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DEVELOPMENT OF TEMPORAL RESPONSE MEASUREMENT SYSTEM FOR TRANSMISSION-TYPE SPIN POLARIZED PHOTOCATHODES

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Abstract

We have developed a system to measure temporal response of transmission-type photocathodes using an rf deflecting cavity. The rf cavity, beam profile monitor and laser pulse stretcher have developed and its performances was confirmed. Now we have measured the temporal response of a transmission-type GaAsP photocathode with 600μm thickness and obtained a temporal response of 7.8 ps.

INTRODUCTION

We have developed transmission-type spin polarized photocathodes with negative electron affinity (NEA). The spin-polarized electron beam is essential for "International Linear Collider [1]", "CLIC [2]" and so on. It is also expected to be applied for "Spin-polarized Low Energy Electron Microscope [3]" and "Pulsed spin TEM [4]". In the development of the transmission-type spin polarized electron sources, the electron spin polarization of ~90% and high beam brightness of ~2 × 10^7 $A\cdot cm^{-2}\cdot sr^{-1}$ were already achieved by using GaAs/GaAsP strained super-lattice photocathode at Nagoya University [5, 6].

For the next step of the development, the temporal response of the transmission-type photocathode has to be characterized. Evaluation of the temporal response is important for confirming the possibility of realizing bunch length of a pico-second order. Therefore we designed and manufactured a temporal response measurement system using a radio frequency (rf) deflecting cavity. In this system, the electron beam whose repetition is synchronized to the rf is kicked transversely. Then the longitudinal pulse structure is projected to the transverse plane and measured by the beam profile monitor at the downstream.

HIGH BRIGHTNESS TRANSMISSION-TYPE PHOTOCATHODE

In a transmission-type high brightness electron gun, a super-high brightness electron beam is obtained by illuminating a small area on the back side of the photocathode. A pump laser light is well focused by a short-focal-length lens (f = 1.5 mm in the vacuum) and the focused size becomes a few micrometres in the diameter. Then an electron beam with a few micrometres is extracted to the front side of the photocathode by an electric field of the electron gun. In our case, the applied voltage is 20 kV and the gap length between cathode and anode materials is 4 mm, (i.e., the electric field is evaluated to be about 5 MV/m).

Concerning the transmission-type photocathode, a GaAs/GaAsP strained super-lattice is fabricated on a GaP (bandgap energy: 2.26 eV) substrate, which is transparent to the pump laser light (photon energy: 1.55 eV), instead of a GaAs (bandgap energy: 1.42 eV) substrate.

Temporal response of the reflection-type photocathodes has already evaluated but that of the transmission-type photocathodes has not measured even now.

MEASUREMENT OF THE ELECTRON BUNCH LENGTH USING AN RF CAVITY

Method

In the measurement of temporal response by using an rf cavity, electron bunch length (σ_z) can be expressed as follows:

$$\sigma_z = \frac{E}{ceL_s B_0 \left\{ \cos\left(\omega \cdot \frac{L_c}{v_z} + \varphi\right) - \cos\varphi \right\}} \sqrt{\sigma_y^2 - \sigma_{y_0}^2}, \quad (1)$$

where the beam size at RF-off (σ_{y0}), at RF-on (σ_y), the length between the exit of cavity and beam profile monitor (L_s), maximum magnetic flux density (B_0), rf phase (φ), velocity of electron beam ($v_z=\beta c$) and relativistic energy of electron beam ($E=m\gamma c^2$). The schematic of the measurement system is shown in Fig. 1 [7].

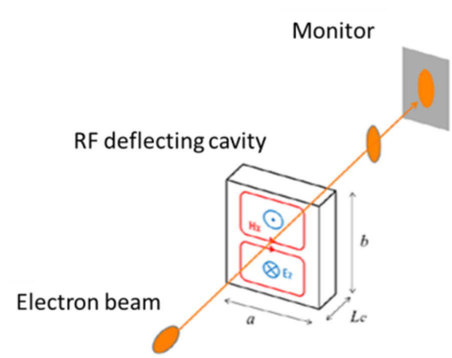

Figure 1: Schematic of the electron bunch length measurement system.

