MG CATHODE AND ITS THERMAL EMITTANCE*

X.J. Wang, M. Babzien, R. Malone and Z. Wu, NSLS, BNL, Upton, NY 11973, USA

Abstract

A Mg cathode manufacture and operational procedure were developed at the Brookhaven National Laboratory (BNL). Mg cathde been operating routinely at a field of 100 MV/m with quantum efficiency (QE) of 0.2 to 0.3%. Good vacuum (better than 10^{-9}Torr operating vacuum) and vacuum based laser cathode cleaning are critical to maintain the above QE. Experimental measurements show that, the photo-emission process in the RF gun is the Schottky dominated surface photo-emission. Emittance as functions of the RF gun phase and laser spot size were experimentally characterized for charges less than 120 pC at the beam energy of 45 MeV. The up limit of the thermal emittance deduced from our experimental data is 0.4 mm-mrad/mm, which contradict with earlier experiment and conventional theory [1-3]. The optimized emittance for a 0.5 nC charge beam is 0.6±0.2 mm-mrad.

1 INTRODUCTION

The performance of the photocathode RF gun has been convincing demonstrated recently by the experimental observation of the saturations of Self-Amplified Spontaneous Emission (SASE) free electron laser (FEL) from visible to UV [4-6]. The major challenges now facing the photoinjector community are further improvement of the emittance with laser shaping and stability and reliability of the photoinjector system.

The stability and reliability of the photoinjector system are primarily dominated by the laser system and photocathode. A robust high QE photocathode is critical in improving the photoinjector stability and reliability. Alkali telluride (Cs_2T) and Mg are two types of cathode materials have demonstrated long life time (longer than several weeks and good quantum efficiency (better than 0.1%), and been used for those saturated SASE FEL experiments [1-3].

Mg cathode has the advantage of longer lifetime, demonstrated compatibility of high field (100 MV/m), and good QE (0.1 – 0.3 %). Further more, our experimental data show that, Mg cathode has smaller thermal emittance due to the surface photoemission and mismatch between the work function and photon energy. In the rest of this report, we first present the Mg cathode production and operating technique as well its performance data; then the emittance was characterized as the functions of the RF gun phase and laser spot size. Those data put the up limit of the Mg cathode RMS thermal emittance at 0.4 mm-mrad/mm.

2 MG CATHODE AND ITS PHOTOEMISSION PROCESS

Since early 1990s, BNL has been exploring the Mg cathode for photocathode RF gun applications [7-8] based on the initial DC testing results. One of the surprising observation in photocathode RF gun experiment is that, the photoemission of the Mg cathode under 100 MV/m RF field is dominated by the Schottky effect even with large mismatch between the Mg work function (3.65 eV) and photon energy (4.66 eV).

2.1 Mg cathode production

We have tried several techniques of making Mg cathode with varying degrees of success. Oven brazing and arc welding were ruled out because of possibility Mg burning at the high temperature. The first Mg cathode installed in the RF gun was made using press fitting technique [7]. An oversize Mg cathode was first dipped into LN_2, and it was then pressed into the Copper cathode plate. Due to the difference of the thermal expansion between Mg cathode and Copper, this type of cathode can not be vacuum baked, and the joint between the Mg and Copper is the source of RF breakdown.

Another cathode with a thin layer Mg (20 – 30 μm) deposited was installed in the RF gun [8]. The cathode was damaged during the RF breakdown at the initial RF conditioning.

To overcome the problems encounter, we started exploring possibility of using frictional welding. Working with the welder, and after several trial errors, we have developed a reliable Mg cathode manufacture procedure. To get the reliable Mg and Copper joint, the contact surface was maximized, and Copper was pre-heated during the friction welding to about 200 - 300 °C. Fig.1 is the picture of the frictional welded Mg cathode. We have produced Mg cathode plates for ANL LEUTL, Waseda University and University of Tokyo using this technique.

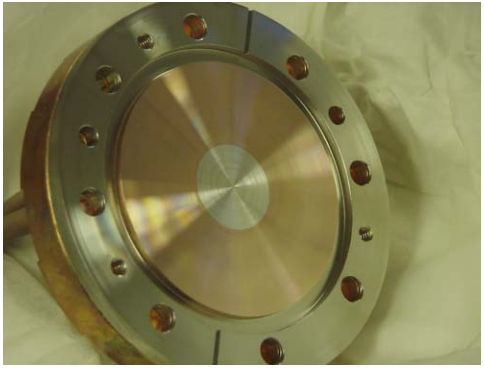

Figure 1: Mg cathode manufactured using frictional welding technique.

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xwang@bnl.gov

2.2 Vacuum based laser cathode cleaning

Produced reliable Mg cathode does not guarantee good QE. We have developed a complete procedure of preparing and operating the Mg cathode. The cathode was polished using three different sizes diamond compound [9]. Care must be taken to avoid the cross contamination during the polishing. The polished cathode was ultra-sound cleaned in the Haxzine bath. The polished cathode was baked at 150 °C at the vacuum better than 10^{-7} Torr for a week before installation.

