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DISCLAIMER

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Abstract. An experiment is under way to prove the feasibility of a super-conducting RF gun for the production of polarized electrons. We report on the progress of the experiment and on simulations predicting the possibility of success.

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INTRODUCTION

Photo-cathode RF electron guns are superior to DC guns in producing high brightness electron beams, because the electric field on the cathode can be much higher without the technical difficulty of voltages higher than 100 kV. However, all successful existing guns for polarized electrons are DC guns because the environment inside an RF gun is usually hostile to the GaAs cathode material necessary for polarization. Ions created by scattering of electrons on residual gas can be accelerated back into the cathode. The number of back-scattered ions is proportional to the vacuum pressure inside the gun and while the typical vacuum pressure in a DC gun is better than 10^{-11} torr the vacuum in an RF gun is in the order of 10^{-9} torr. The cathode can also suffer damage from electrons which are emitted from the cavity walls or the cathode itself and are accelerated during the negative RF phase to impact the cathode with high energy.

Experiments at BINP Novosibirsk in the late 1990s demonstrated the following effects [1,2]: the quantum efficiency in a pulsed normal-conducting 2.8 GHz RF gun was destroyed in as little as 10 pulses. We are now working to repeat this experiment with modifications that we hope will give a positive result: First, instead of a normal-conductive gun we use a superconductive gun. Since the RF fields will not heat up the cavity walls we avoid out-gassing. In fact, the cold walls will act as a cryogenic pump and we expect the vacuum pressure to be better that 10^{-11} torr. Secondly, we will use a lower frequency half cell gun (1.3 GHz) which will help to avoid electron multipacting involving the cathode.

THE EXPERIMENT

The experimental setup has two parts. The first is the electron accelerator, where the gun is placed in a 100 liter cryostat. The layout is shown in figure 1. The gun points upwards, so that the beam exits the cryostat on the top and is bend by a 90 degree dipole (shown in figure 2) into a Faraday cup. A window on top of the dipole is used for the laser. The polarization of the beam is not measured, since we are only interested in the decay of the quantum efficiency. In order to measure the beam current the gun is insulated from the rest of the apparatus with a ceramic break, which is protected from mechanical stress by a G10 sleeve.

