

TESTING A GAAS CATHODE IN SRF GUN

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Abstract

RF electron guns with a strained superlattice GaAs cathode are expected to generate polarized electron beams of higher brightness and lower emittance than do DC guns, due to their higher field gradient at the cathode's surface and lower cathode temperature. We plan to install a bulk GaAs:Cs in a SRF gun to evaluate the performance of both the gun and the cathode in this environment. The status of this project is: In our 1.3 GHz $\frac{1}{2}$ cell SRF gun, the vacuum can be maintained at nearly 10^{-12} Torr because of cryo-pumping at 2K. With conventional activation of bulk GaAs, we obtained a QE of 10% at 532 nm, with lifetime of more than 3 days in the preparation chamber and have shown that it can survive in transport from the preparation chamber to the gun. The beam line has been assembled and we are exploring the best conditions for baking the cathode under vacuum. We report here the progress of our test of the GaAs cathode in the SRF gun.

INTRODUCTION

Future particle accelerators, such as eRHIC and the ILC require high-brightness, high-current polarized electrons. Strained superlattice GaAs:Cs has been shown to be an efficient cathode for producing polarized electrons. Activation of GaAs with Cs₂O(F) lowers the electron affinity and makes it energetically possible for all the electrons, excited into the conduction band that drift or diffuse to the emission surface, to escape into the vacuum. Presently, all operating polarized electron sources, such as the CEBAF [1], are DC guns. In these devices, the excellent ultra-high vacuum extends the lifetime of the cathode. However, the low field gradient on the photocathode's emission surface of the DC guns limits the beam quality. The higher accelerating gradients, possible in the RF guns, generate a far better beam. Until recently, most RF guns operated at room temperature, limiting the vacuum to $\sim 10^{-9}$ Torr. This destroys the GaAs's NEA surface. The SRF guns combine the excellent vacuum conditions of DC guns and the high accelerating gradient of the RF guns, potentially offering a long lived cathode with very low emittance [2]. Testing this concept requires preparation of the cathode, transportation to the SRF gun and evaluation of the performance of the cathode and the gun at cryogenic temperatures.

In our work at BNL, we successfully activated the bulk GaAs in the preparation chamber. The highest

quantum efficient was 10% at 532 nm that fell to 0.5% after 100 hours. We explored three different ways to activate the GaAs. We verified that the GaAs photocathode remains stable for 30 hours in a 10^{-11} Torr vacuum. Passing the photocathode through the low 10^{-9} Torr transfer section in several seconds caused the QE to drop to 0.8%. The photocathode with 0.8% QE can be tested for the SRF gun. The gun and beam pipe were prepared and assembled. After baking at 200°C baking, the vacuum of the gun and beam pipe can sustain a low 10^{-11} Torr at room temperature. The final test to extract electrons from the gun is ongoing. In this paper, we discuss our progress with this SRF gun and the results of the photocathode in preparation chamber and in magnet transfer line.

GaAs ACTIVATION

Details on the preparation vacuum system are published elsewhere[3]. With 200°C baking, the pressure in the main preparation chamber, read from a cold cathode gauge, falls below 10^{-11} Torr. We used a LabVIEW control program to read the current and log the data. After establishing the ultra-high vacuum, the apparatus is ready for cleaning and activation of GaAs.

To obtain a high Q factor in the SRF gun, we chose a 100um commercial GaAs photocathode from the AXE Company [4]. The photocathode was carefully affixed using indium into a recessed plug of high purity Nb. We avoided as much as possible to let the indium leak into the gap between the GaAs and Nb. A clean GaAs surface is essential for successful activation because the Cs/O layer is extremely sensitive to contamination. The sample then can be cleaned by heating it to 580°C that is sufficient to desorb contaminants, but not so high that it damages the stoichiometry of the surface. The activation process is extremely important for assuring the stability and long lifetime of the polarized electron beam. We employed three different activation methods: The yo-yo process with an excess of oxygen; the yo-yo process with an excess of caesium; and full saturation with both. In the typical yo-yo process, the sources of oxygen and caesium are opened and closed periodically. In the saturation process, caesium and oxygen are introduced continuously into the chamber to attain a maximum current. The most suitable time to begin to activate the GaAs is after the temperature of the wafer falls below 30°C. The SAES getter's Cs dispenser is degassed while heat-cleaning of the GaAs is underway.

The background vacuum of the preparation chamber is better than $1 \cdot 10^{-11}$ Torr. During the yo-yo process, when the source of oxygen is open, that of caesium

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should be closed, and vice versa. Fig. 1 shows typical experimental results from the yo-yo process. In the yo-yo process with excess oxygen, the photocurrent fell when the oxygen flowed into the chamber and correspondingly, the photocurrent increased whilst the Cs evaporated.

