

Investigation of secondary electron emission of a monocrystal diamond for creation microchannel devices with high quantum efficiency

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ABSTRACT

Possibility of use and advantages of a monocrystal diamond (HPHT and CVD) as highly effective secondary emitter are shown in this paper. The maximum secondary electron emission (SE) coefficient about 14 at working accelerating voltage is received (several times exceeds SE coefficient of used materials, such as silicon), lack of dependence on diamond type is shown, dependence on current of primary beam is revealed.

The main goals of experiments were to establish optimal characteristic of primary beam (such as energy of primary beam and current) and sample preparation for achievement the maximum coefficient of secondary emission (SE coefficient). Data of experiments were analyzed and our group developed an optimum technique of preparation of a diamond samples surface for use as secondary emitters.

Taking into account outstanding diamond characteristics there is a possibility for creation unique and highly effective detectors and converters based on effect of SE.

Keywords: secondary emission, electron affinities, diamond, surface states.

1 INTRODUCTION

Wide band gap materials have attract interest as materials with high quantum efficiency due to their low or negative electron affinity (NEA), when the bottom of a conduction band is above vacuum level, so low-energy electrons in conduction band should be emitted in vacuum without energy loss.

In general, metals and semiconductors are relatively poor secondary-electron emitters, but wide band gap materials (insulators), on the contrary, are very good in this effect [1]. Carbon provides an excellent example in this tendency. For example, carbon in graphitic form is one of the poorest secondary-electron emitters : the maximum SE coefficient is about 1.0 for graphite and 0.45 for soot [2]. But diamond, wide band gap material, exhibits an unusually

high secondary-electron coefficient: in some articles authors report that the SE coefficient of monocrystal diamond is about 100 [3]. For comparison, a table of the coefficient of secondary electron emission from insulators shows that the previously known highest value is 23, measured on crystalline MgO [1].

Recent researches in the field of a monocrystal diamond growth made this material cheaper. CVD process is actively used now for production depreciation. The fact that price was dropped allows us to use diamond more widely for creation modern electronics with outstanding characteristics.

Therefore, use of diamond as high-effective multiplier of electron current looks perspective.

2 DESCRIPTION OF DIAMOND SAMPLES AND MEASUREMENTS

In this paper we investigated different types of diamond : various levels of concentration of boron (type IIb) and nitrogen (type Ib), various orientation directions, clear and hydrogenated diamond surfaces, samples grown by using HPHT and microwave-plasma CVD methods. CVD diamonds were grown by use HPHT diamond monocrystal substrates.

For the first experiment the following samples were prepared (Table 1) :

Number	Type	Orientation	H-termination
1	IIb	(001)	Yes
2	IIb	(001)	No
3	IIb	(001)	No
4	IIa	(110)	Yes
5	IIa	(001)	No

Table 1: Diamond sample comparison.

Thickness of a diamond plates was from 300 microns to 500 microns. Thus, thickness of plates transcended interaction depth with primary electron beam and secondary electron emission from a diamond plate was measured.

It is known that surface properties of diamond essentially depend on preparation methods and sequence of operations. Annealing in the atmosphere of hydrogen changes physical and chemical properties of diamond surface (H-termination) that is characterized by negative electronic affinity appearance when the bottom of conductivity band is above vacuum level. It is expected that similar preparation has to improve significantly secondary electron emission from diamond since there will be no energy dissipation of electron output from a conductivity band to the vacuum.

Thus, some of plates were terminated by hydrogen (H-termination) in CVD installation. The mode of annealing was chosen the following: 1) heating from room temperature to 800 °C for 30 minutes, 2) then plates was kept at 800 °C for 5 minutes, 3) the subsequent cooling. It allowed to compare coefficients of secondary electron emission of H-terminated samples and samples with free surface. Before H-termination, all samples were polished, consistently washed in acetone and isopropyl alcohol. Samples with free surfaces were washed and polished the same methods.

For investigation scanning electronic microscopes FEI Quanta 200 and Tescan Vega 3 SBH were applied, which allowed to use all required range of energy (from 200 eV to 30 keV) of primary electron beam, had necessary outputs for measurements, movements of positional table on five independent axes (X, Y, Z, rotation and turn with high precision) and standard detector of true and secondary electrons for visualization of areas with various coefficient of secondary electron emission.

