FIRST EMISSION OF NOVEL PHOTOCATHODE GUN GATED BY Z-POLARIZED LASER PULSE

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Abstract

We have developed a laser-induced Schottky-effect-gated photocathode gun since 2006. This new type of gun utilizes a laser's coherency to realize a compact laser source using Z-polarization of the IR laser on the cathode. This Z-polarization scheme reduces the laser pulse energy by reducing the cathode work function due to Schottky effect. Before this epoch-making scheme as a concept, photocathode guns had never utilized laser's coherency. A hollow laser incidence scheme is applied with a hollow convex lens that is focused after passing the beam through a radial polarizer. According to our calculations (convex lens: NA=0.15; 60-% hollow ratio R_{ratio}, inside-out Gaussian beam), a Z-field of 1 GV/m needs 1.26 MW at peak power for the fundamental wavelength (792 nm) and 0.316 MW for the SHG (396 nm). Therefore, we expect that this laser-induced Schottky emission requires just a compact femtosecond laser oscillator as a laser source. We observed the first emission with a hollow laser incidence scheme (copper cathode illuminated by THG: 264 nm). The net charge of 21 pC with 100-fs laser pulse (pulse energy: 2.5 μJ; spot diameter: 200 μm). The maximum cathode surface field was 97 MV/m. This new scheme of gun will be investigated on several metal photocathode materials by comparing radial and with azimuthal polarizations at the three femtosecond laser wavelengths (264, 396,792 nm).

INTRODUCTION

A conventional photocathode RF gun needs a UV-laser source (~260 nm) for robust cathodes like metal copper due to their high work functions. Consequently, the laser system becomes larger and complex. To make the laser source compact, we need to find a cathode with a lower work function and high QE. However, such a high QE NEA-cathode requires an ultra-high vacuum ($< 10^{-8}$Pa) and does not have a long life time in a gun.

One solution to make the work function lower is to apply a high field on the cathode surface. In the field of 1~2 GV/m, the work function of the copper cathode reduces ~2 eV. To achieve such a high field (~1 GV/m) on the photocathode, the tungsten needle (radius: ~1μm) photocathode, the photo-assisted field-emission, was proposed and tested [1]. The obtained QE of the needle tip is found to be proportional to the >10th power of the electric field over 500 MV/m, and it reached up to 3% at about 800 MV/m. This observed field-enhancement of QE is qualitatively explained with a field-emission process including the Schottky effect and photo excitation. However, such a needle cathode tip became round and broken in the cavity during rf conditioning.

Therefore, we started to investigate with a plane-field emitter assisted by laser radiation field. We utilize recent progress of optical technologies to generate radial polarized laser propagation modes. The radial polarization beam is a superposition of π/2 phase-shifted TEM_{01} and TEM_{10} mode in the case of a polarisation direction orthogonal to each other. Focusing a radial polarized beam on the photocathode, the Z-polarization of the laser is generated at the focus point. The generated Z-polarization can exceed an electrical field of 1 GV/m easily with fundamental wavelength from compact femtosecond laser systems. On the other hand, focusing an azimuthal polarized beam on the photocathode results in zero Z-polarization fields. Comparing the radial and azimuthal polarization with focusing, we conduct a feasibility study of the laser-induced Schottky-effect on the photocathode.

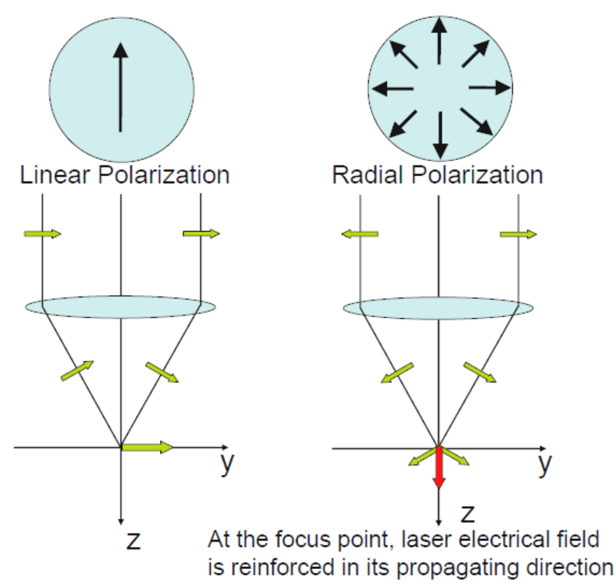

Figure 1: Principle of Z-polarization field on the cathode surface generated from radial polarization.

