FABRICATION OF TWO DEMENTIONAL NANO-SCALE PHOTOCATHODE ARRAYS IN TRANSPARENT CONDUCTOR FOR HIGH COHERENCE BEAM GENERATION*

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Abstract

Electron beam quality for particle source of diffractometer is mainly characterized by transverse and longitudinal coherent length, beam current density and so on. In order to improve a transverse coherent length, it is practically essential to minimize electrons emission area size as small as possible. However, the size of photoemission area is limited by focused laser beam size on the surface of cathode, and the scale is several microns. Aim to get definite overlap between the focused laser and emitters for effective irradiation, as well as to realize generation of nano-scale size electron beam, nano-scale photocathode arrays in transparent conductor are essential. Therefore, I propose to fabricate the nano-scale emission area in replace of limiting the focused laser size on the photocathode for achieving high coherence beam. The fabrication process of this novel nano-scale emitter configuration and its fundamental properties are presented in this paper.

INTRODUCTION

A requirement for modern electron sources is the development of high brightness electron beams; for example, RF-gun photocathode for X-ray free electron laser and ultrafast electron diffractive instruments. With modern electron diffraction techniques, it is possible to image atomic motion at the angstrom scale and at femtosecond time-scales. In addition, it is required to realize observation both of high spatial resolution and low accelerating energy, so that the lower electron energy leads to much lower sample damaging [1]. Metal thin film photocathode that allow ultrafast probing to generate ultrashort electron bunches have been employed as an electron source for these requirements [2, 3]. Recently, a conventional DC type field emission with a small electrostatic-lens was used to obtain images of graphene with spatial resolution at the angstrom scale [4], however, the resolution is limited by spherical aberration.

In photoemission the source size is the main factor in determining the transverse coherent length of the electron beam envelope. However, the size of the photoemission area is limited by the focused laser beam size on the surface of the cathode, which is typically several microns. The transverse coherent length ξ is given by the equation:

$$\xi = \frac{\hbar}{m_0 c}\frac{w}{2\varepsilon}. \qquad (1)$$

where ξ is the reduced Plank constant, m_0 is the electron mass, c is the speed of light, w is the beam size and ε is the normalized RMS emittance. To improve the transverse coherent length, to be smaller the cathode size can be fixed to the diffraction-imaging instrument. In this paper, the nano-scale photocathode that the verification comes from different directions is reported.

NANO-SCALE PHOTOCATHODE

The proposed nano-scale photocathode is fabricated from a transparent conductor, which has a high electric conductivity and optical transmission rate. The photocathode has a diameter of less than 100 nm with the nano-emitter part embedded in the transparent conductor. Because the plane shape can generate the plane wave, electron emission from a nano-scale plane is an ideal way to avoid spherical aberration when employed as an electron diffraction-imaging instrument. The role of the transparent conductor is to provide electrons from an external source. The photon absorption rate of the conductor should be low at the irradiated electromagnetic frequency. From these reasons, we decided to use thin film metal and transparent conductor for the emitter and the substrate, respectively, with two-photon photoemission as the electron emission process. Finally, it is important for application of imaging technology to employ back-illumination, which doesn't interfere with the electron optics. A schematic drawing of this nano-scale photocathode is shown in Fig. 1.

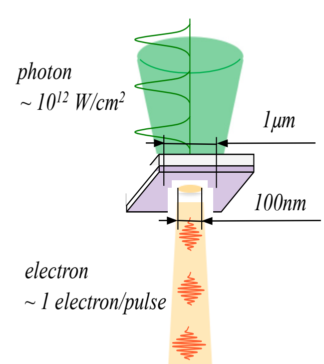

Figure 1: A schematic drawing of a nano-scale photocathode and photoemission. This method employs with a single electron per laser pulse, which completely removes the space charge effect.

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Simulation of Optical Field on Nano-scale Photocathode

When electro-magnetic fields impinge on a nano-object, the field is enhanced locally around the object. Figure 2 indicates the influence of the optical field near the nano-scale photocathode. The simulation result estimates the size of localized electric field components and the electric field in the z direction, which are generated via scattering from the nano-cathode. It is necessary to verify whether these field components affect the coherence of the nano-localized beam.

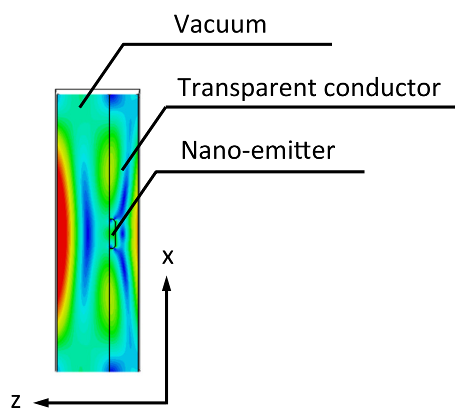

Figure 2: Simulation result of optical field distribution near the nano-scale photocathode.

Quantum Efficiency of Gold Film on SiO_2

Initially, we measured the quantum efficiency of the thin film cathode as a function of film thickness. The SiO_2 substrate for the cathode was washed with acetone, isopropyl alcohol (IPA) and finally ultrapure water. The membrane was deposited on the SiO_2 using DC Sputtering at a pressure of $<5\times10^{-6}$ Pa. The adhesiveness between gold and SiO_2 is improved by inserting Ti, and the thickness of the thin film gold cathode was controlled from 10 to 40nm.

For the quantum efficiency measurement a conventional Nd:YAG laser (wavelength 266 nm, irradiating intensity $< 10^4$ W/cm^2, repetition rate 1 Hz) was used under back illumination and results are shown in Fig. 3.

