DIAMOND AMPLIFIER DESIGN AND PRELIMINARY TEST RESULTS

T. Xin#, 1, 2, S. Belomestnykh1, 2, I. Ben-Zvi1, 2, M. Gaowei1, 2, E. Muller1, 2, T. Rao1, J. Skaritka1
J. Smedley1, E. Wang1, Q. Wu1,

1Brookhaven National Laboratory, Upton NY 11973
2Stony Brook University, Stony Brook NY 11794

Abstract

Diamond as a large band gap material can be easily made to have negative electron affinity (NEA) surface. Using a few keV primary electrons as input and a few kV bias, the NEA diamond will emit cold electrons into vacuum with a large gain. We had tested and reported the performance of the diamond amplifier in our DC system. The best amplification achieved so far was above 170. Next step of the experiment is to test the diamond amplifier in a 112 MHz superconducting RF electron gun. In this report we describe the design of the amplifier containing a DC primary gun and light optics, to be tested in our SRF gun and relevant simulations. We also provide preliminary test results of the laser and electron beam transport.

INTRODUCTION

In previous papers, works on hydrogenation of CVD diamond and on measurements of secondary electron gain in a DC system at Brookhaven National Lab were reported [1-3]. The next step will be testing the diamond amplifier in a Superconducting RF (SRF) gun. For this purpose a specially designed cathode stalk is needed to work as a transporter/holder of a diamond in the gun. Besides that, we also designed a subsystem, which will be inserted into the cathode stalk and act as the DC stage of the amplifier.

DIAMOND AMPLIFIER

A basic diagram of a diamond amplifier is shown in Figure 1. A primary beam, with a few keV energy, hits the Pt coated back of the diamond and generates a cloud of electron/hole pairs inside the diamond. This entrance surface of the diamond is negatively biased hence the electrons separate from the cloud and drift across the bulk of diamond to the opposite, hydrogenated NEA emission surface. An anode is placed 200 μm away from the emission surface so that the electric field will extract the secondary electrons from the NEA surface of diamond into vacuum.

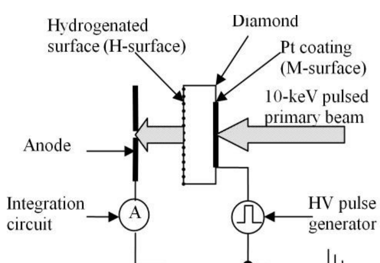


Figure 1: DC test of Diamond Amplifier (conceptual diagram) [1].

* This work was carried out at Brookhaven Science Associates, LLC under Contracts No. DE-AC02-98CH10886 and at Stony Brook University under grant DE-SC0005713 with the U.S. DOE.
#txin@bnl.gov

Design of Amplifier for SRF Gun Test

For the test of the Diamond Amplifier in an SRF gun, we need a special stalk to position the diamond in right location in the cavity and hold it there. The detailed description of the stalk can be found in previous papers [4, 5]. As for the source of primary electrons, we decided to use a newly designed DC assembly with a UV driven copper cathode. A CAD model and a photo of this system, which will hereby be called Amplifier, is shown in Figure 2.

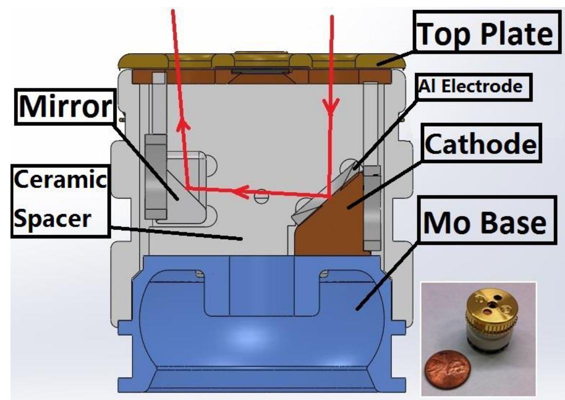


Figure 2: Section view of the Amplifier: red lines show the path of UV light. Smal insert is a photo of the first prototype Amplifier with a penny on the side as size reference.

