Available online at www.sciencedirect.com
ScienceDirect
Diamond & Related Materials 17 (2008) 833 – 837
DIAMOND AND RELATED MATERIALS
www.elsevier.com/locate/diamond

Measurement of charge carrier dynamics in diamond thin films using a fast TOF system with a UV pulsed laser

Y. Oshiki [a,*], J.H. Kaneko [a], F. Fujita [a], A. Homma [a], H. Watanabe [b], K. Meguro [c], Y. Yamamoto [c], T. Imai [c], K. Sato [a], K. Tsuji [a], S. Kawamura [a], M. Furusaka [a]

[a] *Hokkaido University, Japan*
[b] *Advanced Industrial Science and Technology, Japan*
[c] *Sumitomo Electric Industries, Ltd., Japan*

Available online 11 January 2008

Abstract

Charge carrier dynamics in CVD homoepitaxial diamond thin films were evaluated. Thicknesses of these thin diamond films were 4.5–14 μm. Measurement was carried out using a fast TOF system with time resolution of 150 ps. This system adopted the localized irradiation mechanism of a 213-nm UV pulsed laser. Induced current caused by charge carrier motion was simulated by a one-dimensional approximation. Then measured signals were analyzed using the physical model of induced current that was confirmed through the simulation. The best lifetimes, τ, of electrons and holes in evaluated diamond films were 1.8 ± 0.3 ns for both charge carriers. However, drift velocities and mean free paths of trapping were not determined because insufficient charge carriers arrived at the further side electrode without trapping.

Keywords: Charge carrier dynamics; Diamond thin films; Drift velocity; UV pulsed laser

1. Introduction

Diamond is an ultimate wide band gap semi-conducting material whose energy gap is 5.47 eV. Diamond has several excellent electric properties including high mobility, high saturation drift velocity and a high breakdown voltage; it also has the highest thermal conductivity. For that reason, diamond is an ideal semiconductor for use in a high-power and high-frequency field effect transistor (FET). A p–i–p type diamond FET [1] and a surface conduction type diamond FET using hydrogen termination have been developed [2,3]. The p–i–p type diamond FET has an advantage in its stability. It has a large amplification factor of currents using a space charge limited current mode [4]. The upper limit frequency of the p–i–p diamond FET is governed by saturation drift velocity of holes in an *i*-layer [5]. Therefore, fabrication of a high-quality *i*-layer is indispensable.

In general, mobilities of charge carriers in semiconductors are measured using the Hall effect. However, it is very difficult to adapt Hall effect measurements to insulating diamond. For that reason, time-of-flight (TOF) method has been widely used. Hole–electron pairs are created in insulating diamond using a pulsed electron beam [6,7], α-particles [8], pulsed X-rays [9], or a UV pulsed laser [10–12]. Then the induced current, which is caused by motion of charge carriers in the diamond's electric field, is measured.

Through progress of laser technology, fast UV pulsed lasers have been widely used for this purpose. Pan et al. evaluated charge carrier dynamics using UV pulsed laser irradiation to a diamond film with two parallel electrodes on the surface [13]. To reduce the influence of the photoelectric effect occurring at electrodes, Isberg et al. used a mesh type electrode as an injection side electrode for a bulk diamond with planar structure [14]. The combination of alpha particle measurement and UV pulsed laser base TOF measurement for bulk diamonds was reported by Fujita et al. [15,16]. They also developed a fast TOF measurement system whose time resolution was 150 ps for thin diamond films. This system adopted a localized irradiation mechanism of a 213 nm UV pulsed laser to reduce the influence of laser irradiation for charge carrier dynamics [17].

* Corresponding author. Division of Quantum Science and Engineering, Hokkaido University, North 13, West 8, Sapporo, Hokkaido, 060-8628, Japan. Tel.: +81 11 706 6678; fax: +81 11 706 6678.
E-mail address: oshiki_y@queen.qe.eng.hokudai.ac.jp (Y. Oshiki).

0925-9635/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.diamond.2007.12.056

For the present study, measurement of charge carrier dynamics in diamond thin films was carried out using the fast TOF system with localized irradiation of a 213 nm UV pulsed laser. Output signals were analyzed according to an induced charge current model evaluated using a simulation.

2. Experimental

2.1. Diamond films

Diamond films used in this study are described in Table 1. All films were synthesized on (100) surfaces of high-temperature and high-pressure (HP/HT) type Ib single diamond substrates using microwave-plasma assisted chemical vapor deposition (CVD) method. The CVD homoepitaxial diamond films ID #1, 5, 6, and 7 were synthesized using low methane concentration, with the intention of producing high-quality diamond. Diamond films ID #2, 3, and 4 were synthesized using high growth rate conditions [18]. As shown in Fig. 1a) and b), the former diamond films have many unepitaxial crystallites over the surface; the latter diamond films are smooth without any unepitaxial crystallite.