From this result and previous research [5, 6], we can calculate the rate of nonlinear photoemission for any emitter thickness. Also, the relationship between the electron emission rate and laser pulse duration t is normalized by t^{-2}.

FIB Fabrication Procedure

Taking into account this result shown Figure 1 and surface evaporation of thin film emitter, the thickness of gold cathode was chosen as 20 nm, and the transparent conductor as 125 nm. This thickness was measured using contact type thickness meter. Moreover, it was decided to fabricate 5×5 array with a pitch of 20 µm because of the difficulty to find nano-scale emitter embedded into the transparent conductor. In Fig. 4, a demonstration of the fabrication of a nano-scale photocathode is shown using scanning electron microscopy, a focused ion beam instrument (Xvision200DB) was used to fabricate the multilayer structure. The minimum possible etched diameter is about 35 nm, although we decided to use a diameter of 100nm after taking into account the balance between laser incident power and nano-emitter diameter.

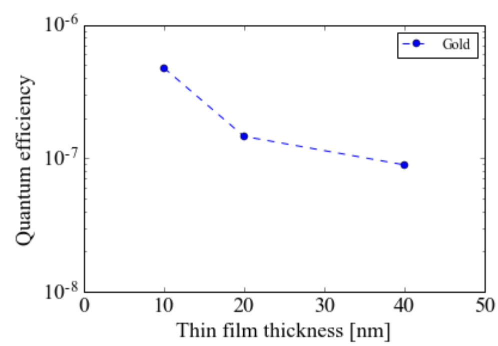

Figure 3: Measurement of quantum efficiency of gold thin film photocathode on SiO_2. This cathode was irradiated from the backside which avoid interference between the optical and electron paths.

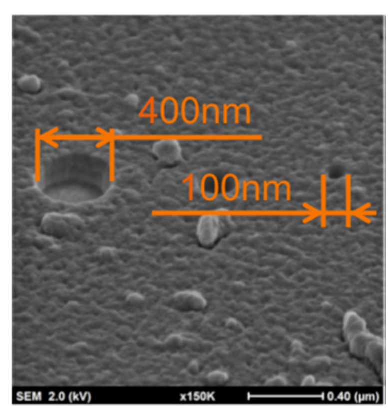

Figure 4: Focused Ion Beam (FIB) etched on multilayer. The scale bar corresponds to 400 nm.

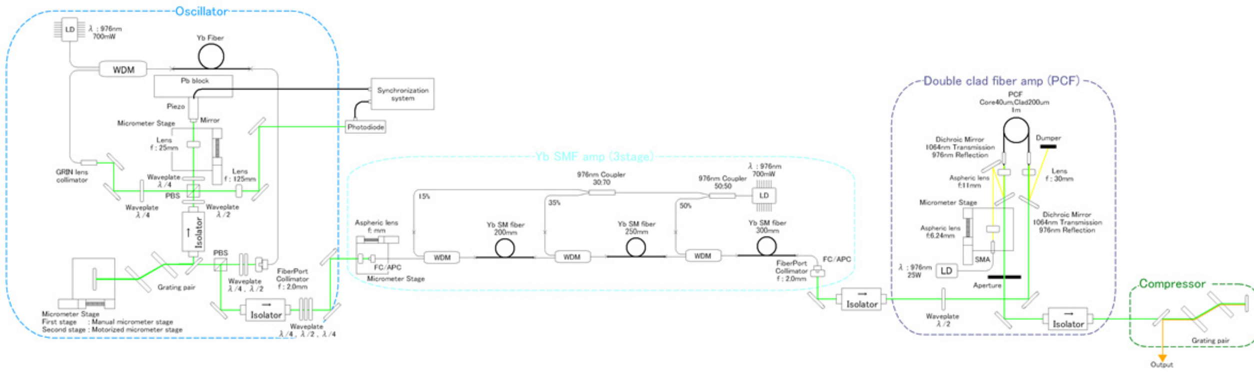

Figure 5: The Yb based fiber laser system for nano-scale photocathode.

YB FIBER LASER SYSTEM

In order to realize single photoemission in the nano-scaled cathode, high laser intensity is required. For example, assuming a quantum efficiency of 10^{-6}, and an emitter diameter of 100 nm, we estimate a laser power 320 mW at a reputation rate of 84 MHz.

Previous research indicated that the work-function of the thin film emitter is between 3.8 and 4.3 eV [6], and therefore the 515 nm wave length ($2h\nu$ corresponds to 4.81 eV) 2nd harmonic of the Yb based laser does not have enough energy to overcome the work function leading to low emittance. The Yb fiber laser system is shown in Fig. 5. The oscillation of this laser is nonlinear polarization rotation mode lock method, and the output power is about 30 mW. The amplifier is constructed using a two stage of Photonic Crystal Fiber (PCF) [7]. The output pulse is then controlled and selected via a laser pulse compressor, two sheets of wave plates, a BBO nonlinear crystal, two sheets of dichroic mirror (515 nm transmission rate > 99.5 %) and telescope pair system. The output power is controlled using a polarizer and wave plate and the beam waist is controlled using a lens-pair (focal length 200 mm and -200 mm).

CONCLUSION AND NEXT PLAN

We have proposed nano-scale photocathode for low energy imaging technology and have evaluated the component of nano-scale photoemission. We measured the quantum efficiency of a thin film gold cathode and fabricated for a test nano-scale photocathode using FIB. Under the circumstances, it has a possibility to realize nano-scale photoemission.

In the future, we plan to perform coherent diffraction imaging using this nano-scale photocathode will be done. The utility of nanoscale photocathode will be demonstrated by evaluating the higher-order scattering component in the Fourier space of the diffractive imaging.

ACKNOWLEDGEMENT

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