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Polarized Electron Source Development for the Japan Linear Collider

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1. Introduction

We have continued the various R/D works in order to construct a polarized electron source which satisfies the JLC (Japan Linear Collider) requirements [1-8]. They contain following subjects; (1) new type of photocathode development, (2) construction and beam test of a 100 kV DC polarized gun, (3) design and construction of a 200 kV DC polarized gun, (4) design study of an RF gun and / or a polarized RF gun, and (5) design studies of system lasers with a sub-ns pulse width for a DC gun and a 10 ps pulse width for an RF gun, respectively.

As this is a short report, the description is confined in the second subject of a 100 kV polarized gun build at Nagoya University. Here, some details of this gun are described, which include the design principles and the construction procedures of the gun, and the experimental results obtained from a series of measurements; dark current, cathode life time, electron spin polarization, and surface charge limited current.

2 Polarized gun

2.1 Design consideration

The second polarized gun at Nagoya University was designed and constructed to investigate the charge limit effect for a nano-second pulse beam with a source energy of 100 keV. Fig. 1 shows the mechanical

structure of our polarized gun. A -100 kV is applied to the cathode electrode to produce a bunch of $\sim 4 \times 10^{10}$ electrons required for the injector of JLC.

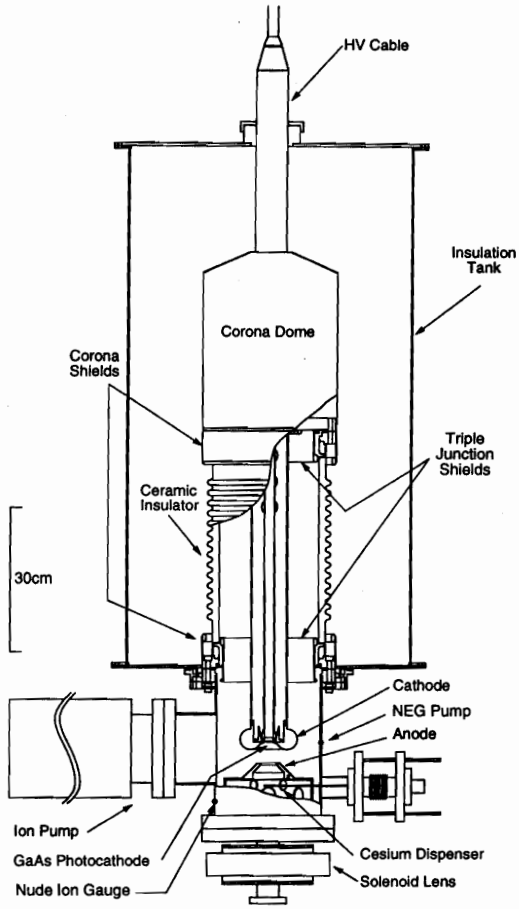

Fig. 1 Polarized electron gun at Nagoya University

2.2 Accelerating electrodes

To reduce the dark current caused by field emission from electrodes to the extremely low level is essential to assure the long cathode lifetime. The field gradients on the electrodes are calculated using a computer simulation code of POISSON [9]. The surface field gradient at the photocathode is estimated to be 1.1 MV/m and the maximum gradient at the cathode edge is 5.1 MV/m at a bias voltage of 100 kV. The perviance and the electron trajectory are calculated by a code of EGUN [10]. The perviance is estimated to be 0.14 μprevs, and the normalized emittance is 12 π-mm-mrad for a 3 A current produced from a 14 ϕ photocathode.

The 316L stainless steel was used as material for the electrodes, since

it has low content of carbon which can be the site of field emission dark currents. An electrochemical buffing was employed for surface polishing and the average roughness of the electrode surface condition could be reduced below 0.1 μm. The electrodes were rinsed with ultra-pure water whose resistance was 18 MΩ-cm and installed to the gun in a clean room. The initial dark current was measured to be very small (< 10 nA) at the 100 kV bias voltage.

2.3 Ultra-high-vacuum and NEA activation

Ultra-high-vacuum is also essential for achieving the high quantum efficiency and the long lifetime of NEA photocathode. The gun chamber was baked out at the temperature of 250°C for 100 hours and a vacuum pressure of 2×10^{-11} torr was achieved by using a 500 l/s NEG pump and a 110 l/s ion pump.