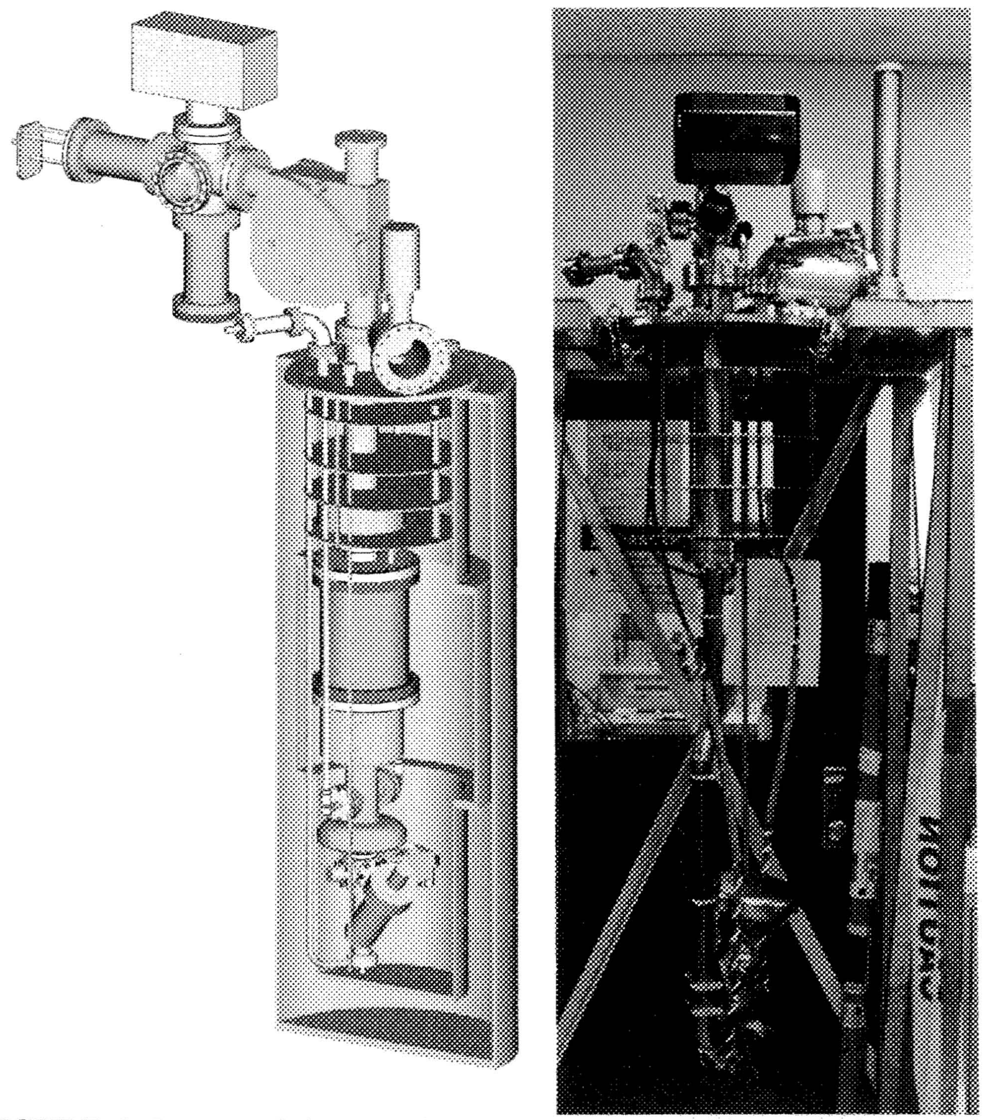

FIGURE 1. Layout of the experiment and gun assembly as used in the first cool-down. The gun is mounted upside-down in this test to prevent particulate from dropping into the gun cavity. The ion pump on to of the assembly was used during the cool-down to measure the vacuum pressure.

A tank filled with NEG pumps close to the gun is maintaining the vacuum when the gun is warm and is not cryo-pumping. Another NEG pump and an ion pump is placed next to the Faraday cup, where the impact of the beam will cause degradation of the vacuum. A set of four aluminum baffles insulates the liquid helium from the top plate and a high temperature superconducting focusing solenoid is placed between the lowest baffles, where a temperature of 17° K was measured

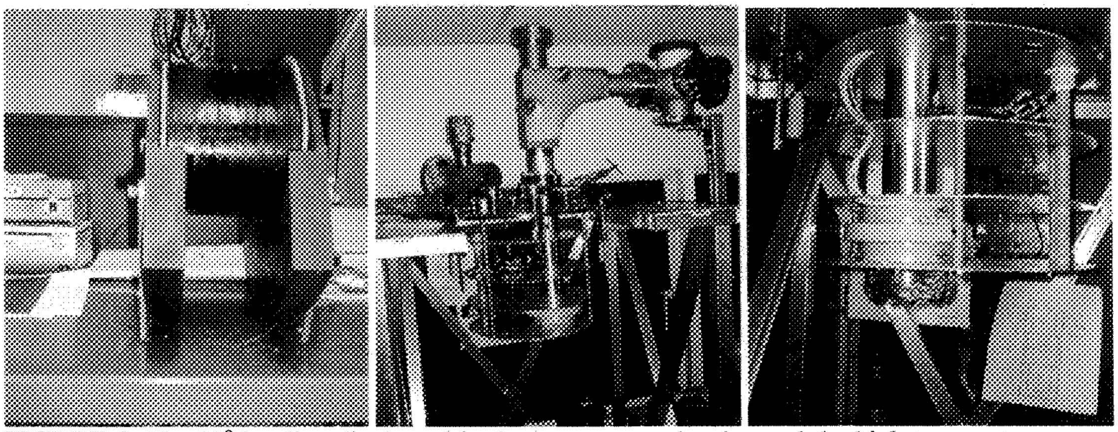

FIGURE 2. The 90° bending dipole and its 3-way vacuum chamber and the high temperature superconducting focusing solenoid.

The other part is the cathode preparation system, which allows heating the GaAs cathode to 600° C for cleaning and the deposition of a mono-layer of Cesium. In normal-conducting guns the preparation system is integrated into the gun, in our case it must be separate with a transporter which allows transfer of the cathode without breaking the vacuum.

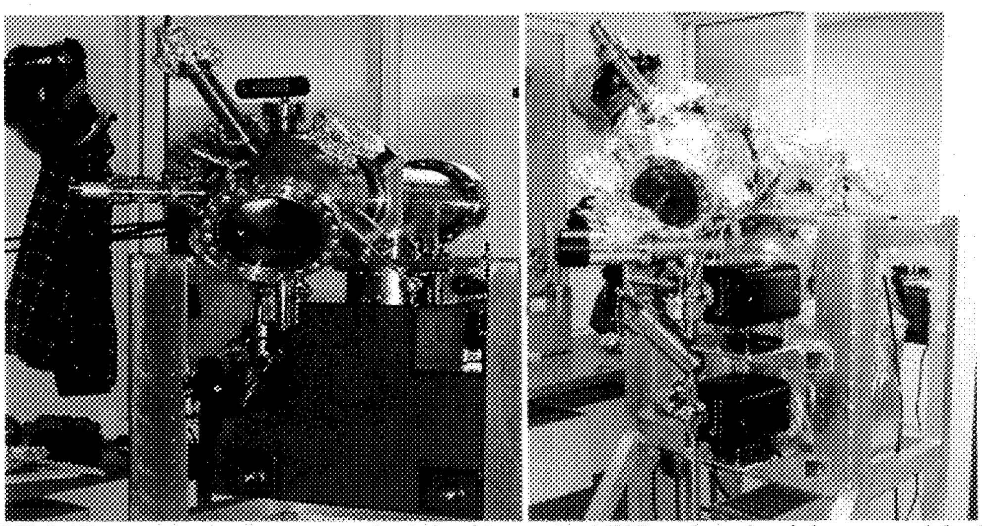

FIGURE 3. The preparation system on the left with attached TSP and on the right wrapped for baking with attached cathode transporter. The two ion pumps are part of the transporter.

