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Abstract

Significant progress has been made in both improving the quantum efficiency and understanding the physics process of photoemission of metal photocathode materials under high electric field. Metal material, copper and magnesium were installed on the photocathode RF gun, and experimentally investigated using frequency quadrupled Nd: Yag laser (266 nm). A systemic procedure was developed for preparing cathode; this involves diamond polishing, ultrasonic cleaning and high-temperature vacuum bake out. Using laser cleaning and explosive electron emission cleaning, the highest quantum efficiency measured for copper and magnesium are 0.02% and 0.3%, respectively. The Schottky effect was experimental investigated, the quantum efficiency of the Cu is dominated by the Schottky effect since the work function of the copper is almost equal to the photon energy used (4.66 eV). The quantum efficiency of the magnesium is significant enhanced by the Schottky effect.

I. Introduction

One of the major improvements in the last few years in photocathode RF gun technology is the development of CST cathode [1], the life time of the semiconductor was extended from days to weeks. But stringent vacuum condition and other considerations limit semiconductor cathode's applications. Rapid developments in laser technology, such as diode pumped laser system and high efficiency nonlinear crystal [2], made it using relative low quantum efficiency (Q.E.) metal cathode more attractive and practical, because its robust and long life time. One of the major challenges in using metal cathodes in photocathode RF gun is its inconsistency in QE measurements and QE improvement technology. We will report the progress have been made in the last few years in metal cathode materials, such as Copper and Magnesium, at the Brookhaven Accelerator Test Facility (ATF).

We will first present the procedure of preparing the metal cathodes for photocathode RF gun, and experimental results of QE measurements for both Copper and Magnesium cathodes. One of the most important effects in photoemission from metal material is the Schottky effect, we will present the experimental measurement of the Schottky effect on both Copper and Magnesium cathode, discuss its application and effect on the performance of the photocathode RF gun.

II. Experimental Measurements.

The quantum efficiency measurements for both Copper and Magnesium were made in the photocathode RF gun several years ago [3,4]. Since then, several labs have reported large variation in their QE measurement for both Copper and Magnesium cathodes. We have developed a procedure of preparing the metal cathode for photocathode RF gun applications, which enable us consistently produce reasonable results. The cathode preparation involves several steps. The initial ultra-sound cleaning in the alcohol bath remove any contamination on the cathode surface left from

cathode manufacture. Then cathode surface was polished using using three different size diamond polishing compound, as polish progressing, the diamond sizes in the polishing compound were reduced from 9 μm , 6 μm to 1 μm . The polished surface was rinsed with Hexane before immersed in the Hexane bath for 20 minutes ultra-sound cleaning. After the cathode surface was blown dry with dry nitrogen, it was placed inside a UHV vacuum chamber for bake out. The bake out usually lasts about a week. The cathode was install on the 1.6 cell photocathode RF gun [5] developed by the BNL/SLAC/UCLA collaboration under dry nitrogen.

Fig.1 The measured photoelectron charge as function of the RF gun phase for Cu and Mg cathodes.

The photocathode of the RF gun at the ATF was driven by a frequency quadrupled (266 nm) Nd: Yag laser system. A small fraction of the laser energy was splitter off allows us monitor both the laser energy and spot size on the cathode. The charge was measured using a Faraday cup half-meter down stream of the RF gun. The solenoid magnet at the exit of the RF gun can be used to focus the photo electron beam on to the Faraday cup for charge measurement. Since the work functions for both Copper (4.0 - 4.6 eV) and Magnesium (3.7 - 4.1 eV) are close to the

photon energy of the frequency quadrupled Nd: Yag laser (4.66 eV), the QE measurement is the strong function of the RF gun phase (i.e. the instant electric field) when laser strikes the cathode. Fig. 1 shows that both Cu and Mg QE measurements as the function of the RF gun phase.

Fig.2 QE measurements for Cu cathode before and after the explosive laser cleaning.

