EXPERIMENTAL RESULTS FOR MULTIPHOTON NONLINEAR PHOTOEMISSION PROCESSES ON PHIL TEST LINE *

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Abstract

One of the prerequisites for the next generation high-luminosity light sources is the availability of the short electron bunches. It also has several applications in other domains, including medical diagnostics and high-resolution imaging. In principle, using photoelectric effect a short electron bunch can initially be generated by illuminating a photocathode with an ultra-short light pulse of appropriate wavelength. Strong EM fields from a RF gun or similar accelerating structures, synchronized with the incoming laser pulses, are then used to accelerate these electron bunches initially up to an energy of tens of MeV.

We present our preliminary results on the experimental investigation of two-photon nonlinear photoemission processes for the generation of picosecond, low-charge electron bunches conducted at PHIL photoinjector facility. A comparison of the emission efficiency and bunch characteristics with the single photon emission process is also made.

INTRODUCTION

In order to reduce the size of the present day electron linacs, we investigate the possibility of generating the short electron bunches using multiphoton emission processes. The advantage of using n-photon emission processes ($n > 1$) over single photon emission processes is that the quantum efficiency of nth order photoemission process depends on the peak intensity of the incident laser pulses at the photocathode.

n-Photon Photoemission Process

The photoelectric effect where the energy of individual photons is less than the effective work function of the metal ($h\nu < e\Phi$), photoemission may still occur by absorbing multiple photons from the incident light beam. Fowler-DuBridge theory provides a simple and yet highly accurate description of the photoemission process. Accordingly, for an incident laser pulse with frequency ν, pulsewidth τ, intensity I, on a metal with work function W_0, the total number of available electrons $\mathcal{N}^{e^-}_{\text{avg}}$ for an n-photon emission process is given by,

$$\mathcal{N}^{e^-}_{\text{avg}} = \frac{2\sqrt{2}\pi m^{3/2}}{h^3}\frac{k^2T^2}{(W_0 - nh\nu)^{1/2}}\mathcal{F}(X_n); \qquad X_n = \frac{nh\nu - e\Phi}{kT} \tag{1}$$

where, $\mathcal{F}$ is the Fowler function [1], e is the elementary charge, h is the Plank's constant, k is the Boltzmann constant, m is the electron mass, T is the temperature and Φ is the modified work function of the metal due to Schottky effect. The n-photon current density $\mathcal{J}_n$, for a metal with surface reflection coefficient R is given by [2],

$$\mathcal{J}_n = a_n A T^2 \left(\frac{e}{h\nu}\right)^n (1-R)^n I^n \mathcal{F}(X_n) = c_n I^n \tag{2}$$

where $A = 120$ A/cm^{2}K^2 is the Richardson constant and a_n is a material dependent constant, representing the probability of occurrence of the n-photon emission process.

The total extracted charge (Q) for the n-photon emission process as a function of the incident laser energy (E) at the photocathode is given by [3],

$$Q_n = \frac{c_n E^n}{\pi^{\frac{n-1}{2}} n^{3/2} \tau^{n-1} (\pi r_0^2)^{n-1}} = b_n E^n \tag{3}$$

This simplifies to the following for a two-photon process,

$$Q_2 = \frac{c_2 E^2}{(2\pi)^{3/2}\tau r_0^2} = b_2 E^2 \tag{4}$$

Schottky Effect

Due the the presence of a strong electric field at the surface of the photocathode at most of the photoinjectors in the world, Schottky effect plays a very significant role. If we could change the field at the surface of the photocathode and measure the total extracted charge without saturating the photocathode, we could be able to visualize the changes in the emission process due to the Schottky effect.

EXPERIMENTS AT PHIL

In this article we present a comparison between the single and two-photon emissions from Magnesium photocathode. These experiments were conducted using the photoinjector facility at LAL (PHIL), Orsay, France. The effective work

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function (due to the RF gun) for Mg at PHIL was found to be less than 3.68 eV. And thus, for facilitating single photon emission processes we used a laser pulse in UV with $\lambda = 262$ nm ($h\nu = 4.73$ eV) and ~ 5 ps pulsewidth; whereas for two-photon emission processes a green laser $\lambda = 524$ nm ($h\nu = 2.37$ eV) with similar temporal characteristics was used. If a very strong electric field doesn't exist at the Mg cathode or in other words, Schottky effect doesn't bring down the effective work function below 2.37 eV, the green laser would not extract any electrons by the single-photon emission process.

Here, we present the preliminary results for single and two-photon emission processes with Magnesium cathode. Figure 1 shows an average image of the electron beams as seen on a YAG screen placed 3.13 m from the photocathode, sample size 10. The red dots in the center of the images

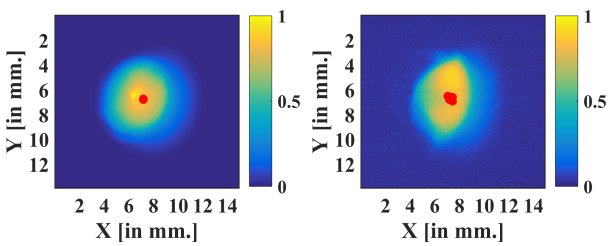

Figure 1: Average electron beam image on YAG screen placed 3.13 m from the Mg photocathode, observed at PHIL for single photoemission (left) and two photoemission (right) processes.

indicate the barycentre for individual images. The movement of the barycentre gives an idea of the stability of the electron beam on PHIL. For example, the maximum shift in the abscissa and ordinates of the barycentre observed over 10 such images is 0.05 mm for the single photoemission process whereas the same for two photoemission process was observed to be 0.4 mm. This could be due to the difference or fluctuations in the incoming laser energy, RF power or magnetic fields.

