PHOTOELECTRON GENERATION BY FEMTOSECOND UV LASER

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Abstract

Photoelectron generation by the femtosecond laser is necessary for the generation of the short pulsed electron source. We performed the experiments using a hundred femtosecond UV laser with a DC photocathode. Magnesium reported to have the high quantum efficiency were selected as a candidate for photocathode material. We compared the bulk with the crystal magnesium. Quantum efficiency of the crystal was larger than one of bulk magnesium.

1 INTRODUCTION

The very short pulse laser in a femtosecond region is a very useful tool to study the mechanism of multiple electronic scattering. In more than GW/cm^2 region, nonlinear dependence on the laser fluence has been observed[1][2] and the high quantum efficiency is expected. It has potential to generate the electron source of the short pulse width and high current density. We studied the crystal magnesium, irradiated by the hundred femtosecond UV laser using the DC cathode under the very high power density.

High brightness electron beam has been studied with RF photocathode illuminated by a short pulse laser[3][4][5]. High brightness electron beam is necessary for free electron lasers(FEL), laser accelerators, wake field accelerators and the generators of short pulse X-ray by Thomson scattering. In order to obtain the high brightness electron beam, the high current, the low emittance and the short beam bunch are required, however, which technologies needed are dependent on applications. The short beam bunch is greatly dependent on the laser performance. Several picosecond lasers have been used for the photocathodes to get several picoseconds short bunch, while subpicosecond beam was obtained with the several methods of beam bunching. With the development of the solid state laser, especially diode pumped lasers, the reliability and the lifetime of the short pulse laser have been improved. Femtosecond lasers just appeared in commercial market.

Material used as cathode is also very important. Materials for photocathode are generally classified into two groups. One is the semiconductor and the another is the metal. When the short electron bunch is required, the metal cathode is suitable because of the very short response time (10^{-14}-10^{-15}second). Many materials have been searched to get higher quantum efficiency. Quantum efficiency of bulk magnesium up to $3x10^{-3}$ being comparable to the semiconductor was reported[5]. It is generally known that the quantum yield is dependent on work function and each crystal with distinctive oriented face has different work function. Crystalline metal with oriented face is expected to have higher quantum efficiency.

We performed the experiments for the crystal [0001] and bulk magnesium as a cathode material irradiated by a hundred femtosecond UV laser to get the information on the difference between the bulk and the crystal.

2 APPARATUS

A laser system that was based on a mode-locked Ti:Sa laser generated 790nm wavelength radiation. The 790nm wavelength radiation was converted to the second and the third harmonics with two BBO(Beta-Barium Borate) crystals.

Third harmonics which is 260nm wavelength, 4.77eV, was used to illuminate the photocathode. Pulse width of fundamental, measured using an auto-correlator was one hundred femtosecond. We estimated the pulse width of the third harmonics of 260nm based on the spectral intensity of fundamental. The conversion efficiency to the second and third harmonics are proportional to square of fundamental intensity and multiplication of fundamental and the second harmonic intensity, respectively. We also calculated the broadening of beam pulse through a focusing lens and a window glass. As a result, we estimated one hundred femtosecond as the pulse width of the third harmonics.

The system of the photo-injection is shown in Fig.1. The third harmonic was separated from other wavelength light by dichroic mirrors and used to illuminate the cathode at 35 degree incident angle.

Voltage between an anode and a cathode was 35 kV at maximum. Charge of electrons emitted from the cathode was measured with a Faraday-cup. Charge detected was normalized by a signal of an energy meter detecting about 10% of laser energy split by a partial mirror. A CCD camera was set at opposite side against the laser beam to measure the beam size at the cathode.