In this study, measurement of saturation drift velocities of holes had priority. For that reason, a Schottky electrode of Pt and an Ohmic electrode of TiC/Au shown in Fig. 1b) were adopted to give higher bias voltage.

The Schottky electrode was biased, and output signals were measured at the Ohmic electrode. The gap between the two parallel electrodes was 500 μm or 1000 μm.

2.2. TOF measurement system

Fig. 2 portrays a schematic drawing of a fast TOF measurement system. This system used fifth harmonics of a Nd:YAG laser with 213 nm wavelength for generation of hole–electron pairs. The pulse width was *circa* (ca.) 100 ps. The UV light was formed to a sheet shape of ca. 50 μm width, as shown in Fig. 3; the irradiation position was controlled using a mechanical stage with position accuracy of 5 μm. The contribution of each charge carrier to an output signal was changed according to the traversing distance. In addition, the localized UV light irradiation mechanism suppressed the photoelectric effect that occurred at electrodes. The induced current caused by charge carrier motion was converted to a voltage signal by impedance of a coaxial cable of 50 Ω. Subsequently, output signals were measured using a digital storage oscilloscope (the input impedance: 50 Ω : Wave Master 8600AS; LeCroy Corp.) whose analog bandwidth and sampling frequency were, respectively, 5 GHz and 20 GS/s. The total time resolution of the system was 150 ps. A diamond sample and the oscilloscope were connected using a semi-rigid coaxial cable to reduce RF noise.

Table 1
CVD diamond films used in this study

Sample ID	Thickness (μm)	CH_4/H_2 ratio (%)
#1*	4.5	0.5
#2**	14	10
#3**	5	9.5
#4**	10	9.5
#5*	5.9	1
#6*	5.9	0.15
#7*	5.9	0.15

All samples were synthesized on a HP/HT type Ib single diamond substrate.
Manufacturer: *AIST, **Sumitomo Electric Industries, Ltd.

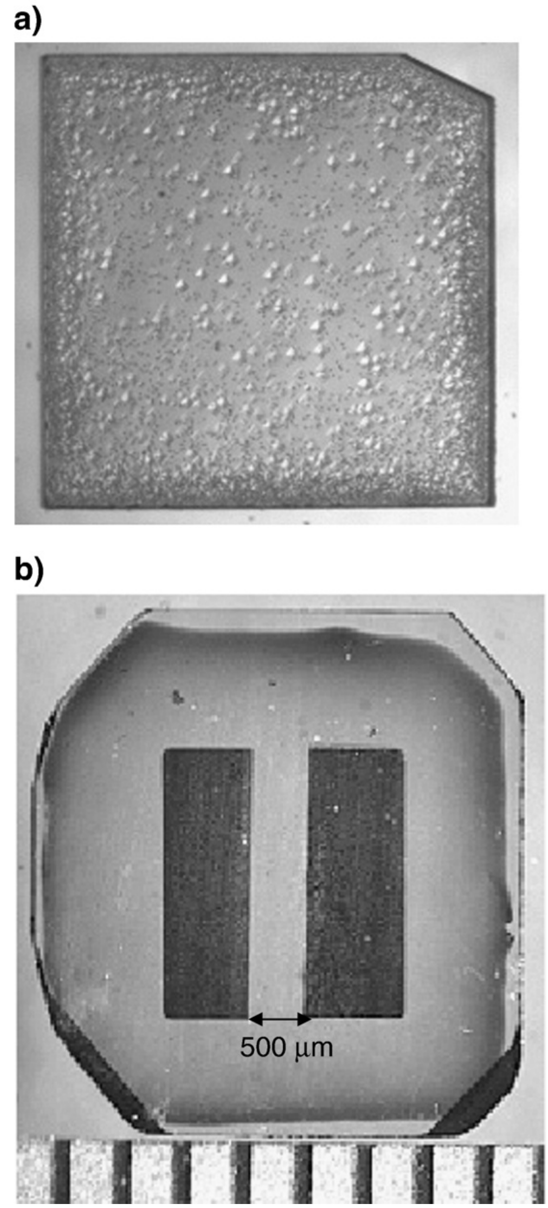

Fig. 1. Optical micrograph a) sample #1, b) sample #5 with Pt Schottky and Ti/Au Ohmic electrodes. The sample #1 surface was covered by many nucleations.

3. Simulation and analysis of output signals

Simulation for output signals was carried out to determine an analysis method. One-dimensional approximation was adopted in this simulation. Charge carriers were assumed to be created in a finite size by a UV pulsed laser between two infinite long electrodes set parallel to one another. The gap separating the