This is the first prototype amplifier we made for SRF test. There are four major pieces. A gold plated copper top plate is used to hold the diamond and ground it to the cavity. A ceramic spacer serves as an insulator between the grounded top plate and biased molybdenum base. It also acts as a holder for the cathode and mirror and defines the crucial distance between the cathode and diamond. The third part is the cathode/mirror pair that will provide electron beam and guide the laser beam out of the cavity. The fourth part is the molybdenum base that works as the connection between the Amplifier and the transport arm.

Laser will come in through a hole in the top plate and illuminate the cathode. There is an aluminium electrode surrounding the cathode optimized for beam focusing. After the laser bounces off the mirror-finished cathode, it will hit a metal-coated mirror on the other side, which will redirect the laser out of the amplifier through an exit hole in the top plate. Figure 3 shows how the amplifier will be positioned in the stalk and cavity as well as depicts the paths of laser and electron beams. The angles of the cathode and mirror are chosen to meet two conditions. The first one allows the laser beam to escape the cavity with no obstacles. And the second condition is that the electron beam must hit the center of the diamond so that we do not

ISBN 978-3-95450-138-0

have to worry about charging up of ceramic spacers. The cathode will be negatively biased by a DC power supply to -5 kV. The top plate will be grounded to the cavity though the gold plated fingers.

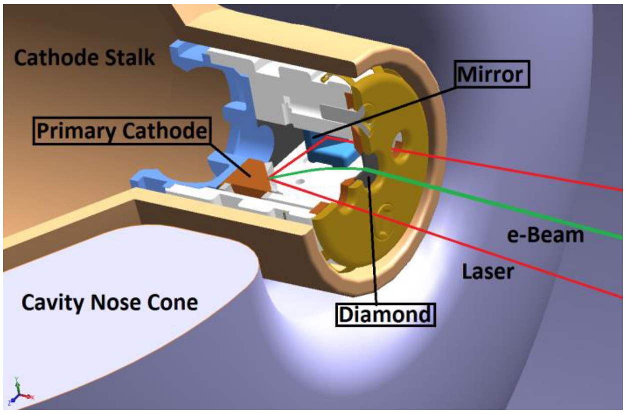


Figure 3: Diagram of laser and electron beam paths.

Simulation Result of Amplifier

In order to find the optimal orientation of the cathode, we used CST Particle Studio to simulate the trajectory of electron beam after it leaves the cathode. Table 1 shows parameters we used in the simulation.

Table 1: Parameters for simulation

Parameters	Value
High Voltage	-5 kV
Average Current	5 nA
Pulse width	1 nS
Repetition rate	80 kHz

After a few iterations the angle between the normal direction of cathode and axis of cavity is chosen to be 42 degrees. The distance between centers of the cathode and the diamond is optimized to 6.6 mm. Figure 4 shows the potential distribution inside the amplifier and the electron beam trajectory. We were able to guide the primary beam onto the center of Pt coating layer on back of the diamond. The distance between the center of the beam spot and the center of the diamond was eventually brought down to 180 μm. RF field leakage through the holes in top plate was taken into consideration and it was found that the field is low enough that there is no observable effect on the beam energy and position.

Prototype Testing Result

We built a prototype Amplifier this year and made some preliminary measurement on it to demonstrate the feasibility of our design in terms of laser and electron beam paths.