To make an NEA surface, the GaAs crystal was heat-cleaned and then cesium and oxygen were deposited on it. The quantum efficiency of 10% at laser wavelength of 633 nm was achieved under these conditions.

2.4 NEA cathode lifetime

The cathode lifetime measurements were done, where the He-Ne laser power was 0.4 mW (ϕ1 spot size) and the vacuum was 8×10^{-11} torr throughout the experiments. As shown in Fig. 2, the lifetime as long as 50 hours was achieved for extraction of the continuous beam of several μA. The dark currents in the experiments were such as 1 nA at 80 kV, 30 nA at 90 kV and 200 nA at 100 kV. The dark current was increased with the repeated NEA activation due to the deposition of cesium atoms not only to the photocathode but also to the electrodes. However, the gun can be operated stably for a long period at the bias voltage of 70 kV since the dark current did not exceed the level of 20 nA.

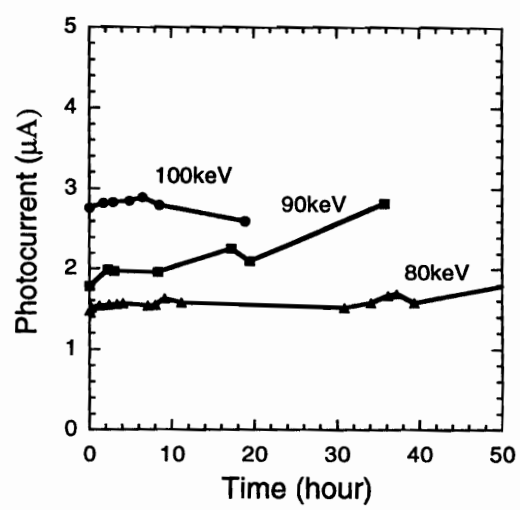

Fig. 2 Lifetime measurement of the NEA photocathode

3 Polarized light source

A Nd:YAG-pumped Ti:sapphire tunable laser system is used to investigate the charge limit effect of the NEA GaAs photocathode. The Nd:YAG laser (Spectra Physics, Quanta-Ray GCR-18S) has an energy of 400 mJ/pulse at 532 nm with 10 Hz repetition rate. The Ti:sapphire laser (Spectra Physics, TSL-1S) produces a laser pulse (5 ns width) with an energy of 10 mJ/pulse for wavelength range of 710~910 nm.

The laser pulse is transmitted from a laser room to a gun room through an optical fiber of 45 m length. It is the multi-mode fiber with a core radius of 100 μm and a numerical aperture of 0.35. In order to avoid a damage of the fiber due to the intense laser power, the pulse energy was attenuated to be less than 50 μJ/pulse. The transmission efficiency of this fiber was measured to be ~70%.

4 Beam transport and polarization measurement system

The electron beam transport system for beam and polarization measurement consists of four solenoid focusing lenses, a bending dipole magnet, four pairs of steering coils, a Wien filter and a Mott polarimeter. It is operated by two modes, one is a high current mode and the other is a polarization measurement mode. Screen monitors were used for the beam tuning. The overview of this system is shown in Fig. 3.