As the first test run, a radial polarized hollow laser is focussed with a hollow convex lens in vacuum to obtain electron emission. The aim of the first test run is observation of the first emission in this new scheme.

Comparing the radial and azimuthal polarizations with focusing, we will use a hollow axicon lens in vacuum to make the laser spot. To relax space-charge limit at the cathode, the emission current is estimated to be relative higher. This is the second test run aiming at a higher charge emission to measure polarization dependencies precisely. We report the first emission results and the preparations of the second step.

PRINCIPLE OF Z-POLARIZATION GUN

Principle of Z-polarization Generation

Focusing a radial polarized beam on the photocathode as shown in Fig. 1, the electric field of the laser is generated in the laser propagating direction (Z-direction) at the focus point. The Z-field oscillates with a periodic time of ~2.6 fs at the fundamental Ti:Sa laser (~790 nm). Roughly estimating in the case of a metal cathode, laser radiations (wavelength: λ) enter into the cathode surface with a depth of ~λ/20, and photocathode response is less than 10 fs. If the Schottky-effect-induced Z-field is large enough, we expected that electrons would make oscillations with the Z-field frequency on the outermost surface of the metal cathode and are extracted with the external electric field of the RF cavity.

To utilize the Z-polarization effectively, it requires developing special hollow optics. Schematic drawing of a Z-polarization gun with hollow laser beam incidence optics [2] is shown in Fig. 2. A hollow laser incidence scheme is applied with a hollow convex lens in vacuum that is focused after passing the beam through a radial polarizer. The Z- field is proportional to the square of numerical aperture (NA). The laser diameter before the final focusing lens should be as large as possible, and the focus length should be as short as possible. To make NA as large as possible, we designed a final focussing lens in vacuum and a hollow laser beam generator with an axicon lens pair. The axicon pair transforms the Gaussian profile from the inside out (so-called hollow beam).

Radial Polarization Beam Generator

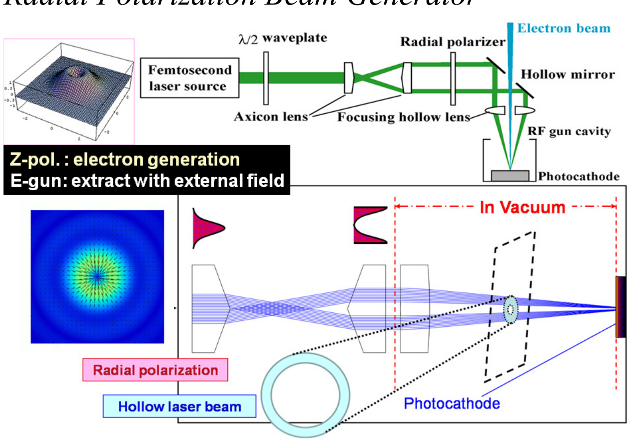

Figure 2: Schematic drawing of a Z-polarization gun with hollow laser beam incidence optics.

The radial polarization fundamental mode is generated from a combination of Hermite-Gaussian mode TEM_{01} and TEM_{10} [3]. Therefore, we chose a simple divided waveplate (see details in ref. [2]) to generate the radial polarization from a conventional linearly polarized beam. We designed an 8-divided waveplate for a hollow beam as shown in Fig. 3. We prepared generators of a hollow beam with a radial polarization at wavelengths of 264, 396, 792, 1064 nm. The current optical set-up for Z-polarization RF gun is shown in Fig. 4.