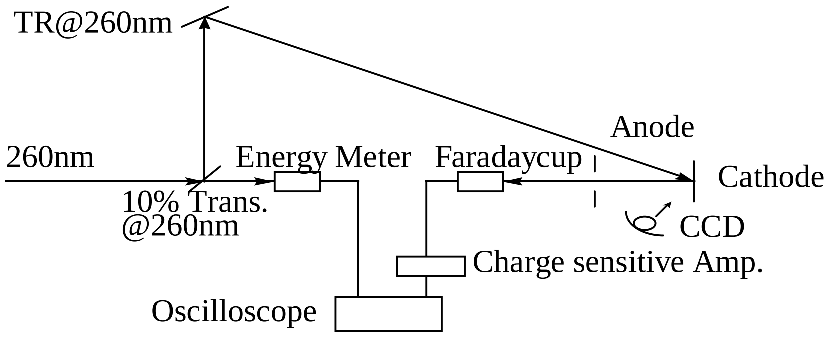

Fig.1 Systematic diagram of the DC photocathode experiment

3 EXPERIMENTAL RESULTS AND DISCUSSION

One hundred femtosecond UV light was irradiated at the cathode. The signals of energy meter and Faraday-Cup were acquired into an oscilloscope at the same time. Signal from the Faraday-cup was normalized by one from the energy meter, because of the large energy fluctuation of each laser pulse. Fig. 2 and Fig.3 show the relations between the current density and the power density for the crystal and bulk magnesium, respectively. The applied voltage of the diode were changed from 10 to 35kV. The current density increases lineary with laser intensity. However, for intensities greater than 80GW/cm^2, the slope of the curve increases suddenly. It might show the damage threshold of the magnesium. Especially, the change of the crystal magnesium is larger. Following discussions are concerning on data below 80GW/cm^2.

In our experimental conditions, the maximum current density might be restricted to 13kA/cm^2 due to the space charge limit, however, the maximum data for the crystal is 18kA/cm^2. In order to explain this phenomenon, the emitted electrons at the cathode should have the high kinetic energy to overcome the space charge limit. One possible theory is anomalous thermal heating of electrons[2]. In electron emission process, at first the electrons absorbing photon are excited and then the thermal relaxation between the electrons and the lattice happens. But for very short laser pulse, the electrons and lattice are not going into thermal equilibrium on the time scale of short laser pulse, so the electrons have high energy due to heating. In addition of this situation, there is high electric field polarized normal to the cathode surface induced from the high power density up to several tens GW/cm^2. The electrons might have the energy normal to the cathode surface by the anomalous heating and the high electric field. It is another hypothesis to explain the excessive current density over the space charge limit. Other authors reported on the energy spectrum of the

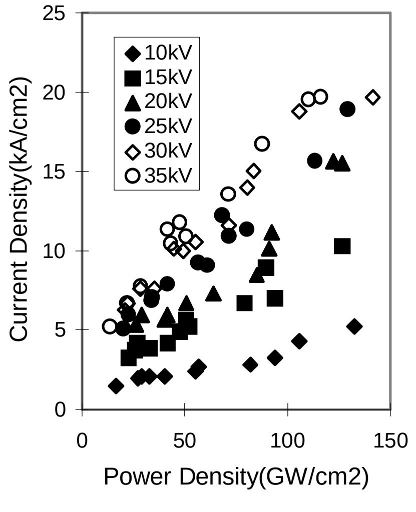

Fig.2 Current density vs. Power density for the bulk magnesium

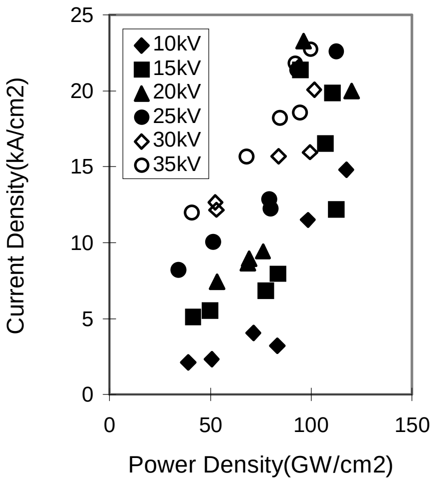

Fig.3 Current density vs. Power density for the crystal magnesium

electrons on 25GW/cm^2 with 8psec width and $h\nu$=1.17eV laser[6]. They think that the electrons with up to 600eV energy are induced by the multiphoton photoeffect of metal. We could not explain the excessive current density definitely.

As comparing the quantum efficiency of crystal magnesium with one of bulk magnesium under 80GW/cm^2, the quantum efficiency of the crystal is about 10% lager than one of bulk magnesium in spite of relatively low efficiency. It might show the difference between the work functions of the crystal and the bulk, and the work function of the crystal may be lower than one of the bulk. The measurement of the work function of magnesium is scarce. The work function reported experimentally in 1964 was 3.66eV. And some authors reported the calculation of the work function of magnesium[8][9]. John P. Perdew et al. reported the work function of some metals with structureless pseudopotensial model based jellium model[8]. Jellium model is a useful tool for the description of the bulk metal with the simple structure. Their calculation is useful to consider our results. They reported that the work function are 3.54 and 3.44 eV for the flat surface of the bulk and the [0001] surface of the crystal, respectively. Their calculation shows that the work function of the crystal is 3% lower than one of the bulk. It is not enough to compare our experimental data with their calculations and discuss the more, because that our data is in the space charge limit region and has errors and the calculations are few. In order to get more precise data, we are also going to perform the experiments without the effect of space charge, e.g. in the low energy region or the high electronic field.

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