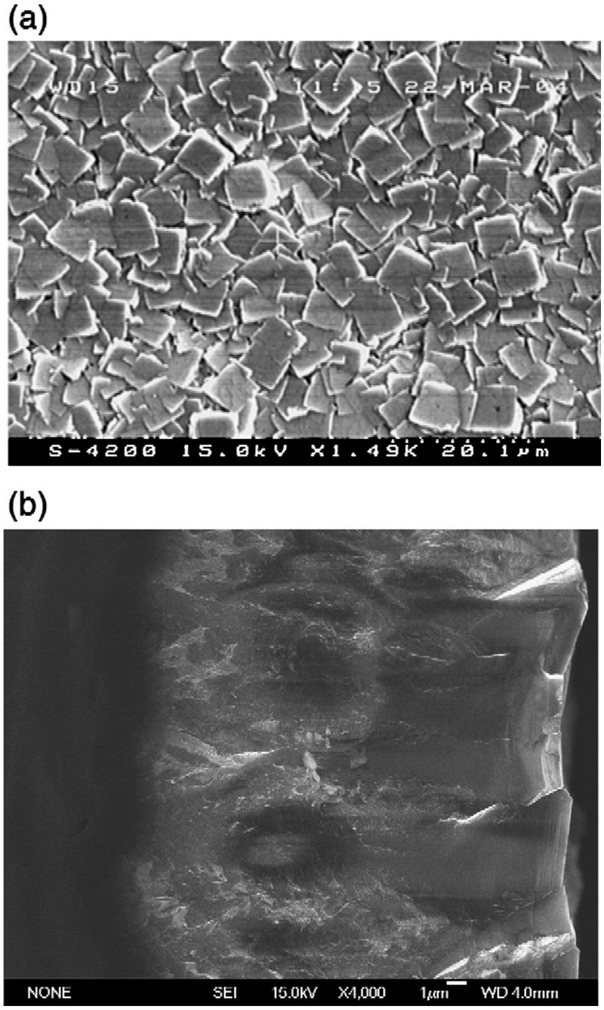

Fig. 1. SEM images of the growth surface (a) and the cross-section (b) of the diamond film by HFCVD method.

evaporated Cr and Au on the final growth side to form a detector with a sandwich structure (metal–diamond–Si). The frontside contact on the final growth side facing α particles is made by thermally evaporating one 1 mm-diameter circle pad of Cr:Au double layers, 50 nm:150 nm thick. In addition to mechanical support, the Si substrate is used as the backside electrode. To obtain ohmic contacts, the sample is annealed at 450 °C in an Ar atmosphere for 45 min.

The film structure is characterized by Raman spectroscopy (HR800). Keithley 4200-SCS is used to measure the current–voltage (I–V) characteristics of the detector in the darkness and 5.5 MeV α-particle irradiation from ^{241}Am source placed above it at a distance of 1 cm in atmosphere at room temperature. The frontside electrode used as the signal output is connected, through an EG and G Ortec 142-IH charge sensitive preamplifier, an Ortec Model 575A spectroscopy amplifier, to a multichannel pulse height analyzer, Ortec Model TRUMP-PCI-2k MCA plug-in card with a computer.

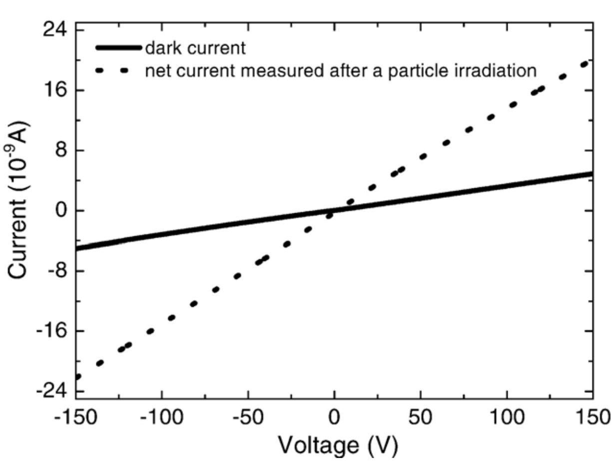

Fig. 2. The dark-current and the net-current introduced by 5.5 MeV ^{241}Am alpha-particle irradiation for the diamond film detector with various bias voltages.

3. Results and discussion

The growth surface morphology of the film observed by SEM indicates a typical microcrystalline structure (shown in Fig. 1(a)) with an average grain size of ~10 μm. It also reveals [100]-textured diamond film, which is also confirmed by XRD. A distinct columnar structure is observed at the cross-section of the film (shown in Fig. 1(b)) and its thickness is about 20 μm. The diamond grains in the nucleation side are obviously bigger than those in the growth side. Generally, [100]-orientated film has better electrical properties and smoother surfaces and is helpful to achieve good performance radiation detectors [10].

The dark-current characteristics as a function of bias voltage for the diamond film detector are shown in Fig. 2. These characteristics appear nearly symmetric and linear both in respect to current and voltage inversion, indicating that a fine ohmic contact important for detectors is formed for bias voltage up to 150 V. Fig. 2 also presents the irradiation response of this diamond detector to 5.5 MeV ^{241}Am α particle, where the net-current denotes the response current which has been subtracted the dark-current from the total current. This response current proportionally increases with the bias voltage due to a linear relationship between the collected carriers and external electrical field, conformed to a simple photo-generation and collection model [11]. Table 1 gives the electrical properties of the detector at a bias voltage of +100 V and −100 V, respectively, where the signal-to-noise ratio (SNR) is defined as the ration of the net-current to the dark-current of the detector. Obviously, the detector at a negative bias voltage (−100 V) has a larger net-current and a larger SNR value. This phenomenon is believed to result mainly from the different structural imperfection distributions between the final growth side and the nucleation side of the diamond film. The effects of structural imperfection distributions of diamond film on alpha particle detection properties have been studied [12]. In this work, the different efficiencies between coplanar and sandwich detectors resulting from the different structural imperfection distributions between the final and the initial growth sides of the diamond film have been elucidated.

Table 1
Electrical properties of the diamond film detector under the bias voltage of ±100 V

Electrical parameters	+100 V	−100 V
Dark-current (nA)	3.3	−3.2
Net-current (nA)	13.6	−15.0
Signal-to-noise ratio (SNR)	4.121	4.688