Even with all care taken, it is necessary to get rid of the Mg oxidation layer since it is a very good insulation material. Laser has been used to burn off this insulating layer periodically (length depends on the vacuum, monthly basis if operating vacuum is better than 10^{-9} Torr). One of the problems we ran into is how to reliably performing laser cleaning without damage the cathode. We have developed vacuum based laser cleaning technique. For an initial vacuum of 2×10^{-10} Torr vacuum, we gradually increase the laser energy (spot size 0.2 mm) until the vacuum increase to about 5×10^{-10} Torr (always keep it better than 10^{-9} Torr during the laser cleaning). This will guarantee removal of only mono-layer of surface without damage the cathode. For the cathode installed at the BNL Accelerator Test Facility (ATF) in March 1999, more than 10 laser cleanings performed, success rate is 100% for QE restoration. More than a factor of 10 improvement was observed after initial laser cleaning. Fig 2 is the QE measurements (0.2%) for Mg cathode at a field of 90 MV/m on the cathode.

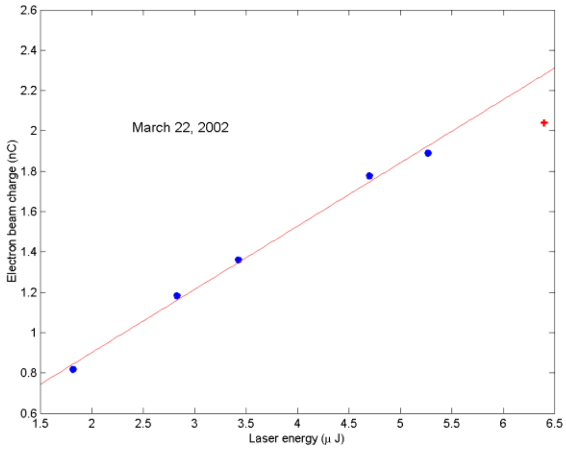

Figure 2: QE (0.2%) measurement for Mg cathode at the field of 90 MV/m.

2.3 Photoemission process in Mg cathode

In the preceding section, we emphasized the importance of good vacuum for Mg cathode because the photoemission process for Mg cathode in the RF gun is surface photoemission, its lifetime linearly depends on the vacuum. Fig 3 plots the photo-electron beam charge as the function of the RF gun phase for a laser energy 2.5 μJ. It shows that, the photoemission process is dominated by the RF electrical field (Schottky effect). The penetration depth of the electrical field is much smaller than the skin depth for the RF field, which is on the order of 50Å or less. Vacuum based laser cathode cleaning provides another proof for the surface photoemission process since it only removes mono-layer molecules based on the vacuum variation.

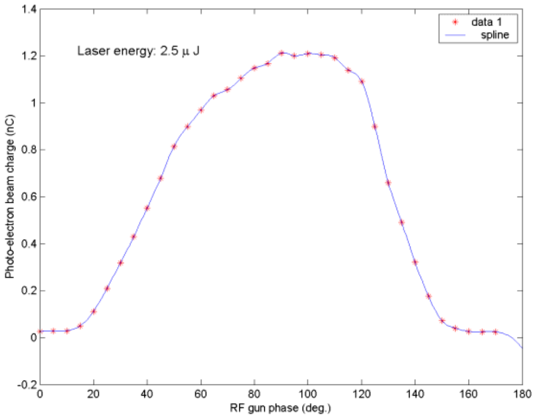

Figure 3: Charge as the function of the RF gun phase.

3 MG CATHODE THERMAL EMITTANCE CHARACTERIZATION

Most photoemission process can be explained by the three-step model. It involves optical absorption by electron, transport (diffusion) of electron to cathode surface, escape of electron through surface potential. We have shown that, photoemission for the Mg cathode in the RF field is surface photoemission, and it has tremendous impact on the thermal emittance. Thermal emittance affect the performance of the photoinjector in two aspects. First, it is the limit the electron beam emittance. And the growth rate of electron beam emittance due to space charge could be also determined by the initial thermal emittance. The normalized rms thermal emittance is,

$$\varepsilon = \frac{\sigma}{2}\sqrt{\frac{E_{th}}{mc^2}} \qquad (1)$$

where σ is rms laser spot size, and E_{th} the thermal energy of photo-electron. The earlier work [1-3] assume photoelectron has the following kinetic energy with random angular distribution,

$$E_{th} = E_{ki} = h\nu - \psi_{Mg} + \alpha\sqrt{\beta E \sin\theta} \qquad (2)$$

where $h\nu$ is the photo energy (4.66 eV), and ψmg is the Mg cathode work function (≈3.6 eV). α is a constant, and $\beta\geq1$ is so called field enhancement factor. E is the RF field, and θ is the phase of the RF field. Using above formula, the minimum thermal emittance for the Mg cathode is,

$$\varepsilon_{mim} \approx 0.7\sigma \quad mm-mrad \qquad (3)$$

Where σ is rms laser spot size in mm. Using this result, Mg cathode was ruled out for future X-ray FEL application (above number will be a factor of two larger if ref 1 convention is used). We will present the analysis and the experimental data in the following to show above analysis is not valid for Mg cathode. Our experimental data shows that, the photoemission process of Mg cathode in the RF field is surface emission. For the surface photoemission, both conservation of energy and momentum demands all photoelectrons has the same energy, and mostly moving in the direction perpendicular to the surface due to the symmetry and recoil of the lattice. Our experimental data shows that, the Mg cathode has a thermal emittance at least a factor of two smaller than Eq.3 prediction.