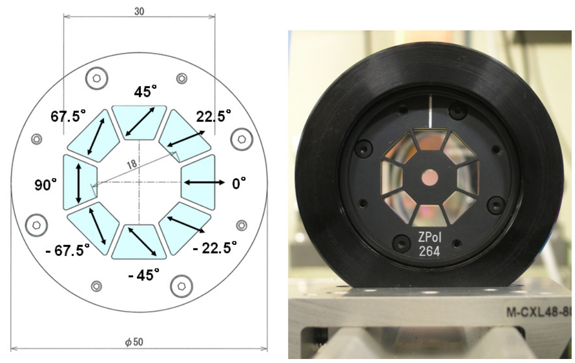

Figure 3: 8-divided waveplate (designed for femtosend; optical-contact) manufactured by Nanophoton Corporation for a hollow beam @ 264 nm: the photo of 8-divided waveplate for a hollow beam (in right) and the direction arrangement of optical axes in each segment (in left) are shown.

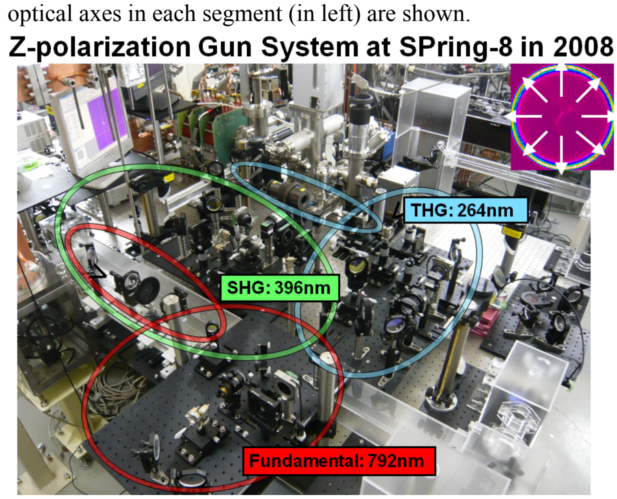

Figure 4: Optical set-up to generate a radial polarized hollow laser beam @263, 396, 790 nm: To generate a femtosecond laser pulse at the cathode, a negative-chirped laser pulse is generated at the laser source with an AO-modulator (DAZZLER HR-800, FASTLITE) to be compensated with the material dispersions.

In order to generate the electrical field in the perpendicular direction on a metal cathode, we have to select a combination of metal cathode material and laser wavelength. Comparison among laser wavelength dependencies of reflectivity on our seven metal cathode surfaces is shown in Fig. 5. For the first test run, we chose the combination with copper cathode illuminated by Ti:Sa THG (264 nm) to compare with the emission at the conventional photocathode RF gun.

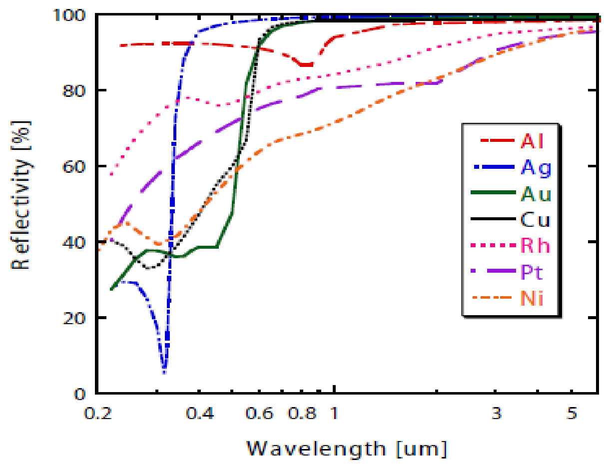

Figure 5: Wavelength dependencies of reflection ratio with metal cathode candidates' surfaces.

The Final Focussing Optical Lenses in Vacuum

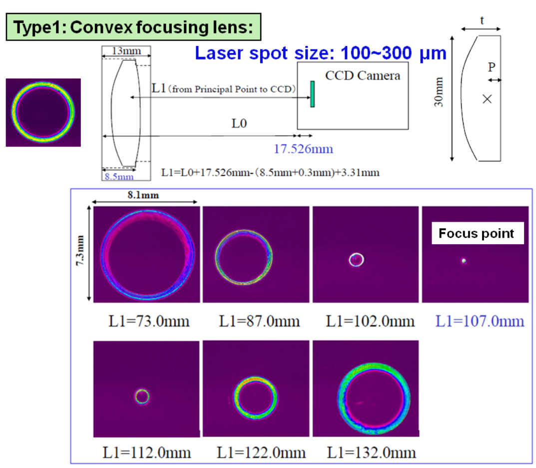

Figure 6: Focus test with a convex lens with a hollow beam.

