ON USING NEA CATHODES IN AN RF GUN*

M. Hüning†, FNAL, Batavia, IL 60510, USA

Abstract

RF guns have been proven to deliver high brightness beams and therefore appear attractive as electron source for a linear collider. Only so far no polarized beams have been produced. To create a polarized electron beam GaAs NEA cathodes are used. Operating rf guns with a NEA cathode poses concerns in three areas, oxidation by residual gas, ion bombardment, and electron bombardment. In this paper we report about an attempt to reduce the vacuum pressure inside the gun by cooling it to cryogenic temperatures. Furthermore the energy deposition by ions will be quantified.

INTRODUCTION

When the application demands an electron source which can deliver high brightness beams, rf guns the premier if not only choice. In the case of the linear collider there are some restrictions to this statement. The emittance required is even smaller than what is state of the art in rf guns, a large ratio of emittances in the two transverse coordinates, and high polarisation of the electrons is required. The first two requirements are met by building damping rings. After it has been shown that beams with large emittance ratio can be produced in rf guns [1], there is hope that the electron damping ring may become simpler or even be avoided altogether. But this is only true if polarized beams can be produced.

POLARIZED ELECTRON BEAMS

Polarized electron beams are currently being produced from NEA GaAs photocathodes. By shining light of the right wavelength into the GaAs electrons are transferred from the valence band into the conduction band. The selection rules of quantum mechanics provide for an excess of one polarization if the laser light is polarized. By applying a strain on the crystal a polarization of ideally 100% can be achieved. The problem is how to get these electrons out of the crystal. This is accomplished with a thin layer of cesium oxide. It lowers the work function so far, that the electrons do not have to be lifted to the vacuum level but merely tunnel through a narrow barrier. This is the mechanism of negative electron affinity. All this is done within one monolayer of cesium. But this means that it does not take very much to destroy the effect.

* Work supported by Department of Energy contract DE-AC02-76CH03000

† mhuening@fnal.gov

DAMAGING EFFECTS

Oxidation by Residual Gas

The first effect one has to worry about is oxidation of the active layer by the residual gas in the surrounding chamber. To achieve a quantum efficiency lifetime in the order of 600 h, the vacuum pressure inside the gun volume has to be in the order of 10^{-11} Torr or better [2]. Obviously the species in the residual gas are important. The most dangerous species are O_2, CO_2, CO, H_2O, and other oxidants, H_2 and the noble gases can be regarded harmless.

The vacuum pressures generally seen in rf guns tend to be higher by up to two orders of magnitude, 10^{-9} Torr during rf operation can be expected. Before working on anything else this has to be improved. There are attempts to improve the vacuum pressure by using very open structures that promise better pumping capabilities. A structure that is being looked into is the plane wave transformer (PWT) [5]. A different possibility is to use the cavity walls themselves for cryo pumping. The next section covers an experimental setup which is used to test this approach.

Ion Bombardment

Secondly there is bombardment of the cathode with high energy particles. In DC guns one is mainly concerned by ion bombardment, electrons obviously do not hit the cathode. In rf guns electrons can hit the cathode. Besides the damage due to the energy deposition they are also believed to be – by secondary electron emission – the cause of large dark currents seen in earlier tests [3].

Ions in an rf gun acquire less energy than in a DC gun because due to their high mass they soon run out of sync with the rf. The maximum net acceleration the ions experience is during the first half period of the rf, afterwards they only oscillate around that value.

$$\triangle p = \frac{2qE_0}{\omega}. \tag{1}$$

In an L-band gun (1.3 GHz) at 35 MV/m this amounts to 2.57 MeV/c. Ions that cross the transition between the cells of the cavity at their peak momentum gain twice as much because of the phase flip. This number is in approximate agreement with tracking results in an L-band rf gun [4]. The distribution of incident energies of the ions is shown in figure 1. The figure shows the origin and impact energies of the ions. On top of that it shows the number of ions that are generated at a specific location per rf pulse. The ionisation of the residual gas is calculated with the Bethe-Bloch formula. It is assumed that the beam is the main source of ionisation. Therefore the ions are generated on

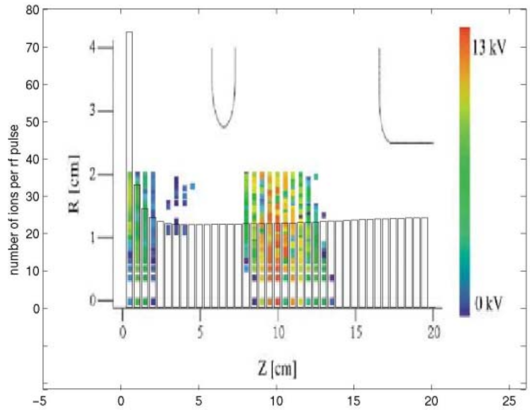

Figure 1: Origin, impact energy and rate of generation of hydrogen ions in an L-band rf gun. The data for origin and impact energy originates from [4]. The number of ions is based on a pressure of 10^{-10} Torr and an rf pulse of 800 μs.

the axis of the gun at a certain phase of the rf and then accelerated on a straight path towards the cathode.

