The investigation of boron-doped diamond absorbance spectrum

A S Aksenova¹, A A Altuhov², E V Ryabeva¹, V T Samosadnyi¹, V S Feshchenko², A P Chernyaev¹ and V A Shepelev²

¹ National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
² LLC PTC UralAlmazInvest, Ivan Franko street 4, Moscow, 121108, Russia
³ Lomonosov Moscow State University, Leninskie Gory 1, Moscow, 119991 Russia

E-mail: axenova.anastasia@gmail.com, VTSamosadny@mephi.ru

Abstract. The trend of using of radiation with shorter wave length in leading high technological processes demands the detected search of materials for the solid-state electronics equipment and optical systems of an ultra violet and vacuum ultra violet spectral range. Diamond photodetectors of ultra violet radiation have the advantage of their opponents due to their unique properties, such as high sensitivity at the range of 190–250 nm and low sensitivity to the solar irradiation. The modification of semiconductive diamond material properties by the doping to get photodetectors with the different width of photosensitivity range is of a great interest. Due to this fact the spectroscopic investigation of artificial diamonds doped with boron took place for the definition of their applicability to produce the wide-spectral photosensitive equipment. The samples of thin diamond films were cut out in a crystallography plane (001). Sample transmission spectra were measured by vacuum infrared Fourier transform spectrometer at the range of 400–7000 cm⁻¹. As a result it was explored that diamond based detectors doped with boron could be applied for the detection of infrared irradiation at the average infrared spectral range, however it is necessary to optimize the doping level of produced diamond materials to reach the compromise between the sensitivity and the speed capability of diamond photodetectors.

1. Introduction

The trend of using of radiation with shorter wave length in leading high technological processes demands the detected search of materials for the solid-state electronics equipment and optical systems of an ultra violet and vacuum ultra violet spectral range [1,2]. Diamond photodetectors of ultra violet radiation have the advantage of their opponents due to their unique properties, such as high sensitivity at the range of 190–250 nm and low sensitivity to the solar irradiation (the ratio of sensitivity to visible light is 5 order-of-magnitudes less then to ultra violet radiation), high-mobility of charge carriers of electrons (<2500 cm²/V·s), and of electron holes (<2100 cm²/V·s), high thermal conductivity (2000 W/(m·K)) [2]. Besides, the diamond possesses unprecedented hardness, chemical resistance, and radiation stability.

However, the rapid development of diamond instrumentation is being prevented by lack of prize appropriate films of the artificial monocrystalline diamond and by the difficulty of the controlled directed doping with p- and n-type doping agents, which are entirely activated at the ambient temperature [3].
Accordingly, the modification of semiconductive diamond material properties by the doping to get photodetectors with the different width of photosensitivity range is of a great interest.

The diamond doping process with different doping agents is considered in depth in literature, for instance [3]. The most important doping agent for a diamond is boron, as it is easily doped into a diamond [3]. Besides, boron forms a rank of shallow levels in a band-gap [2]. Boron-doped diamonds occur naturally [3] as so called IIb-type blue diamonds. Last time it occurred lots of messages about boron-doping of artificial diamonds while growth process is going [5]. From this perspective spectral measurements of boron-doped artificial diamonds were set to define the practicability of these ones for the producing of wide-spectral photosensitive equipment.

2. The subject of research

Diamonds produced by the corporation LLC "New Diamond Technology", St. Petersburg, were used for experimental spectral investigations of thin boron-doped diamond material films.

The samples of thin boron-doped diamond films were cut out in a crystallography plane (001) and polished to get plates of 310–345 μm in thick while HPHT process is going. There are plate-forms on figures 1–4 sketched out by visual augmentation system. Plates have zonal structure that is typical for HPHT crystals. There is a growth four-square slice (001) in the center. The material volume is formed by {111}-type growth sectors drawing up the Maltese cross in directions of <110> of a growth sector (001). Also there are {110}-type and {100}-type growth sectors in directions of <100>. It is well known, that while HPHT process is going, growth sectors differ by impurity capture (including boron). Boron concentration in (001)-type and while {111}-type growth sectors may differ by 1.5-2
orders-of-magnitude. It occurs as different blue-color saturation of growth sectors in visual light. The median concentration of neutral p-type boron-doping is $(0.9\pm0.1)\times10^{17}\text{cm}^{-3}$ in studying films.

3. Research task
The investigation of boron-doped artificial diamond absorbance spectrum is to estimate its effect on photosensitivity spectrum of diamond-films-based hypothetical equipment.

4. Measurement routine
Samples CTB 1–4 transmission spectra were measured by vacuum infrared Fourier transform spectrometer at the range of 400–7000 cm$^{-1}$ with diaphragm diameters of 1 mm and 2 mm. All sample spectra seem to be close.

In this case:
- All the measurements are taken by light inside system, i.e. the contribution of layers in different depth are summarized. Particularly, that is important for (001) HPHT crystal plates where growth layers and bands of growth sectors are under angle to the plate-plane.
- Diaphragm diameters of 1–2 mm are used for measurements, that are covering sections of several growth sectors with different impurity content.

5. Measurement results
We consider boron-doped diamond absorbance spectrum in terms of its appliance in multispectral observation devices (figure 5).

![Figure 5. Boron-doped diamond absorbance spectrum (transmission spectrum of pure IIa-type sample is deducted).](image)

Absorbance spectrum has following peculiar properties [4]. There is a specific set of absorption peaks of 7.75, 4.07, 3.57, 3.41, 2.68, 2.44 μm. The peak of 3.41 μm (0.36 eV) corresponds to the ionization of p-type boron dopant. Absorbance is spreading upward of quantum energy; it connected with electron hole transition into different valence band levels and with absorbance in free holes. The peaks of 7.75, 4.07, 3.57 μm correspond to acceptor transition to excitation levels. It is important to note, that the absorbance presented on figure 5 is in response to isolated, substituting, uncompensated, nonionized boron, i.e. neutral acceptor boron. Consequently, after absorbing of electromagnetic rays, a diamond will produce photoelectric current.

The same diagram with superimposed atmospheric-transmission band at infrared range spectrum is presented on figure 6. As we could see, several boron acceptor absorbance peaks refer to atmospheric transparency windows. The peak of 2.44 μm refers to atmospheric transparency window of 2–2.5 μm,
and the peaks of 3.57 and 4.07 μm refer to atmospheric transparency window of 3–4.2 μm. Proceeding from the above detectors based on boron-doped diamond could be applied for detecting of infrared radiation at the average infrared spectral range.

Figure 6. Boron-doped diamond absorbance spectrum (transmission spectrum of pure IIa-type sample is deducted) with superimposed atmospheric-transmission band. Atmospheric transparency windows are marked with white colour.

By increasing doping level of a diamond, film peaks will diffuse. That will raise agreement state of spectral-response characteristic of diamond photodetector with atmospheric transmission spectrum, i.e. it will raise detector sensitivity to object irradiation with uniform infrared spectrum. However, increasing of doping level of a diamond leads to decreasing of charge carrier mobility. Considering this fact, it could have an effect on detector sensitivity and speed capability. In relation to it, it is necessary to optimize the doping level of diamond materials to reach the compromise between the sensitivity and the speed capability of produced diamond photodetectors.

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