Available online at www.sciencedirect.com

SCIENCE DIRECT

Diamond & Related Materials 14 (2005) 556–560

DIAMOND AND RELATED MATERIALS

www.elsevier.com/locate/diamond

Mechanism of photoconductivity in intrinsic epitaxial CVD diamond studied by photocurrent spectroscopy and photocurrent decay measurements

Z. Remes[a,b,*], R. Petersen[c], K. Haenen[a,c], M. Nesladek[a,c,d], M. D'Olieslaeger[a,c]

[a]Institute for Materials Research (IMO), Limburgs Universitair Centrum, Wetenschapspark 1, B-3590 Diepenbeek, Belgium
[b]Institute of Physics, Academy of Sciences of the Czech Republic, Cukrovarnicka 10, 16200 Praha 6, Czech Republic
[c]Division IMOMEC, IMEC vzw, Wetenschapspark 1, B-3590 Diepenbeek, Belgium
[d]LIST (CEA-Recherche Technoloqique)/DETECS/SSTM, CEA/Saclay, Bat 451, Gif-sur-Yvette 91191, France

Available online 28 January 2005

Abstract

We report experimental results on photocurrent spectra and the transient decay of photocurrent in intrinsic CVD diamond films grown homoepitaxially on natural, (100) oriented, single crystal type IIa diamond substrates. The detectors fabricated from these layers were developed in the frame of the LYRA project (the LYman-alpha RAdiometer onboard the European satellite PROBA-2) and will be used in space for UV solar monitoring. The typical photosensitivity is about 10^{-2} A/W at 200 nm and 10^{-6} A/W at 300 nm; the typical response time well below 0.1 ms. The enhance in photosensitivity, related to defects in CVD diamond layer and accompanied by long, non-exponential tails in photocurrent transients (persistent photocurrent), is observed in some detectors. The enhancement in photosensitivity also correlates with a long effective lifetime of photo-excited carriers. New defects at about 3.8 eV and another at about 4.3 eV are observed in the photocurrent spectrum of the sample with enhanced photosensitivity.

Keywords: Detectors; Homoepitaxy; Optical properties characterization; Electrical properties characterization

1. Introduction

Diamond is an interesting semiconducting material with rather extreme optical and electronic properties. The wide band gap, high carrier mobility and radiation hardness suggest that diamond is an ideal material for the fabrication of photodetectors [1,2] which respond to deep UV light (<225 nm) while being "visible blind", i.e. having a low sensitivity for the visible and infrared part of the spectrum. It is well known, that the electronic properties of diamond are influenced by recombination and trapping of free carriers on defect-induced localised states in band-gap [3,4]. The exact picture of defects in diamond is not complete yet. However, the chemical vapour deposition (CVD) offers a technology for producing high-quality, intrinsic homoepitaxially grown layers on single crystal diamond substrates under tightly controlled conditions. LYRA (the Lyman-alpha Radiometer, see http://lyra.oma.be) is the diamond-based solar UV radiometer that will embark in 2006–2007 onboard PROBA-2-(PRoject for OnBoard Autonomy), a technologically oriented ESA space mission. The detectors developed in the frame of the LYRA project will be the first diamond detectors in solar space physics to monitor the solar irradiance at Lyman-alpha (121.6 nm), and 10–200 nm ranges [5].

In this paper we present the results of two complementary tests made on LYRA detectors. In the first test, the sub-band gap defect density is monitored by photo-current spectroscopy. In the second test, the lifetime of photo-excited carriers is measured by the transient decay of photo-excited current.

* Corresponding author. Institute of Physics, Academy of Sciences of the Czech Republic, Cukrovarnicka 10, 16200 Praha G, Czech Republic. Tel.: +420 220318516; fax: +420 233343184.
E-mail address: remes@fzu.cz (Z. Remes).

0925-9635/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.diamond.2004.12.036

2. Experimental

The CVD intrinsic layers (about 1 μm thick) were grown homoepitaxially at IMO/IMOMEC on selected natural, type IIa (100) oriented, single crystal diamond substrates (diameter 5 mm, thickness 0.5 mm) in a stainless steel chamber reactor (ASTeX). The process parameters were a pressure of 100 Torr, a substrate temperature around 700 °C, microwave power of about 600–620 W and a low methane-to-hydrogen concentration (1 sccm CH_4; 500 sccm H_2, 99.9999% purity). Prior the contact deposition all layers have been oxidised in boiling H_2SO_4+KNO_3 solution to clear the surface. The 1 μm wide, 5 μm separated interdigitated Ti/Pt/Au (20/10/80 nm) contacts were deposited on the CVD diamond surface by photolithography at *Garching Analytics, GmbH*, München, Germany. The short distance between contacts enhances photosensitivity, limits the electric filed penetration into the substrate and reduces the substrate photoresponse.