Our group investigated possibility of use of various measurement schemes, but the best measurement of low-energy electrons, the best shielding from undesirable breakthroughs on measuring wires and devices were in the scheme specified in Figure 1.

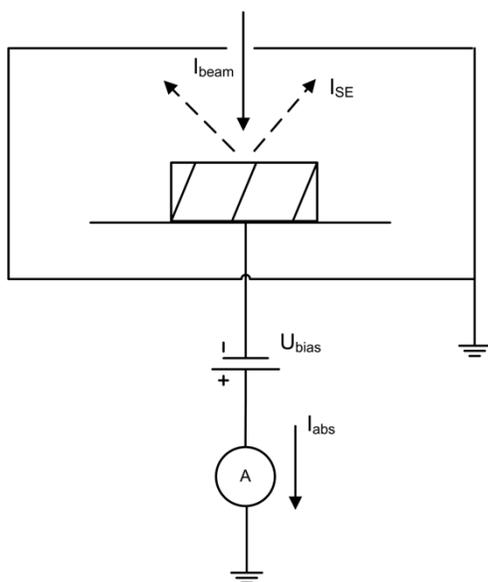


Fig.1 Schematic model of experiment.

As in a microscope the set of various detectors (detectors of secondary and the low-loss electrons, x-ray and optical quanta, the screen for electronic diffraction, etc.) is established with their own power supply or voltage shift, distribution of electric field inside chamber is very difficult to calculate. Therefore, to predict a trajectory of movement of secondary electrons in advance is impossible. In order not to consider influence of internal elements of a design of a microscope on collecting secondary electrons, the grounded screen near a sample was installed.

At research of samples with insufficient conductivity there is possible accumulation of a surface charge near interaction area of a primary beam with a sample. For example, if coefficient of secondary electron emission is more than 1.0, a surface of a sample charges positively. So, surface charge distorts local distribution of electric field near interaction area. This field tries to return the secondary electrons back. Owing to energy distribution of secondary electrons in their range low-energy electrons with kinetic energy less than 100 eV prevail. Thus, existence of positive charge on a sample surface can significantly distort measurements of coefficient of SE since we can't measure a beam of secondary electrons which return back to a sample. This process is shown in Figure 2. For the solution of this problem it was offered to apply negative potential of shift that would allow to minimize process and influence of charging on collecting secondary electrons.

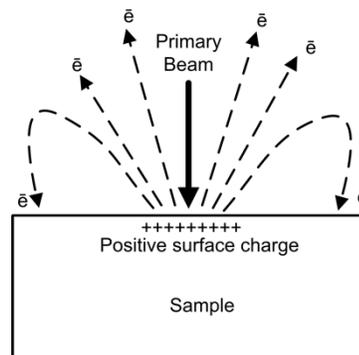


Fig.2 Process of surface "charging" of a sample.

So, we can measure SE coefficient being based on the following reasons. The electron gun of SEM creates a beam of primary electrons and described by I_{beam} current. At interaction of primary electron beam with a sample from its surface layer secondary electrons are beaten out to the vacuum. This beam is described by I_{SE} current. If we control the absorbed current of I_{abs} , i.e. to measure current transmitted through a table, according to Kirchoff's law we can write :

$$I_{abs} = I_{beam} - I_{SE} \quad (1)$$

So, the stream of secondary electrons equals :

$$I_{SE} = I_{beam} - I_{abs} \quad (2)$$

And, respectively, a coefficient of secondary electron emission equals :

$$K_{SE} = \frac{I_{SE}}{I_{beam}} = \frac{I_{beam} - I_{abs}}{I_{beam}} = 1 - \frac{I_{abs}}{I_{beam}} \quad (3)$$

Value of primary beam current remains only conditionally constant therefore when we change accelerating voltage, current of a beam must be controlled by means of Faraday cup. Negative shift in the scheme was made by constant battery of 40 V. Value of currents was measured by using multimeter Keithley 2612A.

3 SECONDARY ELECTRON EMISSION MEASUREMENT

3.1 The First experiment

At the beginning, efficiency of secondary electrons creation was estimated by means of the built-in detector of true-secondary electrons on brightness of the received image. In Figure 3 images of samples No. 1, No. 2 and No. 3 are given, in Figure 4 – No. 4 and No. 5.

