# DEVELOPMENT OF A 250-KV PHOTO-CATHODE ELECTRON GUN FOR THE ERL LIGHT SOURCES AT JAEA

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## *Abstract*

A 250-kV, 50-mA electron gun has been developed at JAEA for establishing fundamental technologies to generate and evaluate an ultra-small emittance beam, which is required for future ERLs such as a coherent X-ray source and a high-flux gamma-ray source. The gun has been assembled and apparatuses for beam measurements have been installed to evaluate the transverse emittance and the temporal response of a photo-cathode. The first photo-current was obtained from the cathode of NEA-GaAs and the initial emittance was measured.

## INTRODUCTION

Next generation ERL light source requires an electron gun capable of producing a high average current of 100 mA with extremely low emittance of 0.1 mm-mrad. However, there still remains a huge gap between the demand of ERL light source and existing gun technologies, thus gun development is one of the top issues in the ERL communities.

A 250-kV, 50-mA electron gun has been developed at JAEA for establishing fundamental technologies to generate and evaluate an ultra-small emittance beam. The gun has been assembled and apparatuses for beam measurements have been installed to evaluate the transverse emittance and the temporal response of a photo-cathode. Current status of the gun and the installed beam measurement apparatuses are presented in this paper. The initial emittance measurement result is also shown.

## 250-KV PHOTO-CATHODE GUN

The 250-kV, 50-mA photo-cathode electron gun consists of three vacuum chambers for a photo-cathode loading, a Cockcroft-Walton DC high-voltage generator and a solenoid magnet for emittance compensation as shown in Fig. 1.

Titanium alloy is used for those three vacuum chambers, because titanium alloy with a special chemical polishing has very small out-gassing rate. A chamber made of titanium alloy after 20 hours of 150 °C baking has out-gassing rate of less than $6\times10^{-13}$ Pa m/s at 300 K [1], which is 2-3 orders smaller than a enough-baked general SUS chamber. Loading and preparation is performed in a similar way to other load-locked guns. A piece of GaAs wafer is installed on a cathode puck and introduced into the loading chamber and heat-cleaned with an IR heater. The cathode puck is then transferred into the preparation chamber where caesium and oxygen are deposited on the GaAs wafer to a NEA surface. The activated cathode is finally transferred to the main chamber for generation of photo-emitted electron.

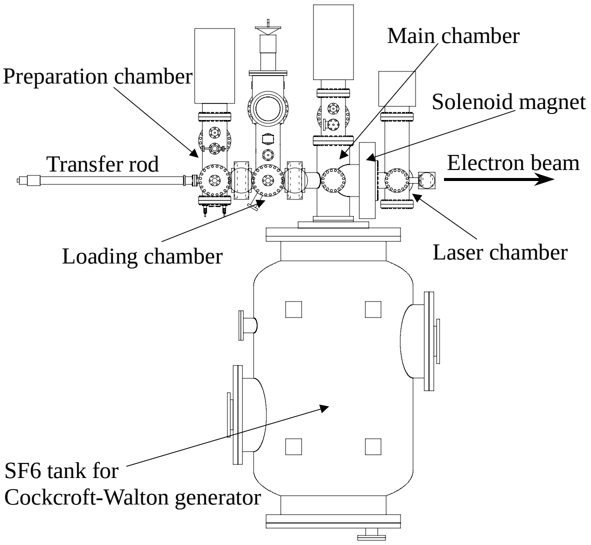

Figure 1: Top-view of the 250-kV, 50-mA photo-cathode electron gun.

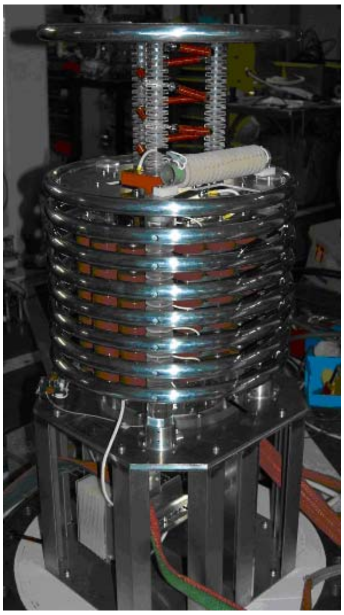

Figure 2: The 250-kV, 50-mA Cockcroft-Walton generator.

The Cockcroft-Walton high-voltage generator is 6-stage symmetrical type with a LC low-pass filter [2]. It has a capacity of 12.5 kW (250 kV and 50 mA) and is driven by an IGBT based PWM inverter circuit with a frequency of 20 kHz. The stage capacitance, the filter capacitance and

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inductance are 8.4 nF, 1.4 nF and 1.2 H, respectively. The coil of the filter is protected from the serge of the electrical discharge by serge absorber [3]. The voltage ripple of $1.9\times10^{-4}$ has been achieved at the maximum output loading.