The final peak photocurrent was reached in one hour and 20 minutes with excess oxygen. In the yo-yo process with excess Cs, the photocurrent decreases while the Cs was evaporating, and then increases when oxygen was let into the chamber. The oxygen partial pressure was $2 \cdot 10^{-9}$ Torr. The photocurrent is very sensitive to the amount of oxygen, so the rise in the photocurrent was much quicker than when oxygen was in excess. The final peak photocurrent was reached in one hour with excess Cs. We routinely obtained a QE above 8% at 544nm from a 100um bulk CVD GaAs sample. For the saturation process, the oxygen's partial pressure and Cs's evaporation rate must match very well. In our system, the preparation chamber oxygen pressure is $(2.2 \pm 0.2) \cdot 10^{-10}$ Torr while the Cs source current is 6 A. The photocurrent increases constantly at first and then becomes a little unstable. Though vernier regulation, we matched the oxygen leak-valve to the rate of evaporation of Cs; then, the photocurrent attained its maximum. The total process took 35 minutes and the QE was 9% at 544nm.

Comparing the two yo-yo processes and saturation condition, the following differences are apparent:

At each peak in the yo-yo process, there is not a sufficient NEA effect on the GaAs surface due to the lack of caesium/oxygen in the chamber after opening oxygen/caesium, so the photo current experiences a slight temporary decrease. This does not occur in the saturation process, where the amounts of oxygen and caesium are matched well.

The saturation process has the advantage of lessening activation time. Thus, the cost of the process in time is less than half that of the yo-yo process.

The saturation process is difficult to control. The speed of the Cs evaporation and the oxygen flow rate must be carefully monitored and regulated throughout the procedure.

One of the important parameter of the photocathode in the SRF polarized gun project is the dark lifetime. The time delay between cathode preparation in the preparation chamber and its use in the SRF gun is expected to be ~ 36 hrs., determined by the bake and cool off time of the load-lock section. The QE of the photocathode is degraded by the internal instability of the activation layer and by the residual gas in the vacuum system. When the GaAs photocathode is transferred from the preparation chamber to the storage cube, the vacuum of the transferring line is a low 10^{-9} Torr. Experiments show that the lifetime of the GaAs photocathode is less than 10 minutes in this vacuum. Slowly moving of magnetic-coupled transfer rod preserves the vacuum at this level. In our load-lock system, the middle section is opened to the atmosphere

when connecting the storage cube to the gun. We found the heat developed while baking the middle section and during pumping through the gate valve destroys the Cs-O layer of the GaAs photocathode. So the middle-section baking process is avoided. The GaAs must pass through the middle section in seconds, so that the time they spend in the bad vacuum is as little as possible. In a dry run, the QE of GaAs remained at 0.7% when it was stored in the cube for 50 hours after moved through the vacuum in the middle section. This test proved that the QE of the GaAs is more than 0.7% after the SRF gun cooled down, a value that is sufficient for the lifetime test of the GaAs in the gun.

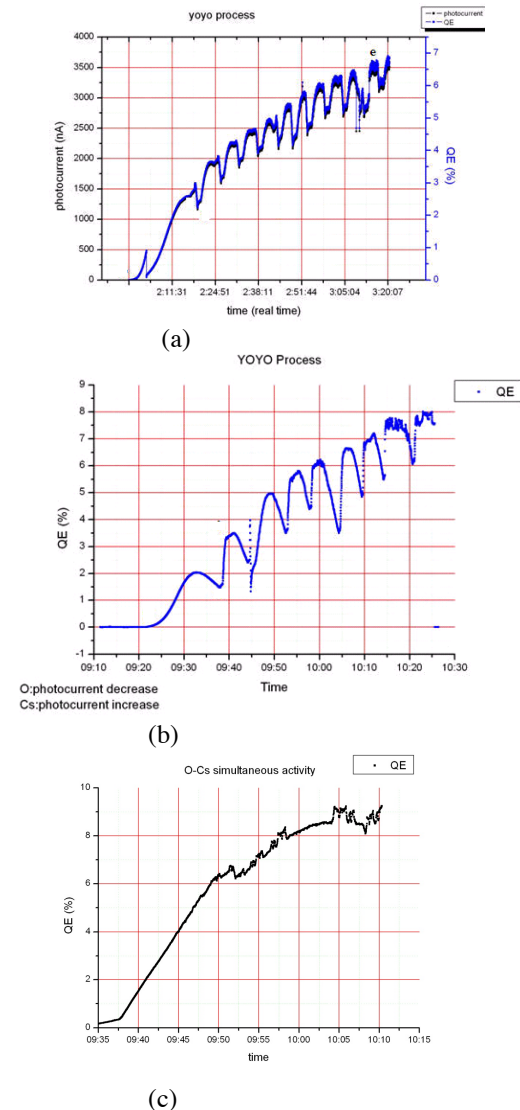


Figure 1: GaAs photocathode activation. (a) is the yo-yo process with excess oxygen, (b) is the yo-yo process with excess Cs; and, (c) is the saturation process

BACK BOMBARDMENT TEST SETUP

Based on the BINP's experiment [5] and the electron back-bombardment-induced multipacting simulation [3], it appears that the electron back-

bombardment is the main cause of degradation of the GaAs in the RF gun. Judicial choice of the laser pulse with respect to the RF phase is critical to minimize the back bombardment and x-ray generation.

