MEASUREMENT OF THE SECONDARY EMISSION YIELD OF A THIN DIAMOND WINDOW IN TRANSMISSION MODE*

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Abstract

The secondary emission enhanced photoinjector (SEEP) is a promising new approach to the generation of high-current, high-brightness electron beams. A low current primary electron beam with energy of a few thousand electron-volts strikes a specially prepared diamond window which emits secondary electrons with a current two orders of magnitude higher. The secondary electrons are created at the back side of the diamond and drift through the window under the influence of a strong electrical field. A hydrogen termination at the exit surface of the window creates a negative electron affinity (NEA) which allows the electrons to leave the diamond. An experiment was performed to measure the secondary electron yield and other properties. The results are discussed in this paper..

INTRODUCTION

The creation of high average-current, high brightness electron beams is a key technology for a large number of accelerator-based systems, such as ultra-high-power Free-Electron Lasers (FELs), Energy-Recovery Linac (ERL) light sources, electron cooling of hadron accelerators, and many more.

Fig.1 shows a schematic layout of such a device.

The laser light illuminates on a high-QE photocathode, such as CsK_2Sb. The primary electrons produced on the photocathode are accelerated to a few thousand electron-volts by the DC field applied between the photocathode and a diamond window. The primary electrons penetrate the thin metal film deposited on the backside (left side) of the diamond window and produce in the diamond a large number of secondary electrons. The Secondary Electron Yield (SEY) can be more than 100. The secondary electrons drift through the diamond under a high RF electric field and emerge into the accelerating proper of the "gun" through a Negative Electron Affinity (NEA) [1] surface of the diamond.

Most of the work on Secondary Electron Emission (SEE) from diamond has been in the reflection mode where the primary and secondary electrons are on the same side of the sample with no external electric field. But for SEEP application the electron must go through diamond.

In general, diamond may has the following defects: foreign substitutional atoms, e.g., B, N and P, foreign interstitial atoms, e.g., H and Li, self-interstitial interstices, vacancies and grain boundaries, which are formed by group of interstices.

The defects generate states with energy levels in the band gap. When charge carriers (electrons or holes) move though the lattice, they can be captured by the defects. Once the carriers are captured by defects, they can be released by thermal excitation or light. The release time can be much longer than the capture time.

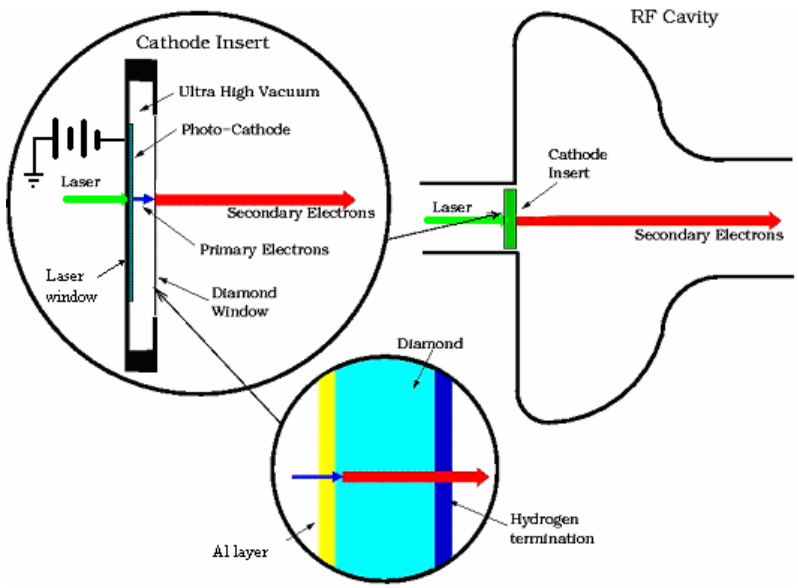

Figure 1: The schematic of the secondary emission enhanced photo-injector

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Trapping creates space charge and partially compensates the external field (field shielding). It also generates dark currents and heat. The trap concentration in the diamond must be small for the diamond amplified cathode application.

It is expected that the single crystal diamond with high purity would have the best electron (and hole) transmission.

THE EXPERIMENTAL SETUP

The test setup is schematically shown in Fig.2. The diamond is coated on both sides with aluminum. The stainless steel (SS) plates, which are isolated from one another by kapton films are pressed against the aluminum films. They are mounted onto a sample holder and placed in a vacuum system. The electrodes are connected to the SS plates and are led out of the vacuum so that one can apply voltages on the aluminum films and measure the currents. The primary electrons are emitted from a 0~5keV electron gun. The primary electrons strike the front side (right side) of the diamond with current ranging from 0 to 10μA. The minimum spot size of the primary electron beam is less than 1mm in diameter.