The challenges in measuring the thermal emittance is to distinguish various sources of electron emittance. We must consider emittance due to space charge, RF , measurement error and resolution. We carried out our experiment at the beam energy 45 MeV for a laser pulse length 10 ps (FWHM), cathode field at about 100 MV/m. For a charge less than 125 pC, we observed little emittance dependency on the charge, so we concluded that measured emittance will be dominated by RF effect and measurement errors. Fig.4 is the normalized rms emittance as function of the RF gun phase, where 90 deg corresponding to the peak acceleration field. The large growth of the emittance at the higher RF gun phase shows that, emittance measurement must be done in the lower gun phase to minimize the RF contribution.

We then measure the RF gun emittance as the function of the laser spot size at the gun phase 15 deg. Fig.5 plots the normalized rms emittance as thefunction of the laser spot size. Linear dependency of the emittance as a function of the laser spot size indicates that, either emittance now is thermal emittance or resolution dominated. Our detailed analysis show it is resolution dominate [10]. For argument sake, let us even assume it is thermal emittance. Fig. 5 plots the emittance for a 0.5 nC charge over about 1.5 hours time. It shows the measurement error is about ±0.1 mm-mrad. Combing fig. 5 and 6, we concluded that, the up limit of the thermal emittance for the Mg is about 0.4mm-mrad/mm, which is about a factor two smaller than prediction.

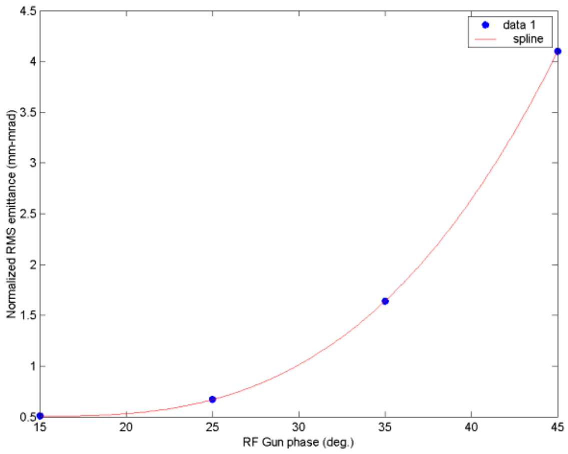

Fig.4: Normalize rms emittance as the function of the RF gun phase.

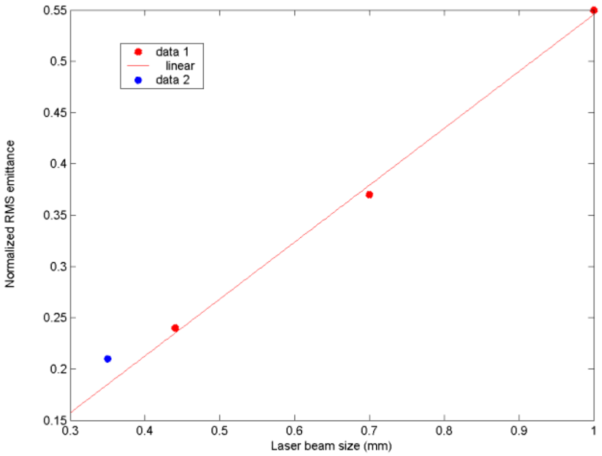

Figure 5: Normalize rms emittance as the function of the laser spot size.

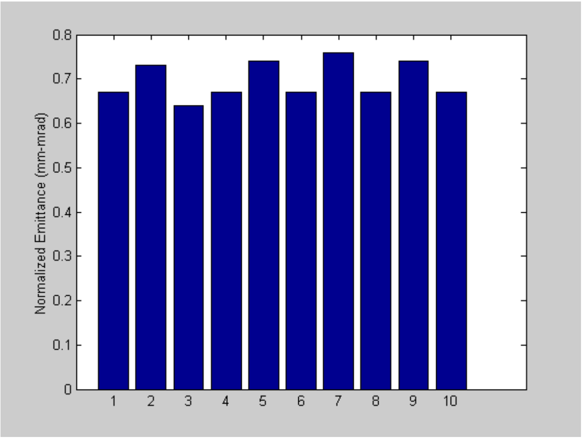

Fig.6: normalize rms emittance as function of No. of measurement for a 0.5 nC charge.

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