The DC photosensitivity (in A/W) at wavelength range below 230 nm was calibrated at the Physikalisch-Technische Bundesanstalt (PTB) Laboratory, Berlin, Germany (BESSY II synchrotron). The sub-band-gap photocurrent spectra in the 210–1000 nm wavelength range were measured at IMO/IMOMEC. A schematic representation of the set-up can be found in Ref. [6]. In short, the monochromatic light is generated by using a water-cooled UV-enhanced 150W Xe lamp and Acton Research Spectra Pro 275 monochromator. A mechanical chopper modulates the light intensity (typically at 10 Hz). This enables the use of lock-in techniques for photocurrent detection. A spectrally independent CaF_2 beamsplitter directs about 10% of the monochromatic light towards a spectrally independent, calibrated pyrodetector to monitor the incident light intensity that varies from 10^{-4} W at 830 nm to 10^{-6} W at 210 nm.

The photocurrent decay in time scale above 0.1 s (slow component of photo-current decay) was measured using a Keithley 6514 electrometer with sampling speed 2500 readings in 170 s and a blue LED diode (total light output about 1 mW). The photocurrent decay (after illumination by full light from the 150W Xe lamp in continuous regime) in time scale 0.1–100 ms was measured by a Tektronix TDS 620B oscilloscope via 100 kΩ resistor. Short open/close time (0.1 ms) was achieved by a combining fast chopping frequency and a small spot size of focused light. The periodic nature of the measured signal allowed improving the signal/noise ratio by averaging over 100 periods.

3. Results and discussion

The main parameter to evaluate the photosensitivity of a semiconductor-based photo resistor with ohmic contacts is the gain $G=L/D$ (Ramo's theorem [7]), where L is an average total distance that the free carriers move apart under the action of applied voltage U (5V for LYRA detectors) before recombination and D is distance between contacts. Since $L=\mu\tau\ U/D$, the gain $G=\mu\tau\ U/D^2$. Here, μ is the drift mobility and τ lifetime of photoexcited carriers. In addition to gain, the photocurrent I is also proportional to the light intensity P and the absorption coefficient α. Thus, the sub-band-gap photocurrent sensitivity can be increased not only by increasing the optical absorption coefficient, but also by increasing the lifetime of photoexcited carriers.

Fig. 1 shows the normalised photocurrent spectra of three selected detectors, corrected for the spectral response of the system. The photosensitivity in all samples has its maximum at about 6.2 eV (200 nm) and varies from 2.7×10^{-2} A/W to 1.4×10^{2} A/W (see also Table 1, discussed further). The photosensitivity at 300 nm (below the absorption gap) varies from 1.8×10^{-6} A/W to 4.0×10^{-3} A/W. It has been reported previously, that CVD diamond often contains some residual nitrogen or boron [8,9]. By detailed inspection of Fig. 1 we can see that the photocurrent in our CVD layers show a characteristic onset of absorption at about 2.2 eV that is practically identical to the onset of the optical absorption in nitrogen-rich single crystal HPHT Ib diamond as measured by photothermal deflection spectroscopy [10]. The optical absorption in CVD diamond in the visible part of the spectrum has been associated with the electron photo-ionization from a N-related defect (the single-substitutional nitrogen) with well-known electron paramagnetic resonance

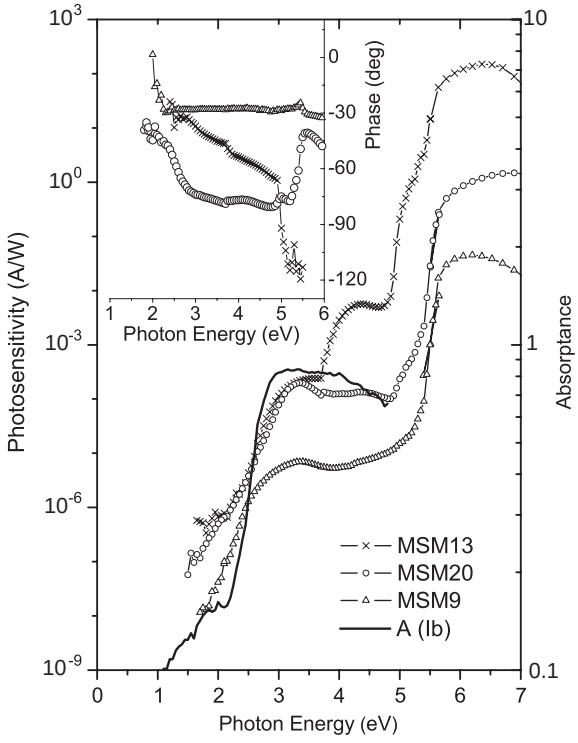

Fig. 1. The photosensitivity spectra of selected LYRA detectors under 5V bias voltage measured in DC mode above the diamond absorption edge (5.5 eV) and in AC mode (10 Hz) below 6 eV. Both the normalised photocurrent as well as the AC photocurrent phase are shown. The optical absorption spectrum (A (Ib)) of a single crystal HPHT Ib diamond (Sumitomo, 0.5 mm thick, about 10^{19} N/cm^3) has been added for comparison.