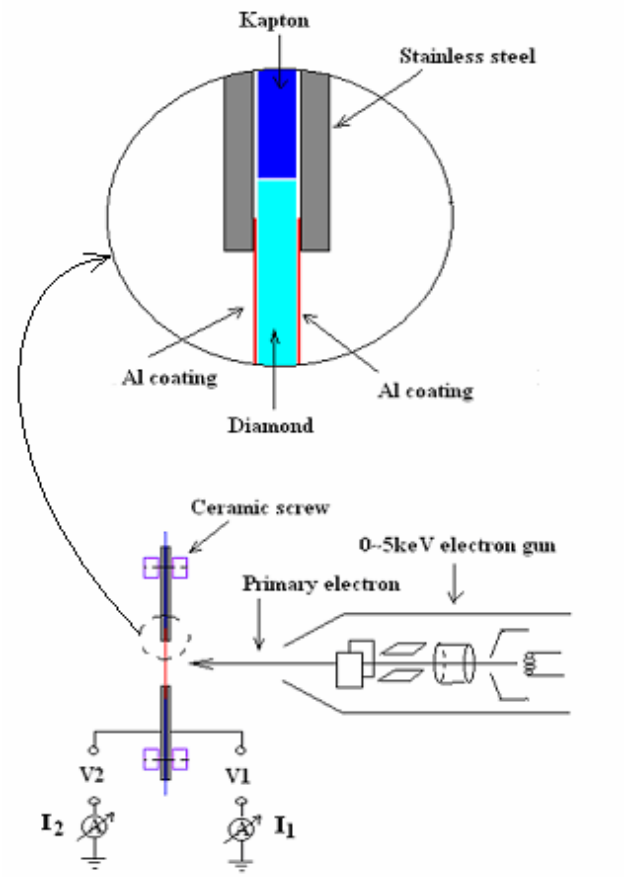

Figure 2: Schematic of the electron (or hole) transmission experiment. V1 and V2 are floating power supplies ranging from -5kV to +5kV independently.

THE EXPERIMENTAL RESULTS

- Polycrystalline diamond:

We first measured a Polycrystalline diamond sample with thickness of 200μm and diameter of 6mm provided by Harris International. The aluminum coating on the front side has a diameter of 4mm and a thickness of 20nm, were the back side (left side) coating has a diameter of 4mm and a thickness of 50nm. The diameter of the SS plate holes is 2.5mm, to enable easy alignment and good contacts with the coatings.

The primary electron energy ranges from 0eV to 6keV and the current ranges from 0A to 5μA. No electron or hole transmission was measured.

- Sample 1 diamond:

Another measurement was done on a diamond sample provided by the Apollo Company with the same dimensions as the above sample. The maximum transmitted hole current measured (V1 is positive while V2 is grounded) is listed in Table 1.

Table 1: Hole transmission in a single crystal diamond. E_{eff} is the effective primary electron energy, I_p is the primary current and F is the electric field across the diamond

E_{eff} (keV)	I_p (μA)	F (MV/m)	Gain (I_2/I_p)
8	0.1	20	>200
8	0.5	20	~30
6	8.5	10	2~3

At low temperature (80K) the gain was reduced by more than 3 orders of magnitude. The reason is presumably that the sample quality is not good enough, i.e., there are too many traps and grain boundaries in the sample.

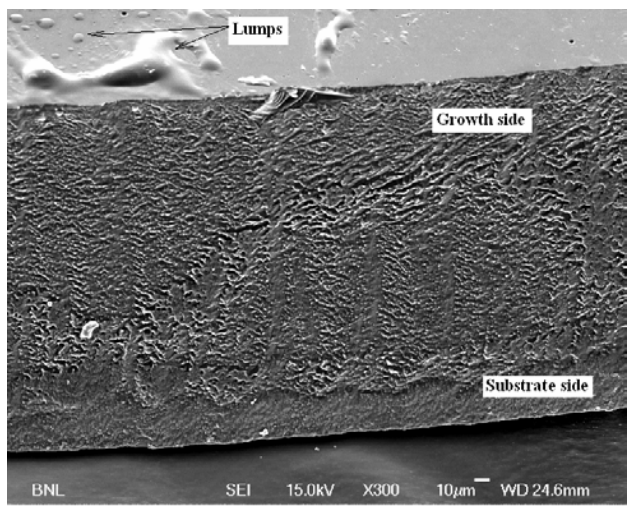

Figure 3: SEM picture of the cross-section of the sample 1 diamond.