From Eq. (3) we can see that the dependence of the extracted charge from a photocathode for the n-photon photoemission process depends on the incident laser energy raise to the power n. Figure 2 shows the total extracted charge as a function of the incident laser energy at the Mg photocathode. The total extracted charge was measured using one of the integrated current transformers (ICTs) at PHIL [4]. The laser energy on the other hand was measured using a standard power/energy meter.

The curve for extracted charge versus incident laser energy for the two-photon process fits well with the 2nd order polynomial of the form $Q_2 = (0.09 \pm 0.01)E^2$. On comparison with Eq. (4), we estimate $b_2 = 0.09 \pm 0.01$ pC/μJ^2. For single-photon emission process (curve in blue), we expect to see a linear behaviour in the extracted charge with the incident laser energy, however, due to higher extracted charge even at low laser energies, we saturate further extrac-

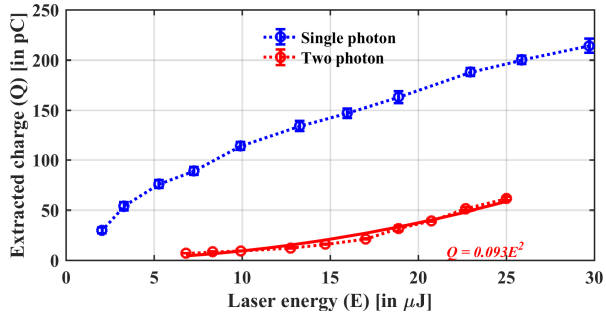

Figure 2: Extracted charge versus incident laser energy on Mg photocathode for single and two photon emission processes measured on PHIL.

tion of charge due to the mirror charges developed at the photocathode.

Figure 3 shows the variation of the total extracted charge with the RF gun phase (Φ) for three different values of the peak electric field inside the gun, 26 MV/m, 34 MV/m and 50 MV/m. Due to different values of the electric field in

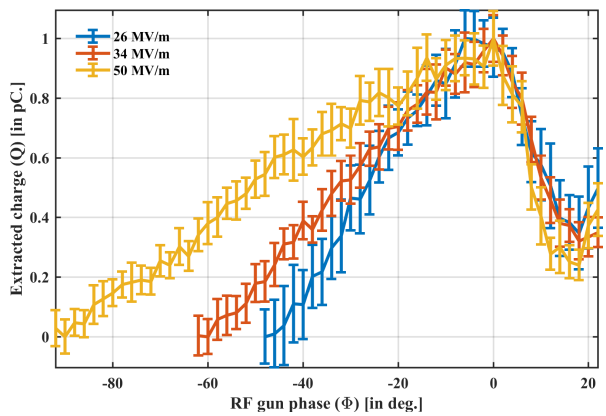

Figure 3: Variation of total charge with RF gun phase for different accelerating gradients inside the gun. 0 deg. phase corresponds to the phase for which the extracted charge is maximum.

the RF gun, the field at the surface of the photocathode is different, which induces different Schottky effects for the three cases. The difference in the extracted charge between -40 to 0 deg. is due to the Schottky effect [5]. Whereas, the shift in the RF gun phase in Fig. 3 for the onset of emission of electrons for different electric fields at the cathode, with the same incident laser energy is a signature of the multiphoton emission processes. This shift is not seen in case of single-photon photoemission process [5].

CONCLUSIONS

From the experiments involving single and two-photon photoemissions from Mg cathode at PHIL photoinjector facility, we can conclude the following:

- We were able to extract a measurable amount of charge (~ 50 pC) with ICTs at PHIL (bunch length ~ 10 ps)

using 25 μJ of incident laser energy for two-photon emission process.

- The value of the constant b_2 has been estimated to be 0.09 ± 0.01 pC/μJ^2 for Mg using this measurement. This is about 10 times larger than that for Copper [3].

We have a new high power infra-red laser facility (λ = 800 nm) capable of providing 1.5 J of pulse energy in 30 fs duration, installed near the PHIL photoinjector and in future we would use this laser facility to drive the photoinjector for multiphoton/multicolor photoemission experiments.

For single photoemission processes in metals we need ultra-violet laser pulses which are usually up-converted from visible or infra-red laser pulses. Multiphoton emission processes could save a lot of energy if we do not have to up-convert visible or IR laser pulse to UV. The efficiency of this conversion could be as low as 10% depending upon the fundamental wavelength and number of times this up-conversion is needed. Also at present, high power IR and visible pulse lasers can be found in abundance, including all sorts of optics for pulse shaping, diagnostics, etc. compared to the high power UV pulse lasers and the corresponding optics. Therefore, we think such kind of studies are extremely important and show a lot of potential for the future.

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