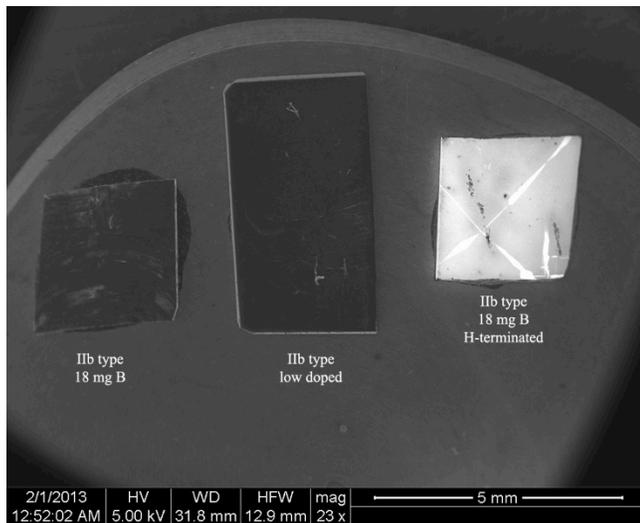


Fig.3 Comparison of secondary electron emission efficiency from IIb diamonds.

Apparently from figures, assumptions of increase of secondary electron emission coefficient at H-termining of a surface of diamond completely were confirmed. Thus, the observed increase occurs as on high-pure (dielectric), and the doped (conductive) samples. Also it should be noted that after H-termination in the picture of secondary electron emission the areals of diamond growth was obviously shown.

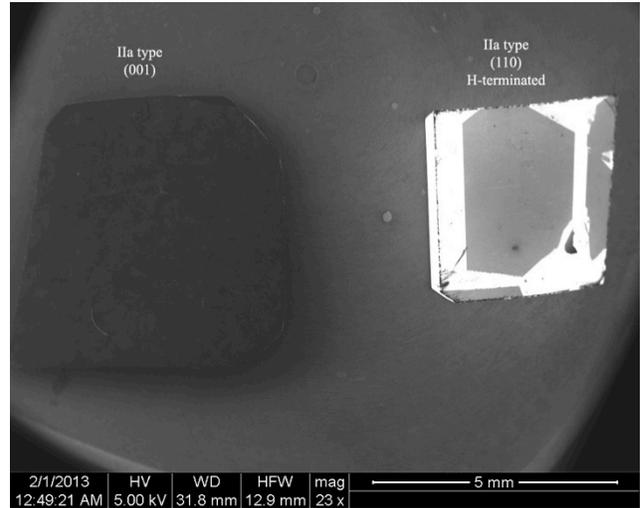


Fig.4 Comparison of secondary electron emission efficiency from IIa diamonds.

Further measurements of dependence of secondary electron emission coefficient (according to the scheme shown in Figure 1) from current of primary beam were carried out at two accelerating voltage of 1 kV (Figure 5) and 10 kV (Figure 6). Apparently from the figures, both samples, which surfaces were H-terminated, have coefficient of secondary electron emission 4-5 times higher, than other samples with an unprepared surface. Thus, the difference between doped and high-clear diamonds isn't revealed. It's important to note that we found dependence of secondary electron emission coefficient on current of primary beam on both samples with H-termination.

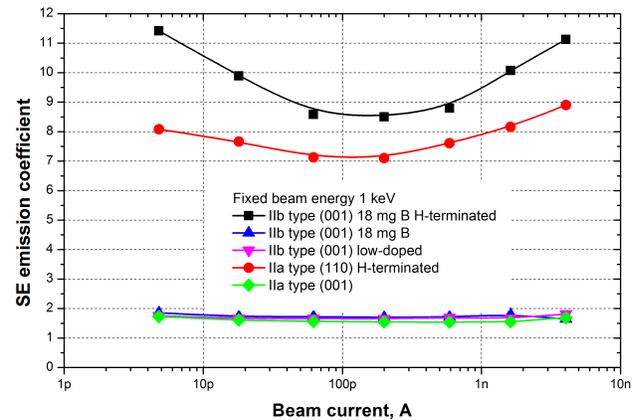


Fig. 5 Dependence of secondary electron emission coefficient on current of primary beam (1 kV).

Also attempt to measure dependence of secondary electron emission coefficient on an angle of primary beam of electrons was made. However, the received dependence differs from theoretically expected (see Figure 7) that can be explained by change of a sample area of the analysis at rotation. Thus, for the next area real value of secondary

emission coefficient can differ or can have another condition of charging.