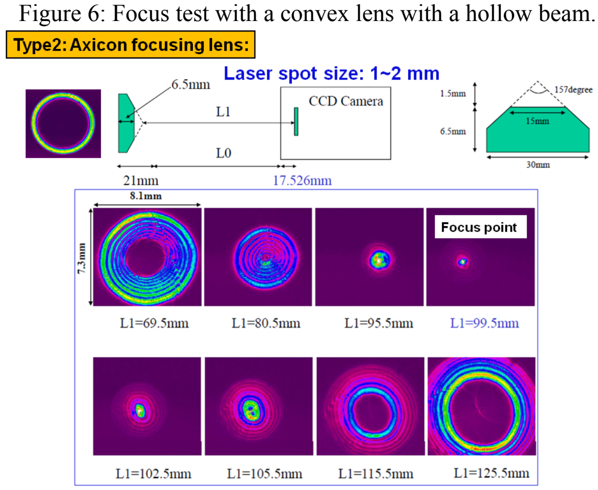

Figure 7: Focus test with a axicon lens with a hollow beam.

We prepared two types of final focusing lenses with a central hole. One is a conventional convex lens for a low charge generation. The other is an axicon lens for a relative higher charge generation (relaxation of space-charge limited emission current). The laser diameters and profiles with the both of lens types are shown in Fig. 6-7.

The outer diameter of the incident hollow laser beam was 27.2 mm at a wavelength of 546 nm (He-Ne green laser was chosen as a standard wavelength to test optics). At the focus point, diameters were 200 μm with the convex lens and, 800 μm with the axicon lens.

FEASIBILITY TEST RESULTS

In first test run, radial polarized THG was focused on a copper cathode with the convex lens (NA=0.15, 60-% hollow ratio R_{ratio}, inside-out Gaussian beam) to maximize the Z-field. The maximum cathode surface field was 97 MV/m. In this feasibility test set-up is shown in Fig. 8, we set a hollow beam with an outer diameter R0 of 30 mm and an inner R1 of 18 mm (R_{ratio}=R1/R0=60%). We observed the emission with 100-fs and 1-ps THG pulses. The net charges were 21 pC with 100-fs laser pulse (pulse energy: 2.5 μJ; spot diameter: 200 μm), and 11 pC with 1-ps laser (1.7 μJ; 200 μm), respectively. We could not see the significant differences between radial and azimuth polarizations.

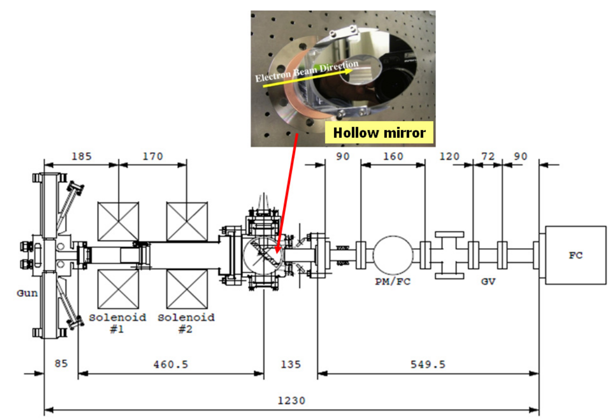

Figure 8: Experimental set-up for Z-polarization RF gun with hollow laser beam incidence optics.

SUMMARY AND DISCUSSION

We reported recent progresses of our Z-polarization RF gun and its feasibility test. Focusing a radial polarized 100-fs and 1-ps THG pulses on the copper cathode, we observed the first emission of this new concept of photocathode. We could not see the significant differences between radial and azimuthal polarizations, because of dark currents. We required ten-time more emission currents to measure the difference between them. We make clear the feasibility with an axicon focussing lens. The emission current seems to be larger than the space-charge limited emission current, it should be investigate the physics behind this emission process.

REFERENCES

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[3] S.C. Tidwell, et al., Applied Optics, 29(15)(1990) 2234.