COLD CAVITY TEST

Setup

In figure 2 the setup for the cryogenic rf gun is scetched. The gun is a 1.3 GHz, 1.6-cell L-band gun. It is cooled by flowing liquid nitrogen through the channels originally foreseen for water cooling. The gun is insulated by a box full of Perlite (TM), the copper piping is wrapped with Armaflex (TM).

There are three ports available for pumping, the beam pipe, one port at the waveguide, and the cathode port where the cathode has been removed. Each pumping port is equipped with an ion pump and a titanium sublimation pump. The cathode port is also equipped with an ion gauge and a residual gas analyzer (RGA), a gate valve can be used to separate the RGA and pumps from the rest of the vacuum system. A fan is used to blow air onto the RGA with the hope to keep it at a stable temperature in this way. Prior to the tests the system was set at a defined pressure and the RGA was cross-calibrated with the ion gauge. The end flange of the beam pipe is isolated from the gun by a ceramic ring, this way it serves as a Faraday cup.

The rf is generated in a 0.5-5.0 GHz synthesizer which can be tuned to follow frequency drifts of the gun. During cooldown the resonance frequency of the gun increases by approximately 4 MHz. The rf is amplified by a klystron delivering nominally 5 MW peak power. The klystron is slightly detuned from the 1.3 GHz room temperature resonance of the gun, limiting the maximum power including losses in the isolator and waveguide to 2.5 MW. This allows for a maximum acceleration field of 35 MV/m. The 1.304 GHz of the cold gun lie on the other side of the klystron resonance. The rf losses at nitrogen temperature are reduced by a factor of 2.4 so that 1 MW is sufficient to reach 35 MV/m, the preliminary goal for the field strength. The rf is interlocked on reflected power, vacuum level, and light detection by a photomultiplier at the waveguide port of the gun.

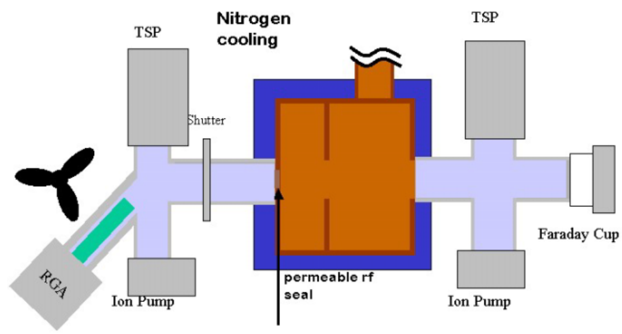

Figure 2: Schematic of the cold gun test setup. In reality the RGA is mounted horizontally perpendicular to the axis of the gun. The ceramics of the Faraday cup on the right caused problems due to leaks. On the waveguide port on top of the gun there is another set of pumps and an evacuation port. Opposite the RGA there is a second evacuation port.

Processing

The gun body was scrubbed from the outside and then soaked in a bath of Citranox (TM) for 24 h. Afterwards it was rinsed with ultra-pure water and then dried with nitrogen gas. The rf window was treated for 30 min in an ultra-sonic bath. All the above treatment and the assembly of the vacuum system was performed in a class-1000 clean room. The whole apparatus was baked at 150° C for 72 h. The pumping port used for the original bake is at the waveguide of the gun. At a later point in time a separate bake-out was performed on the RGA section with a pumping port close to the RGA. After the bake a vacuum pressure in the low 10^{-11} Torr was reached. During rf conditioning a leak developed in the RGA section, so that it had to be baked a third time (120° C, 72 h). A vacuum level in the low 10^{-11} Torr was recovered.

The rf conditioning was performed with the gun at room temperature to avoid accumulation of gases inside the gun. During processing the gun delivered a large amount of dark current. At 35 MV/m 300 μA were measured in the Faraday cup. This is probably due to sharp edges at the dismantled cathode port. This large amount of charge is the most likely reason for two leaks in the Faraday cup ceramics that developed during high power rf sessions, and a third one which finally terminated the test. The leaks could be closed with Vacseal (TM), but after the second leak it was decided to perform the cold testing although it was somewhat premature in terms of conditioning of the gun.