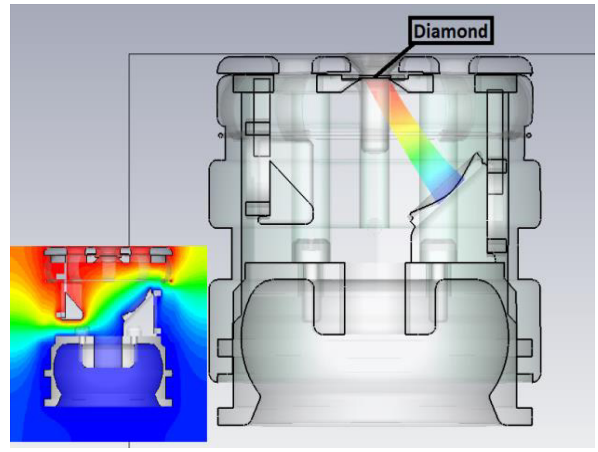


Figure 4: Trajectory of electron beam between primary cathode and diamond. Smaller picture shows the potential distribution inside the Amplifier.

Figure 5 shows the test with a green alignment laser. Incoming laser goes through the half pass Kapton film then illuminates the copper cathode. After two reflections it comes out of the exit hole on the other side of the top plate. The reflected laser beam was captured by the half pass film and indicated as a weaker spot.

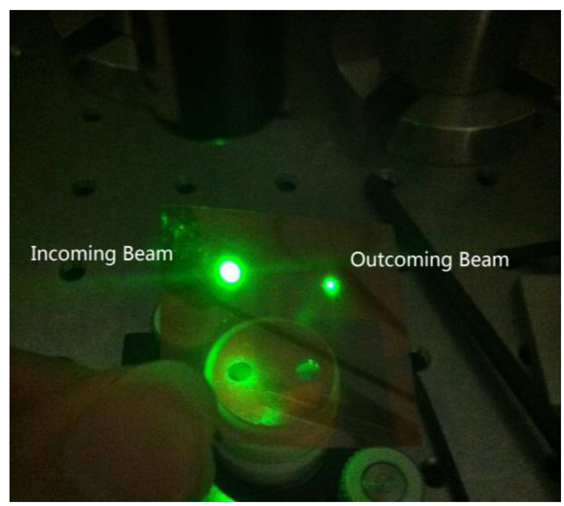


Figure 5: Demonstration of the laser beam passage.

We also measured the percentage of electrons that we were able to capture with a dummy electrode, which is acting in place of diamond. In this measurement we successfully applied -5 kV bias to the cathode. Then a 220 nm UV light was introduced to the amplifier. A deuterium lamp/monochromator system was used to generate the required UV light.

We recorded the current leaving the cathode and the current intercepted by an isolated dummy electrode under different bias voltages. The result of the measurement is shown in Figure 6.

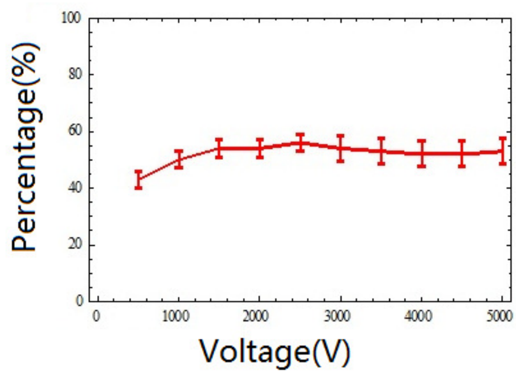


Figure 6: Percentage of electrons reaching dummy electrode over electrons leaving cathode.

One can see that about half of the electrons that left the primary cathode didn't make it to the dummy electrode. This can be result of stray light illuminating the cone shaped electrode sitting on top of the cathode. Since the spot size of UV light from lamp could not be reduced to exactly match the size of the copper cathode, we are expecting certain amount of electrons from the aluminium electrode. Figure 7 shows the effect of changing light spot size on the percentage of intercepted electrons.