The solenoid magnet for emittance compensation has a pure iron yoke and a backing coil to insure a vanishing magnetic field on the cathode. The magnetic emittance is given by [4]

$$\varepsilon_{n,rms}^{magnetic} = \frac{e r_0^2 \left| B_{Z0} \right|}{8 m_0 c}, \qquad (1)$$

where $B_{Z0}$ is a the cathode magnetic field and $r_0$ is laser spot radius. The thermal emittance is given by

$$\varepsilon_{n,rms}^{thermal} = \frac{r_0}{2} \sqrt{\frac{kT}{m_0 c^2}} . \qquad (2)$$

The magnetic field has to be less than 3.5 mT for a laser spot radius of 0.5 mm to obtain the same degree of the magnetic emittance as the thermal emittance that corresponds to the thermal energy of 35 meV. As shown in Fig. 3, the magnetic field of 0.4 mT on the cathode surface has been achieved in the solenoid magnet, when the backing coil field is appropriately adjusted.

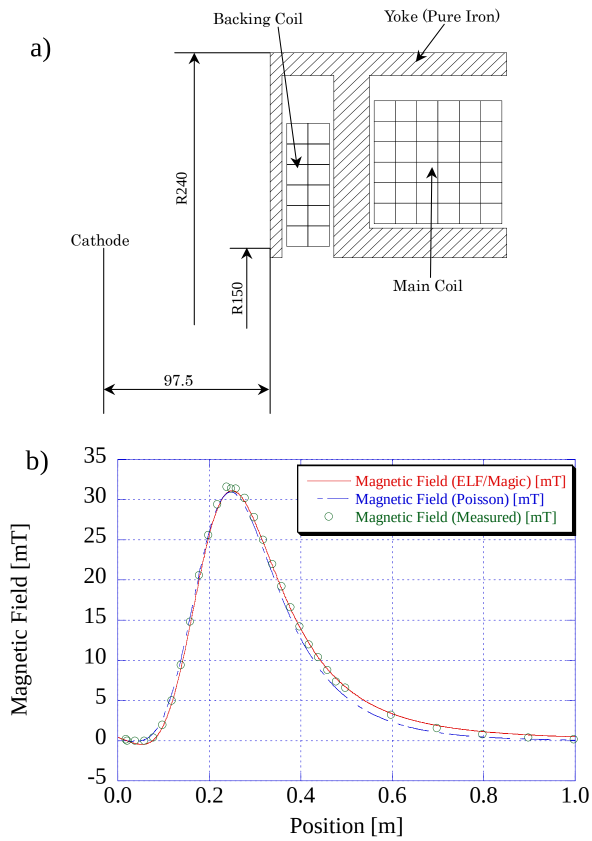

Figure 3: The solenoid magnet: a) cross sectional view; b) field distribution with backing coil adjusted to cancel the magnetic field on the cathode.

# BEAM MEASUREMENT APPARATUSES

To evaluate the performance of the 250-kV electron gun and an NEA photo-cathode, beam measurement apparatuses shown in Fig. 4 have been installed directly after the gun. The geomagnetic field of the beam line is degaussed by Helmholtz coils. The beam dump is water-cooled and has the capacity of 12.5 kW (250 kV and 50 mA).

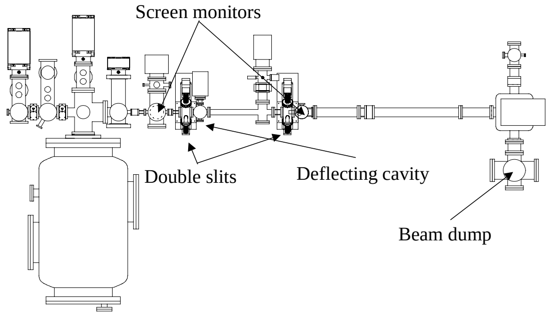

Figure 4: Layout of the beam measurement apparatuses.

Double slits are placed 1.1 m downstream from the anode electrode. The slits for the first beam measurement have 50 μm widths, which are made of tungsten. The slit of 20 μm or less is necessary in future experiments for the measurements of space charge dominated beams. The double slits are distanced in 1.2 m. For the double slit measurement, a Faraday cup is temporarily put just behind the second slit.

Metal-coated YAG screens with 0.1 mm thickness are used to visualize the electron beam and perform beam profile measurements. The screen monitor is equipped with an analog CCD camera via Laser Beam Analyzer (Spiricon, LBA-200) interfaced to a computer.