The QE measurement for the Cu cathode at 90° of the RF gun phase is plotted on Fig.2. The initial QE without any laser cleaning is about 2×10^{-5} . To further improve the QE, we adopted so-called explosive laser cleaning. By reducing the laser spot to 0.3-mm diameter, with 50 μJ laser energy, the laser induced explosive electron emission will occur [6]. After first explosive laser cleaning, more than a factor of two improvements in QE was observed. We also observed an order of magnitude variation in QE on the cathode surface (2-mm diameter). After several more cleanings, we reduced the QE variation on the cathode surface to less than 50 %, and measured QE is about one order magnitude improvement over the initial QE (2×10^{-4})).

Fig.3 shows the QE measurement for a Mg cathode. Mg cathode is made of 99.8% pure magnesium cylinder with half-inch diameter, it was press fit on to the copper. It took more than a week of RF conditioning for the Mg cathode to reach the Normal RF gun operating field gradient of 100 MV/m. The initial QE of the magnesium cathode is less than That Cu's, we attributed that to the oxidation of the Mg surface. We first cleaning the cathode with laser only, the laser energy used is about 15 μJ for a laser spot diameter of 0.3 mm. Almost a factor of two improvement of QE was measured. Then we turn on the RF power (with field gradient on the order of 30 MV/m), and 25 μJ laser energy, we were able to clean the cathode using explosive laser Cleaning

Fig.3 QE measurements for bulk Mg cathode before and after laser cleanings.

technique. After several laser explosive cleanings, the variation of QE over the cleaning surface is less than 50%, and the best QE measured is 0.3 %. The QE decayed to about 0.1% in eight hours. And it took several weeks for Mg QE decay to about 0.04%. We always be able to restore the Mg QE to 0.1% with explosive laser cleaning.

We have observed that the joint of the press fit of Mg on the Cu is one of the main cause for RF break down in the RF gun, this limits the field on the cathode to about 100 MV/m. We also explored other technique of mounting the Mg on the Cu cathode plate. One technique we used is sputtering a thin layer of Mg on the Cu cathode (20 μm). It was measured that the damage threshold for sputtered Mg is more than twice high than bulk Mg. Fig.4 shows QE measurement for sputtered Mg before and after laser cleaning without RF on. One interesting feature we observed, that the QE of sputtered Mg decay much faster than bulk Mg (fig.5).

Fig.4 QE measurements for sputtered Mg cathode before and after laser cleanings.

Fig.5 the QE lifetime measurement for sputtered Mg cathode.

III. The Schottky Effect

The photoelectron current density can be described by the following formula [7],

$$j = AI(t)(h\nu - \phi + \alpha\sqrt{\beta E(t)})^2 \quad (1)$$

Where $I(t)$ is the time dependent laser intensity, $h\nu$ is the photon energy, ϕ is the work function of the cathode material, and $\beta > 1$ is so-called field enhancement factor, and $E(t)$ is the instantaneous electric field on the cathode. For metal cathode used, the photon energy and work function is close, so the time dependency of the photoelectron beam will strongly depend on the instantaneous electric field. Fig.1 shows that, for both Cu and Mg, the charge of the photoelectron beams were determined by the RF gun phase. This clearly shows that, the Schottky effect plays important role in photoemission process of the metal cathode in the RF gun.

The schottky effect not only affect the QE of photoemission (Fig.1), it also plays important role in charge distribution inside the photoelectron bunch and space charge effects. For example, Fig.3 shows that the QE change dramatically for high charge situation due to the space charge field. And this implies that the later part of the charge of photoelectron bunch is suppressed by the space charge induced Schottky effect. This will change the bunch length of the photoelectron beam and dynamic process inside the photocathode RF gun (Fig.6).

The schottky effect can be used to determine the absolute RF gun phase relative to the laser. The most important application for this effect maybe, the longitudinal distribution shaping of the photoelectron

beam by adjusting the relative phase between the laser and RF gun for a fixe charge.

Fig.6 The photoelectron charge as the function the RF gun phase for four different laser energies.

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