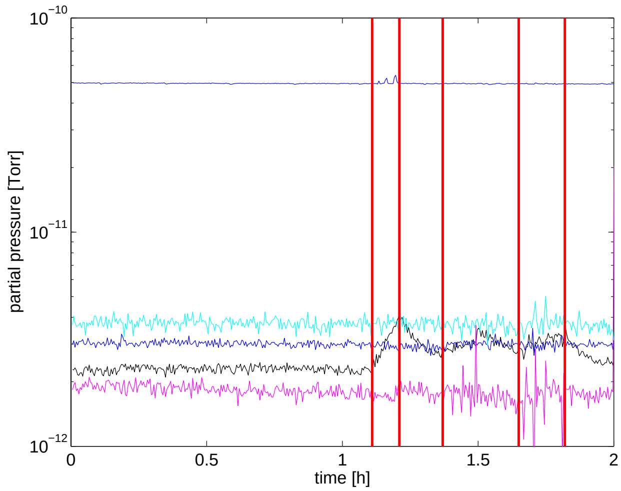

Figure 3: RGA trend graphs during cooldown and rf operation of the cold gun. Changes in the rf power are marked with vertical lines, see text for details.

Results

The figure 3 shows an RGA trend graph during the end of the cooldown and rf operation of the cold gun. From the time the RGA was switched on to a few days later the partial pressure reading of hydrogen had risen by more than a factor of ten.

The nitrogen flow was started 4 h before the start of the zoomed region. There were minute changes in the partial pressures of H_2O, N_2/CO, and CO_2. These changes were so small that it would have been impossible to reproduce the trend graph well enough to make them visible. The changes on the hydrogen line were clearly visible. It changed from $5.1 \cdot 10^{-11}$ Torr to $4.9 \cdot 10^{-11}$ Torr. It may however be possible that these changes have to be attributed to changes in the ambient temperature of the shielding enclosure caused by insufficient insulation of the nitrogen piping.

The effect of the rf is most visible on the Methane pressure (16 AMU). It reacts instantaneously on changes in the rf setup. Different stages in the rf operation are marked by vertical lines in figure 3. The leftmost line marks the switching on of the rf at low power (200 kW) to tune the cavity to resonance. It was however not tuned completely but the rf drive was a few kHz to low. This caused outgassing and the development of light which was picked up by the photomultiplier. The rf was retuned at the second line after which the light signal vanished and the pressure quickly dropped. The rf forward power at that time was 490 kW and the field in the gun 25.2 MV/m. The pulse length was 40 μs throughout. The third line marks where the rf power was increased to 660 kW. The step on the pressure a few minutes later may have been caused by a minor arc, which also generated noise on the spectrum. At the fourth line the power was set to 820 kW and a field of 32.1 MV/m. At the fifth line the rf power was switched off for 10 minutes.

When the rf was switched back on a leak occured which stopped the test.

CONCLUSION AND OUTLOOK

To use a NEA GaAs cathode in a rf gun it is necessary to improve the vacuum pressure during opertion. An attempt is made to achieve this by cooling a normalconducting gun to 80 K. Although the first measurements with such a system are not completely convincing, they do show a lot of promise. After the pressure in the gun reached its final,optimal value, the vacuum measurements were dominated by the pressure in the auxiliary systems. So the pressure in the gun was too good to be measured. Before the next attempt some details of the system have to be modified, like the Faraday cup and the vacuum fluence between the gun and the RGA. The following bake will then have to clean the system enough to allow more sensitive pressure measurements.

Improving the vacuum pressure is of course not the real goal. Success can only be claimed if a NEA GaAs cathode survives a reasonable time inside the rf gun. Testing this is part of an phase I SBIR proposal that has been submitted by Advanced Energy Systems (AES) and was approved. After repairs and cleaning the gun will be used to test activated GaAs cathodes under various operating conditions.

Acknowledgements

The author would like to express his gratitude to J. Clendenin of SLAC and C. Sinclair of Cornell for their support and advice, and to T. Favale and T. Schultheiss of AES for joining the work on polarized guns.

REFERENCES

[1] D. Edwards et al. *Status of Flat Electron Beam Production*, PAC 2001, Chicago, 2001

[2] R. Alley et al, *The Stanford linar accelerator polarized electron source*, Nucl. Instr. Meth. Sect. A 365 (1995), pp 1-27

[3] A.V. Aleksandrov et al., *High Power Test of GaAs Photocathode in RF Gun*, EPAC 98, Stockholm

[4] J.W. Lewellen, *Ion tracking in photocathode rf guns*, Phys. Rev. STAB 5 (2002), 020101

[5] D. Yu et al., *Development of a Polarized Electron Gun Based on an S-Band PWT Photoinjector*, PAC 2003, Portland, 2003