Polarized Electron Gun Development at the Brookhaven National Laboratory

J. Kewisch, X. Y. Chang, I. Ben-Zvi, V. Litvinenko, T. Rao, J. Skaritka, B. Sheehy, A. Pikin, W. Meng, E. Wang, Q. Wu, D. Pate, A. Burrill, T. Xin,
Brookhaven National Laboratory, Upton, NY 11973, USA

D. Holmes
Advanced Energy Systems, Medford, New York 1176, USA

Abstract. Development of two different polarized electron guns is ongoing at BNL. One aims at extremely high brightness at a moderate beam current. This design uses a superconducting RF gun and a test setup is built to show that a Gallium-Arsenide cathode with negative affinity has a sufficiently long quantum efficiency lifetime in such an environment. An electron injector using this technology may eliminate the need of the electron damping ring and a long transport line at the International Linear Collider. The other project aims at producing a high beam current with moderate emittance requirements, dubbed the "Gatling gun". In this DC gun, bunches are extracted from 20 separate cathodes and merged into a single beam using a rotating magnetic field. Such an electron gun could serve as an injector for the electron-ion collider eRHIC, which is planned at BNL. We will report on the status of these projects.

1. Introduction
Since the luminosity in a collider is proportional to the number of particles in each bunch and inversely proportional to the bunch area there are two ways to obtain high luminosity: One can increase the beam current or increase the brightness of the beams. When polarized electrons are required both these methods have their own set of problems, but they are ultimately limited by the rapid aging of the cathodes caused by ion back-bombardment. The number of ions which are created in the gun and hit the cathode, is proportional to the beam current and the vacuum pressure. A high beam current is therefore a direct cause of cathode aging. A high brightness requires a high accelerating voltage near the cathode, which can be obtained using an RF gun. However, normal conducting RF guns heat up during operation, which causes outgasing and a high vacuum pressure.

Two R&D projects at BNL are trying to address these problems: The “Polarized SRF Gun” project tries to eliminate the vacuum pressure problem of normal conducting guns by using a superconducting gun, which not only eliminates the outgasing, but also acts as a cryo-pump. The experiment is designed to show that the cathode in such a gun has a useful quantum efficiency lifetime and that the cesium layer does not contaminate the cavity.

The “Gatling gun” project is the construction of a DC gun with twenty separate cathodes. The beams from these cathodes are merged using a rotating magnetic field. The destruction caused by the back-scattered ions is therefore reduced for each cathode by a factor of twenty.

Published under licence by IOP Publishing Ltd
2. The polarized SRF gun
The setup consists of three parts: a cathode preparation chamber, which is used to clean and cesiate the cathode, the gun itself consisting of the beam line, Faraday cup and cryostat and a transporter which allows transferring the cathode from the preparation chamber to the gun without exposing it to air.

Figure 1: The preparation chamber with attached transporter. The transporter can be detached between the two valves for moving the cathode to the gun. The pictures on the right show the insertion of the cathode plug into the heater block and the location of the ring-shaped anode and holder of the cesium source.

Figure 1 shows the preparation chamber with attached transporter. During the cathode preparation the plug is inserted from below into a heater block in the preparation chamber (lower right picture). The cathode is heated to 580° Centigrade. The upper right picture shows the ring-shaped anode and the holder for the cesium source. A laser beam shines from above onto the cathode during preparation in order to measure the change of the quantum efficiency. O₂ is used instead of NF₃ in the cathode preparation, since oxygen does not require any special safety procedures.

Cathodes with a quantum efficiency of up to 10% have been prepared successfully. Figure 2 and 3 show the quantum efficiency as a function of time during the Yoyo procedure and during a preparation where cesium and oxygen are applied at the same time. With this procedure the final quantum efficiency is slightly better, which may be explained by the improved vacuum pressure. However, the preparation time is 30% shorter.
The transporter consists of a movable rod, which is used to retract the cathode plug into the vertical pipe. Two ion pumps are used to keep the pressure in the transport chamber and the load lock chamber low. A NEG pump and a cold cathode gage with an Americium source were added to the original design. Although the manufacturer recommended not to exceed 250°C for baking the pipe was baked at 400°C without damage.

The gun assembly is shown in Figure 3. In the back wall of the gun is an adapter, which allows insertion of the cathode plug and a valve, which is opened after the transporter is attached and the volume between the valves is pumped down. After the insertion of the cathode into the gun the transporter is removed and replaced by a pipe which leads to an ion pump outside the cryostat. The pipe also serves as a pressure relief path in case the gun volume is filled with liquid Helium through a vacuum leak. NEG pumps above the gun improve the vacuum when the gun is warm. The electron beam exits through the top plate and is deflected into a Faraday cup. The assembly of the beam line is completed. We are waiting for the completion of the radiation safety system and the Helium recovery system, which is expected by the end of 2010.
3. The “Gatling” gun

The Gatling gun project is in the designing and prototype constructing stage. The 200 kV DC gun will be designed to produce bunches of 3.5 nC with a bunch frequency of 14 MHz, resulting in a beam current of 50 mA. The final normalized emittance shall be not more than 20 mm mrad with a bunch length of 3 mm and an energy spread of 1% at 10 MeV. Figure 5 shows the layout of the accelerator. The 20 cathodes are arranged on a circle with 30 cm diameter. After acceleration and initial focusing, the beams are deflected to the center of the circle, where the beams are bent onto a common axis with time varying fields.

![Figure 4: Layout of the Gatling gun accelerator.](image_url)

![Figure 5: Three dimensional model of the Gatling gun (left) with the attached cathode preparation chamber.](image_url)
Figure 6 show the three-dimensional model of the gun and preparation chamber. The beam will exit the gun towards the top. The green lines indicate the path of the laser beams. For the regeneration of the cathodes the cathode plugs are transferred from the circle onto a linear holder and moved through the connection pipe.

For spin dynamics reasons both deflections of the bunches have to be of the same type: either electric or magnetic. We use the magnetic deflection because the magnetic deflection is much more efficient than the electric deflection at our 200 keV of electron energy level. The combiner magnet has a ring shaped ferrite core with 20 separate coils which are powered with a frequency of 700 kHz and peak current of 124 Amperes AC current. With the correct phase relations this produces a rotating dipole field.

With only a dipole field the magnet also focuses, which makes the bunches elliptical. This increases the emittance of the combined beam. For compensation another 40 coils are added to create a rotating quadrupole, driven with 1400 kHz and 2.4 Amperes. Figure 6 shows a proto-type of the combiner magnet with 8 dipole coils and 16 quadrupole coils. Measurements show that the field quality of this magnet is sufficient not to increase the beam emittance.

Figure 6: Prototype combiner magnet.

References
[1] Kewisch J, Ben-Zvi I, Rao T, Burrill A, Pate D, Grover R, Todd R, Bluem H, Holmes D and Schultheiss T 2007 AIP Conference Proceedings 980 118
[2] Kewisch J, Ben-Zvi I, Rao T, Burrill A, Pate D, Wang E, Todd R, Bluem H, Holmes D and Schultheiss T 2008 AIP Conference Proceedings 1149 1133