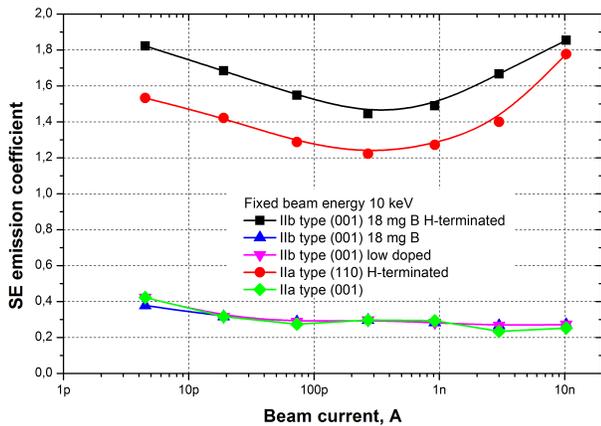


Fig. 6 Dependence of secondary electron emission coefficient on current of primary beam (10 keV).

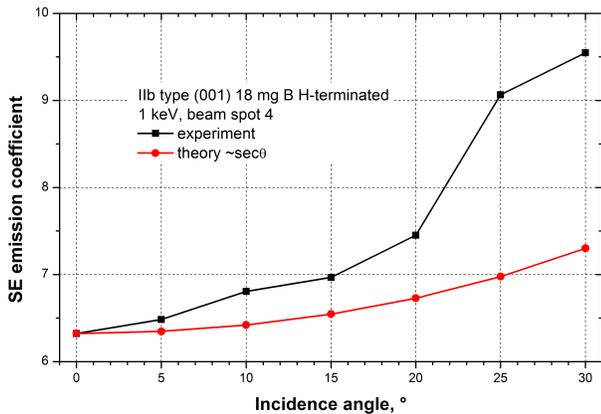


Fig.7 Dependence of secondary electronic emission coefficient on an angle of primary beam.

3.2 The Second Experiment

For the second experiment the following samples were prepared (Table 2) :

Number	Type	Orientation	H-termination
2	IIb	(001)	Yes
5	IIb	(001)	Yes
6	IIb	(001)	Yes
7	IIb	(001)	Yes
8	CVD	(001)	In the process of growth

Table 2: Diamond sample comparison.

Methods of preparation were as in the previous experiment, but temperature of process changed in range from 475 °C and to 850 °C.

Using the scheme shown in Figure 1, dependence of secondary electron emission coefficient on the accelerating potential were established. The comparative graphic chart for diamond samples in all range of the accelerating tension available on this SEM was graphed. Results are shown in Figure 8.

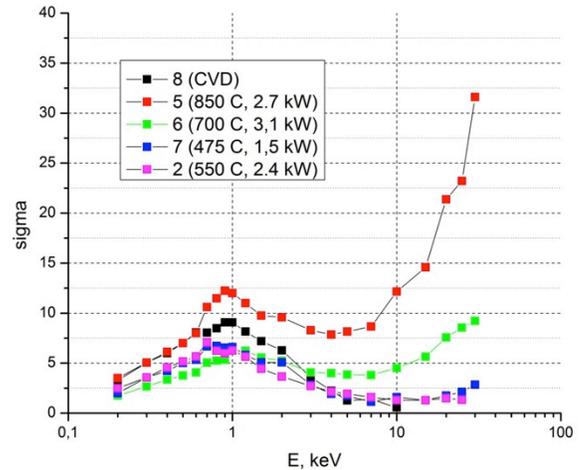


Fig.8 Comparative analysis of secondary electron emission coefficients.

It is necessary to note an existence of dependence of secondary electron emission coefficient from temperature of process of H-termination. When the process temperature was higher, secondary electron emission coefficient was higher too at the same accelerated voltage.

4 CONCLUSION

Thus, in this work possibility of creation of highly effective secondary emitters for production of the advanced electronics is shown. But the set of questions and technical details remain undecided and require further researches.

REFERENCES

- [1] O. Hachenberg and W. Brauer, "Advances in Electronics and Electron Physics", Academic, p. 413, 1959.
- [2] H. Bruining, "Physics and Applications of Secondary Electron Emission", New York, 1954.
- [3] D. P. Malta, J. B. Posthill, T. P. Humphreys, M. J. Mantini, and R. J. Markunas, MRS 1995 Fall meeting, Boston, 1995.