In order to achieve this experimentally, we propose the following procedure: When the peak electric field reaches 15MV/m at the photocathode's emission surface, the simulation shows that those electrons that are emitted from the photocathode in the RF phase between 100° to the 180° are in the back-bombardment range, and the highest backward-oriented energy is 300KeV.

Figure 2 shows the energy of the electron back-bombardment response to the RF phase of the photocathode. Such bombardment triggers X-ray radiation from the gun due to bremsstrahlung radiation. A radiation detector mounted at the outside of the dewar close to the gun detects these x rays when the energy of the electrons back-bombardment is higher than 120KeV. The gun is insulated by a DC block and a ceramic break so that one can measure the electron emission current.

We use the low-power laser to drive the GaAs photocathode. If electrons are emitted in the phase range between 0° to 100° , the photocurrent can be measured, but no x rays are generated. If the electron is emitted in the phase range between the 100° to the 180° , x rays are detected but the photocurrent does not escape the gun and can not be measured. For electrons emitted in the phase range between 180° and to the 360° , there is no photocurrent no x rays.

After identifying the initial phase of the laser, the 0° critical RF phase can be searched for without staying too long in the back- bombardment phase range.

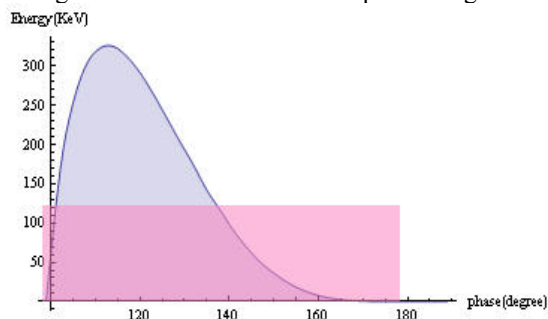


Figure 2: The energy of the electron back-bombardment response to the RF phase of the photocathode. The x ray generated by electron back-bombardment energy in the pink range cannot pass the Dewar's wall.

The beam line for the final test has been assembled (Figure 3). The beam exits the gun through the high-temperature superconductor solenoid and is bent by a 90-degree dipole magnet into a Faraday cup. A moveable YAG crystal placed before the faraday cup is detects the beam's image. A NEG pump close to the gun and another NEG pump and an ion pump are situated at the end of beam line to provide sufficient

pumping rate. The whole system is baked to 200°C to maintain the vacuum to better than 10^{-11} Torr while at room temperature. We are making progress on details of the lifting device and the vacuum. The vertical test shows the Q_0 of the gun is $1.3 \cdot 10^8$ [4] with the GaAs photocathode. With our improved photocathode holder design the Q_0 of the gun is estimated to be higher than $5 \cdot 10^8$. To match the beam load, the external Q of the input coupler is set to $1 \cdot 10^8$ and the external Q of the pick-up coupler is set to $1 \cdot 10^{11}$. The photoemission measurements are expected to take place in a few months.

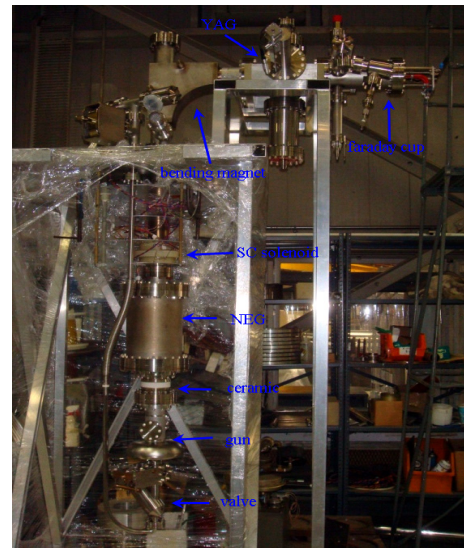


Figure 3: Gun assembly in the beam line

CONCLUSION

The activity of our GaAs cathode is satisfactory at BNL. Three different ways to activate the GaAs have been explored. The activated GaAs after QE decay in transferring can be tested for the SRF gun. The gun and beam pipe were prepared and assembled. The beam line test procedure was proposed and the final beam-line test is ongoing.

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