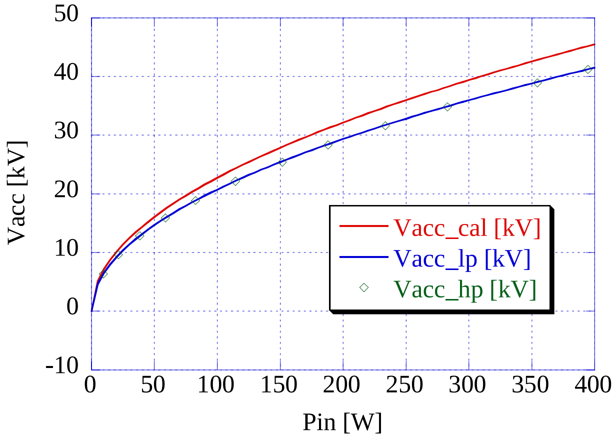

Figure 5: The deflecting voltage vs. RF input power. Blue dotted line, red line and solid circle are calculated value, low-power measured value and high-power measured value, respectively.

A 499.8 MHz deflecting cavity for temporal profile measurement is placed just downstream of the first slit. The deflecting cavity has shunt impedance of 4.3 MΩ and λ/2 type cavity. The cavity generates the deflecting voltage of 40 kV by the RF input of 400 W as shown in

Fig 5. The deflecting angle is 7 mrad for 20 ps length electron beam with 165 W input RF power.

## INITIAL EMITTANCE MEASUREMENT

The initial emittance was measured for drive laser wavelength of 633 nm (He-Ne laser) by slit and screen method. The slit and the screen are distanced in 1.36 m. The laser beam spot was Gaussian profile with rms size of 0.15 mm. The GaAs wafer has been activated in the preparation chamber of the load-lock system connected to the gun. A yo-yo preparation with caesium and oxygen gave typical quantum efficiency of 8 % at 670 nm. The measurement is made at currents less than 1 μA and the beam energy of 150 keV so that space charge effect is negligible.

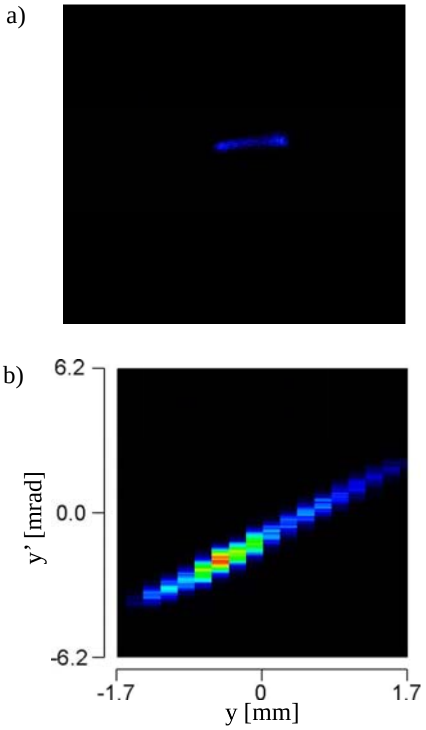

Figure 6: A typical result of initial emittance measurement: a) image on the screen of the beam that passed through the slit; b) reconstructed phase space plot.

Figure 6 shows an image on the screen of the beam that passed through the slit and a reconstructed phase-space plot. The image rotates slightly though the slit is the horizontal because of the solenoid field error or geomagnetic field. For the emittance calculation, this rotation was corrected, and typical normalized rms emittance was found to be 0.13 mm-mrad after subtraction of background noise, which is assumed to be 1% of peak signal.

The initial emittance of the beam that emitted from a photo cathode is given by

$$\varepsilon_{n,rms}^{initial} = \frac{r_0}{2}\sqrt{\frac{h\nu-\varphi}{3m_0c^2}+\frac{kT}{m_0c^2}}\,, \quad (3)$$

where $h\nu$ is energy of the drive laser and $\varphi$ is band gap of the photo cathode. The equation gives the theoretical emittance of 0.096 mm-mrad for the experimental parameters. The measurement value is about 50% larger than the theoretical value. The larger emittance at the experiment may be attributed to residual magnetic field on the cathode surface, finite resolution of the screen, and other unexpected errors. We continue to improve the measurement system for further discussion of initial emittance.

## CONCLUSION

The gun has been assembled and the first photo-current was obtained from a cathode of NEA-GaAs. Apparatuses for beam measurements have been installed. The initial emittance of a low-current CW beam was measured by slit and screen method. We plan to measure the transverse emittance of a bunched beam by a double-slit configuration and the temporal profile with a deflecting cavity.

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