FIRST COOL-DOWN

In the first cool-down the Q of the cavity was verified and the thermal properties and vacuum pressure of the system was measured. After the cryostat was filled the ion pump was turned off and the pressure fell by cryo-pumping alone below the range of the pressure gauge. The heat load of the system was approximately 5 Watts.

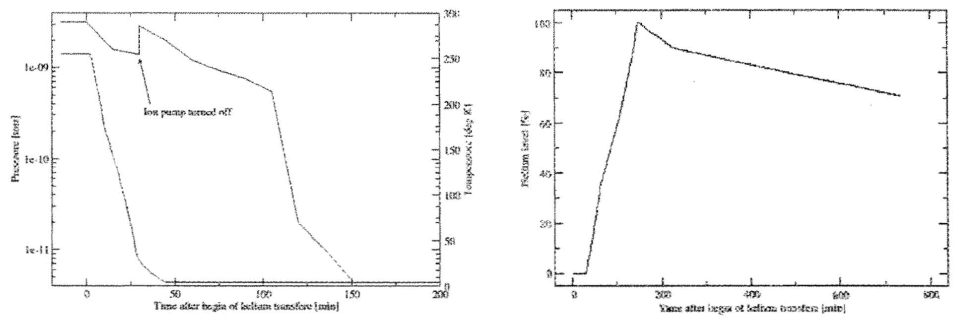

FIGURE 4. The preparation system on the left with attached TSP and on the right wrapped for baking with attached cathode transporter. The two ion pumps are part of the transporter.

ION AND ELECTRON BOMBARDMENT

The above measurement gives us confidence that the vacuum pressure will be comparable or better than found in DC guns. Also, only a fraction of the generated ions will return to the cathode and the impact energy will be significantly lower than in a DC gun [3]. But as suggested by Aleksandrov [2] electron bombardment may be the cause of the short cathode lifetime in the BINP experiment.

Electrons emitted from the cathode at the RF phase between approximately 100 and 180 degrees in the RF phase will not leave the gun cavity, but will be accelerated backwards and impact the cathode, in our case with energies up to 350 MeV.

The effect is twofold: one is the damage to the cathode; the other is to lift thousands of secondary electrons from the valence band into the conduction band. These electrons will drift under the influence of the RF field to the surface and leave the cathode due to the negative affinity.

A tracking program was developed to investigate the possibility of multipacting involving the negative affinity cathode. The program calculates the maximum phase advance from an emission of an electron to the emission of its secondary electrons including the motion inside the GaAs, were the penetration depth of the electric field and the dependence of the drift velocity on the field must be considered.

The results are shown in figure 5, where the maximum phase advance of the electron impact and the emission of the last secondary electron are plotted vs. the gradient at the cathode. The condition for multipacting is that the phase advance is 360 degrees. Therefore, if the range overlaps the 360 degree line multipacting must be expected.

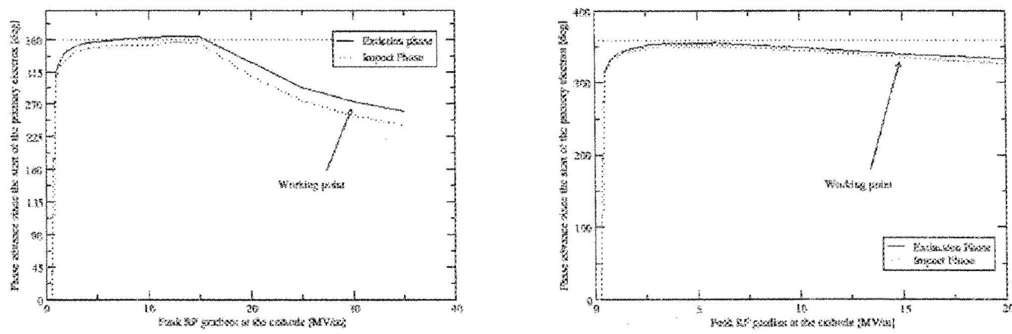

FIGURE 5. Maximum phase advance between the emissions of an electron to the emission of its secondary electrons, on the left for a pill box cavity similar to the BINP gun, on the right for our 1.3 GHz gun. Since the exact dimensions of the BINP gun were not available, the gun shape was approximated by a pill box cavity, matching the data given in [1]. The green curve shows the impact, the black curve the last emitted secondary electron.

We see that this is the case for the BINP gun while the in the electric gradient range between 10 and 15 MV/m. This agrees with the observation that dark current was observed above 10 MV/m. In order to improve the vacuum in the gun the RF was pulsed. Therefore the multipacting condition was fulfilled every pulse. The calculations for our experiment show that we escape this disaster, but with little room to spare.

These calculations were done assuming bulk GaAs with p-doping of $10^{18}/cm^3$. The skin depth is in our case 45μ. In strained GaAs, where only a 5 nm thick surface layer is doped, it will be important to make the cathode crystal thin enough to prevent multipacting.

ACKNOWLEDGMENTS

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