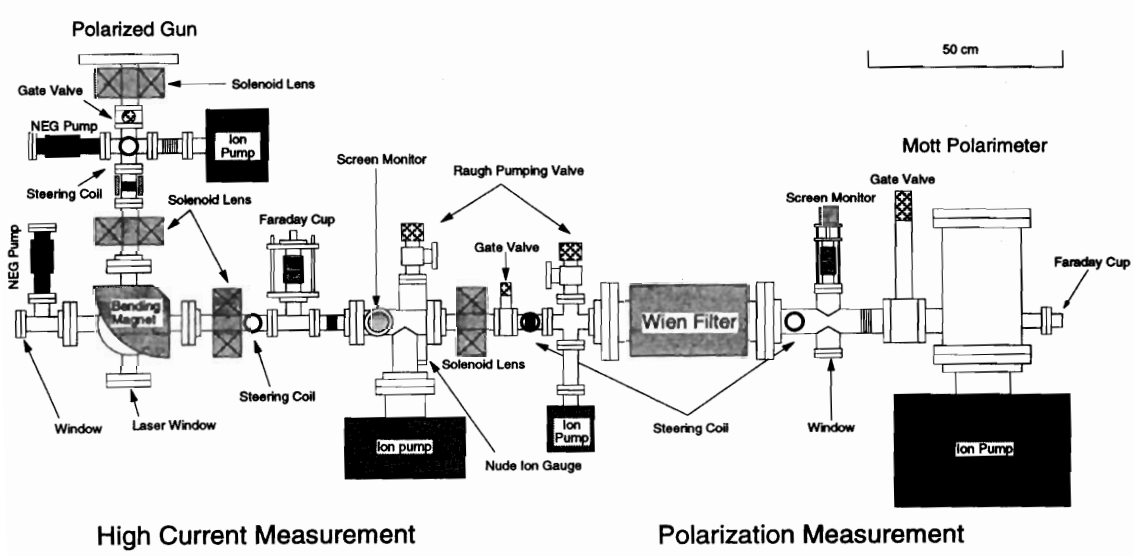

Fig. 3 A schematic of beam line and polarization measurement system

5 Photocathode performance

5.1 Charge limit

A polarized pulse beam was produced using the 5 ns Ti:sapphire laser pulse. The laser wavelength was fixed at 800 nm in this experiment, where the photocathode was a 140 nm thick strained GaAs with Zn doping of 5 $\times 10^{18}$ cm^{-3} and the bias voltage was 70 kV. A time profile of the laser pulse measured by the PIN photodiode is shown in Fig. 4.

Fig. 5 shows the electron pulse shape measured by a Faraday cup at different laser pulse energies. The QE (quantum efficiency) was 6.2% measured by a low power He-Ne laser. The characteristic feature of the charge limit can be seen in these data. (1) A saturated peak current of 1 A is less than a space charge limited current of 2.6 A estimated by EGUN simulation. (2) The photocurrent produced by the laser tail becomes significant with the increases of the laser power and dominant at pulse energy >10 μJ/pulse. These results suggest that a laser pulse for producing a multi-bunch electron beam required by the JLC must have a fast fall-time, and the peak to background (tail) ratio must be as small as possible.

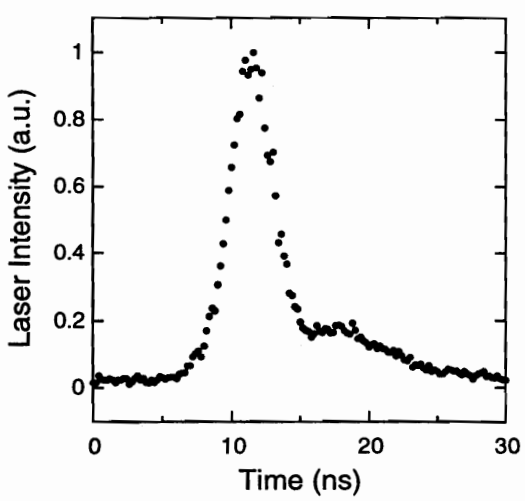

Fig. 4 A time profile of the Ti:sapphire laser pulse

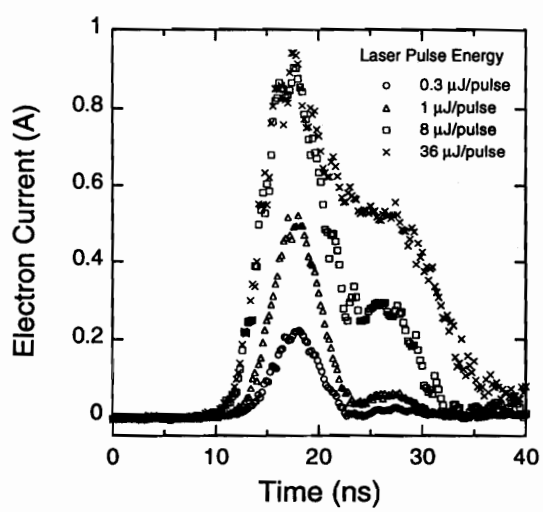

Fig. 5 Electron pulse shape measured by a Faraday cup

The charge vs. laser pulse energy data taken at different QE conditions are shown in Fig. 6. The significant dependence of the maximum extracted current on the QE shows that this limit is caused not by the space charge limit, but by the NEA surface charge effect [11]. Further experiments are scheduled for this phenomenon using the multi-bunch laser beam in near future.