Fig.3 is the Scanning Electron Microscope (SEM) picture of the cross-section of the sample 1 diamond. It's clear that the substrate side (bottom) is different from the growth side (top). The grain size is very small (<1μm) on the substrate side and even on the growth side the grain size is not very big. The small lumps on the surface (~ a few μm) may also indicate small grains.

We got high electron transmission gain (I_2/I_p~200) under the following conditions: Ep=4keV, V1=80V, Eeff≈4keV, Ip≈5nA and F=20MV/m.

- Natural diamond

The natural diamond was purchased from a Russian company. It has a rectangular shape, 3x2.64mm^2 and a thickness of 160 microns. The diamond is a type 2a with a modest nitrogen concentration of about 60 ppm ($1.3x10^{-19}$ /cm^3). No other contaminant atoms were reported although we suspect there may be other contaminants too. The diamond was checked with a microscope and was verified to be of good crystal quality. The diamond was coated on both faces with aluminum 30 nm thick.

Fig.4 shows four plots of electron transmission gain through the diamond for constant primary current of 20 nA at room temperature and four primary energies: 1, 2, 3 and 4 keV. It is obvious that the maximum gain decreases fast as we decreases the primary electron energy. At an electron energy of 1 keV the gain disappears because the low energy electrons are totally absorbed in the aluminum coating. One also notices that the high gain curves do not show the saturated gain property at high field gradient. The slope of the curve at high field gradient increases as the current through the diamond increases. This may possibly due to ionization of impurity atoms, leading to a larger SEY.

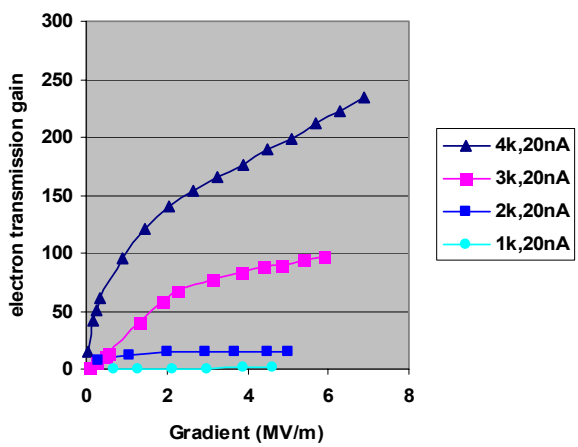

Figure 4: Electron transmission through the natural diamond for constant primary current of 20 nA at room temperature and primary energies of 1, 2, 3 and 4 keV

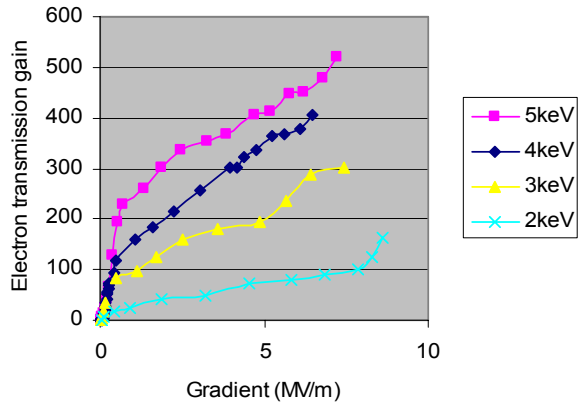

Figure 5: Electron transmission through the natural diamond for constant primary current of 20 nA at 80K and primary energies of 2, 3, 4 and 5 keV

Fig.5 shows the plots of electron transmission gain for constant primary current of 100nA at a diamond temperature of 80K. Even at low temperatures we still get very high gain. Similar to the room temperature case, at high current through the diamond, we observe a higher gain than expected just by SEY from the primary electrons. We are not sure what the exact mechanism for that is. Other details of the curve also will require further investigation, such as the clear bend in the current vs. field curve."

The transmission through the natural diamond was sensitive to the primary beam position and spot size. This led to large variation of the electron transmission between sets of experiments as seen in the room temperature and low temperature measurements.

We also measured the hole transmission by changing the polarity of the field across the diamond. No hole transmission was measured. This is because the Nitrogen impurity is a deep trap for holes while a shallow trap for electron.

CONCLUSIONS

The measurements of charge carrier transmission through diamond films are presented. To have better transmission properties, a single crystal pure diamond is desired. Single crystal requirement seem more important. With better quality diamond, we expect that the electron transmission through diamond will be appropriate for SEEP.

REFERENCES

[1] J. E. Yater, A. Shih, and R. Abrams, "Electron transport and emission properties of C(100)", Physical Review B, V56, R4410.