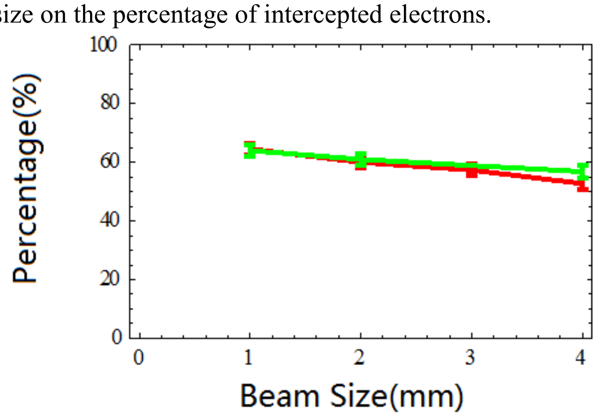
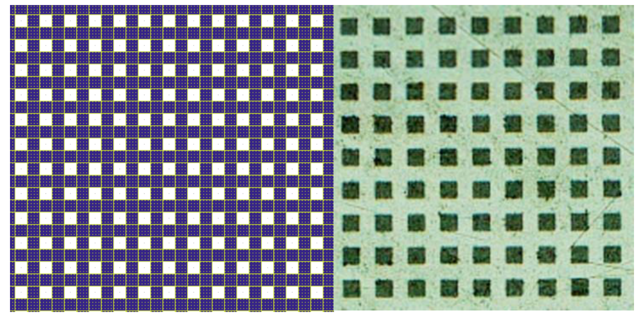


Figure 7: Percentage of electron intercepted by dummy electrode *vs.* UV light spot size.

Considering the total area of the electrode and the QE of the aluminium, it is possible that nearly half of the signal in the measurement of current leaving cathode was due to the photoemission from aluminium. In future tests the light source will be changed to a UV laser and the spot light will be sufficiently reduced to minimize the number of electrons caused by stray light.

Future Modification

We are planning to change the previous one hundred percent coverage metal coating to a lithographical patterned grid coating. Because the metal layer will reduce the energy of primary electrons, less coverage means larger effective impact energy from primary beam. Hence the total number of secondary electron product in each pulse will be increased according. The trade off is that the weaker electric field established by grid coating inside diamond will drag less secondary electrons to the emission surface. Figure 8 shows the pattern we are planning to use and the coating made from it.



a b

Figure 8: (a) Mask used for lithography; (b) Picture of back electrode made with patterned mask. The grid spacing is 50 μm.

CONCLUSION

For future tests of the Diamond Amplifier in a Superconducting RF gun, a DC subsystem was designed to provide primary electron beam inside the RF cavity. The system includes the following parts: a primary photocathode made of copper; an aluminium electrode for beam regulation; a metal-coated dielectric mirror to guide the laser out of the cavity; a holding mechanism to hold the diamond in position and ground it to the cavity; and a molybdenum base part to connect the amplifier to the transport arm. Simulation result from CST Particle Studio shows good aiming of electron beam onto the center of the diamond and acceptable DC field strength near the dangerous region. Experimental result verified the design of the optics for the laser beam and showed a reasonable capture ratio of electrons by the diamond. We are still working on improving the Amplifier in order to make it more compatible with our SRF electron gun.

REFERENCES

[1] X. Chang, et al, Electron beam emission from a Diamond-Amplifier Cathode, Phys. Rev. Lett. **105**, 164801 (2010).

[2] E. Wang, et al, Secondary-electron emission from hydrogen-terminated diamond: experiments and model, Phys. Rev. ST Accel. Beams **14**, 111301 (2011).

[3] E. Wang, et al, Systematic study of hydrogenation in a diamond amplifier, Phys. Rev. ST Accel. Beams **14**, 061302 (2011).

[4] T. Xin, et al, Design of the fundamental power coupler and photocathode inserts for the 112 MHz superconducting electron gun, Proceedings of SRF2011, Chicago, IL USA.

[5] T. Xin, et al, Simulations of multipacting in the cathode stalk and FPC of 112 MHz superconducting electron gun, Proceedings of IPAC2012, New Orleans, Louisiana, USA.

ISBN 978-3-95450-138-0