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Synchronization of an RF Field and the Electron Beam

In order to measure the electron bunch length, it is important to synchronize the electron pulses with the rf magnetic field. The resonance frequency of the cavity was decided to be an integer multiple of electron beam repetition. The repetition rate of electron beams depends on the pump laser for photocathodes. In our case, the repetition rate is 90.1 MHz. Then the resonance frequency of the rf cavity is set to 2612.9 MHz which corresponds to the multiple of the 90.1 MHz. The rf frequency of the cavity enables us to measure the bunch length in the range between a few picoseconds and a few hundred picoseconds. The schematic of the whole system is shown in Fig. 2.

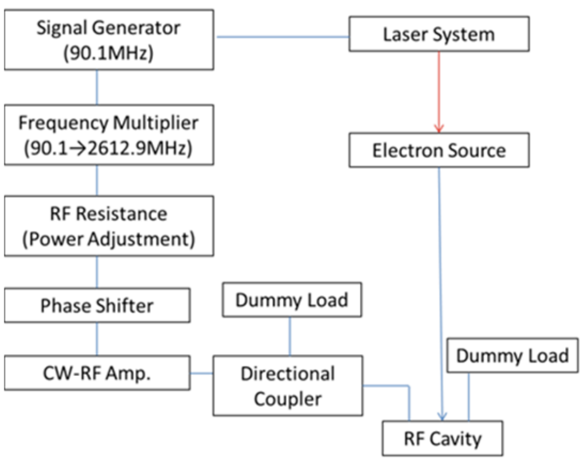

Figure 2: Schematic of the electron bunch length measurement system.

Laser System

The pump laser pulses are provided by a mode-locked Ti:sapphire oscillator (Mira, Coherent). Maximum average output of the laser system is 700mW with central wavelength of 800 nm. The bandwidth and pulsewidth are 13 nm and 130 fs, respectively. Schematic of the laser system is shown in Fig. 3.

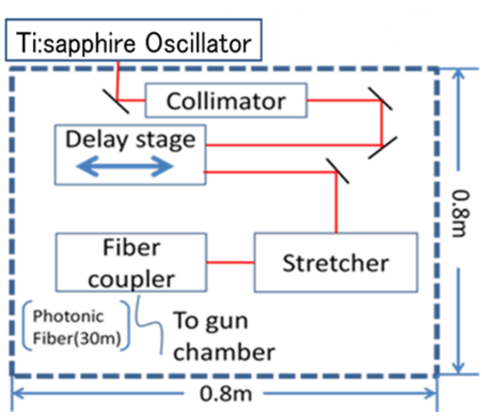

Figure 3: Schematic of the laser system.

In order to adjust the laser irradiation timing to the photocathode, the delay stage, shown in Fig.4, was prepared. The movable range is 25 mm and position resolution is 0.05 μm. This resolution corresponds to the temporal resolution of 0.33 fs and satisfies the required performance.

There is 30 m distance between laser oscillator and the electron gun due to the geometrical reason. To transport the laser light, a photonic crystal fiber (LMA-25, NKT Photonics) is used. The wavelength dispersion of about 41 ps is estimated in the photonic fiber.

The pulse stretcher system is installed for the dispersion compensation. The system with a compensation grating applies arbitrary wavelength dispersion that is an inverse of that of expected value in the fiber. The stretcher system enables us to adjust the pulse length in the range between 20 and 45 ps. The schematic is shown in Fig. 4.

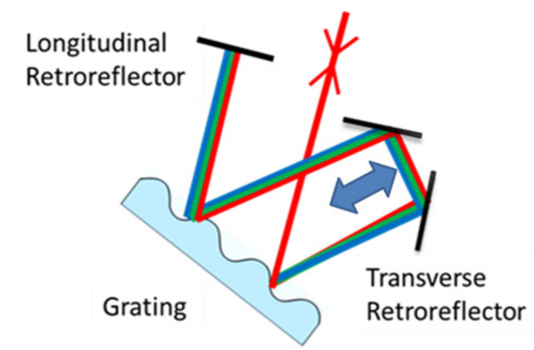

Figure 4: Schematic of the pulse stretcher system.