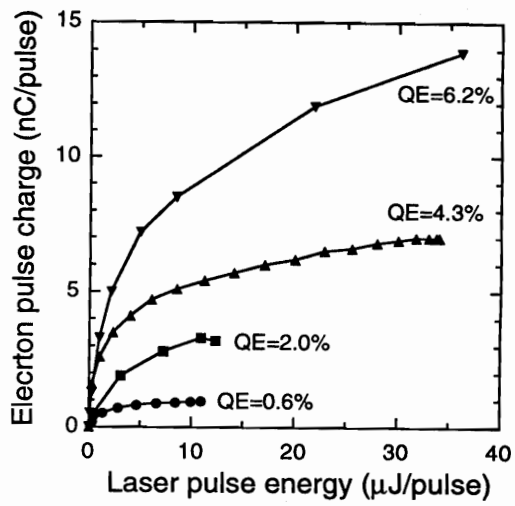

Fig. 6 Charge limit effect observed in extracted pulse beam

5.2 Polarization measurement

The polarization measurement was done by the Mott polarimeter using cw diode laser. In order to confirm the spin rotation from longitudinal to transverse at the Wien filter, transverse component of polarization was measured by changing the spin rotation angle as shown in Fig. 7. The spin rotation angle was estimated from the integrated magnetic field along the beam axis and the data is well fitted by a sine curve.

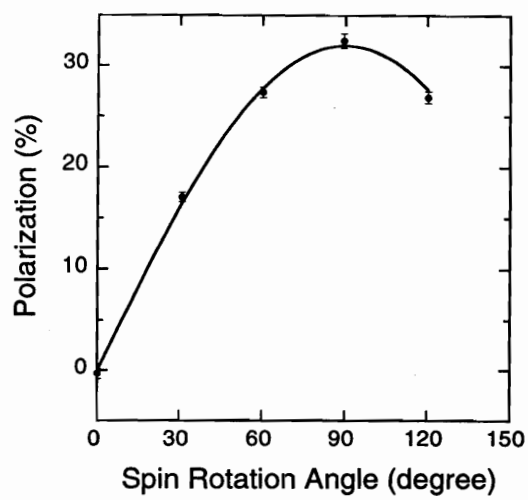

Fig. 7 Spin rotation measurement using Wien filter and Mott polarimeter

6 Conclusion

A test bench of a 100 kV polarized electron gun has completed at Nagoya University. The ultra-high-vacuum on the order of 10^{-11} torr has been achieved in the gun chamber. The initial high voltage performance of the electrodes showed a good result, that is, the fine electrochemical buffing

and the rinsing with ultra-pure water lead to the dark current less than 10 nA at 100 kV. The photocathode lifetime as long as 50 hours was achieved for a continuous extraction of several μA current at the bias voltage more than 70 kV.

The surface charge effect of the NEA photocathode was observed for the 70 keV pulse beam with 5 ns pulse width and 1 A peak current using a Ti:sapphire pulse laser. The polarization measurement could be done by a Mott analyzer on this apparatus using a cw Ti:sapphire laser.

The know-how obtained by these experiments will contribute to the design and the construction of the next 200 keV polarized gun. This gun is designed to have a load-lock system and to extract a peak current more than 20 A at a bias voltage of 200 kV. The design is almost finished and the construction and test of some components are already started.

References

[1] T. Nakanishi et al., Phys. Lett. A158 (1991) 76

[2] T. Saka et al., Jpn. J. Appl. Phys. 32 (1993) L1837

[3] T. Omori et al., Phys. Rev. Lett. 67 (1991) 3294

[4] Y. Kurihara et al., Jpn. J. Appl. Phys. 34 (1994) 355

[5] T. Omori et al., Jpn. J. Appl. Phys. 33 (1994) 5676

[6] H. Horinaka et al., Jpn. J. Appl. Phys. 34 (1994) 6444

[7] T. Nakanishi et al., Proceedings of SPIN96 - pre-symposium Workshop on Polarized Elecrton Source and Low-Energy Polarimeters, Amsterdam, Netherland, September 1996

[8] H. Matsumoto, Proceedings of the 18th International Linear Accelerator Conference, Geneva, Switzerland, August 1996

[9] M. T. Menzel et al., LA-UR-87-115

[10] W. B. Herrmannsfeldt, SLAC-Report-331 (1988)

[11] R. Alley et al., Nucl. Inst. and Meth. in Phys. Res. A 365 (1995) 1