RF Deflecting Cavity

Parameters of the manufactured deflecting cavity (Fig. 5) are summarized in Table 1. A rectangular shaped cavity was employed to realize the wide frequency spacing for each resonance mode. The resonance mode of TM120 is selected as an rf deflecting field [8]. The longitudinal length was chosen to be 46.81 mm with the consideration for beam deflecting efficiency. The length is 1.5 times longer than the product of the rf half-wavelength and the Lorentz factor β.

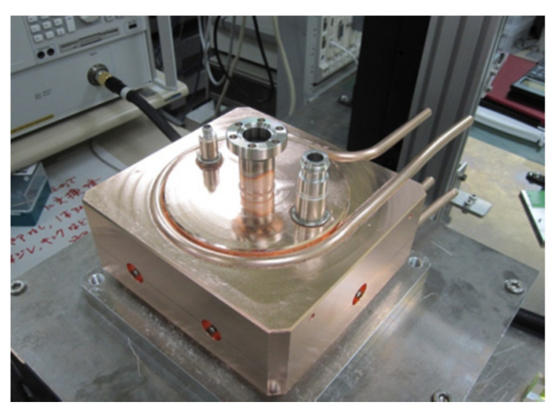

Figure 5: RF deflecting cavity.

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Table 1: Parameters of the RF Cavity

Size	
Width	121.01 mm
Height	129.98 mm
Lngitudinal length	46.81 mm
Rsonance frequency	2612.9 MHz
Quality factor(Loaded)	10,155
Quality factor(Unloaded)	20,565
Input coupling factor	1.02
Magnetic field at 1W	1.57G (Max.)

Measurement of the Beam Size

The beam size is measured by using CMOS camera (The imaging source, DMK23GM021) with a fluorescent screen. The schematic of the measurement system for the electron beam size is shown in Fig. 6.

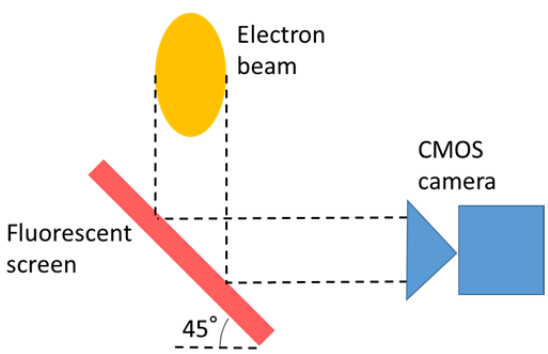

Figure 6: Schematic of the measurement system for the electron beam size.

BEAM DEFLECTING TEST

After the installation of the rf cavity to 20 kV electron gun system [9], the beam deflection test was carried out and the expansion of beam size on fluorescent screen was clearly observed. The result shows that the induced field is strong enough for deflecting the 20 keV electron beam.

Furthermore, we carried out a measurement test for the GaAsP photocathode with thickness of 600 nm. As the results, for 40.5 ps laser pulse, the electron pulse length was measured to be 48.3 ps. Then the stretching of bunch length is observed to be about 7.8 ps. We considered that this result is consistent in view of the thickness of GaAsP active layer. . In the present stage, the initial beam size is too big to measure the electron bunch length with high resolution. This problem is settled in future by attaching a solenoid coil to a beam duct to focus the beam at the fluorescent screen.

CONCLUSION

We have developed the measurement system of the temporal response for 20kV beams. Furthermore it is confirmed that the deflecting cavity can produce the magnetic field strong enough for deflecting the 20 keV electron beam. We have obtained a preliminary result indicating that the transmission-type GaAsP photocathode has a few picoseconds stretching of bunch length.

Finally, in near future we are planning to shorten the pump laser to 1 ps by improving the pulse stretcher and we will make systematic measurement for the various transmission-type photocathodes.

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