HIGHLY POLARIZED AND HIGH QUANTUM EFFICIENCY ELECTRON SOURCE USING TRANSMISSION-TYPE PHOTOCATHODE

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Abstract

Transmission-type spin polarized electron sources have developed at Nagoya University of Japan. In the developments, we manufactured transmission type photocathode (T-PC) and high brightness electron gun. For T-PC, GaAs-GaAsP strained superlattice layers were grown on a commercially available GaP wafer instead of conventional GaAs wafer and the electron spin polarization of $\sim$90 % and quantum efficiency of 0.4 % was achieved simultaneously. For the electron gun, the laser spot size of a few micro meter could be obtained at the PC surface. As results, the beam brightness of $\sim$2 $\times$ 10^7 A.cm^{-2}.sr^{-1} and the charge density lifetime of 1.8 $\times$ 10^8 C/cm^2 were obtained.

INTRODUCTION

The GaAs-type semiconductor photocathodes (PCs) with a negative electron affinity surface have been used as a polarized electron source and are expected as electron sources for next generation accelerators, such as Linear Colliders and Energy Recovery Linacs.

Recently, we have developed transmission-type photocathodes (T-PCs). Conceptual diagrams of conventional and transmission-type photocathode are shown in Fig. 1. By using T-PCs, polarized electron beam is extracted from the back-side of laser irradiation-side. This scheme offers great merits in designing electron guns, such as short focusing of the laser light for a high brilliance electron beam and a simple geometrical structure avoiding an interference problem between the laser and the electron beam.

In the early phase of the development, the high beam brightness was achieved, but both of the electron spin polarization (ESP) and quantum efficiency (QE) were relatively lower than conventional reflection-type PCs [1, 2]. Nowadays, the electron spin polarization of $\sim$90 % and quantum efficiency of 0.4 % was already achieved simultaneously using the transmission PC with GaAs-GaAsP strained superlattice layers.

TRANSMISSION PHOTOCATHODE

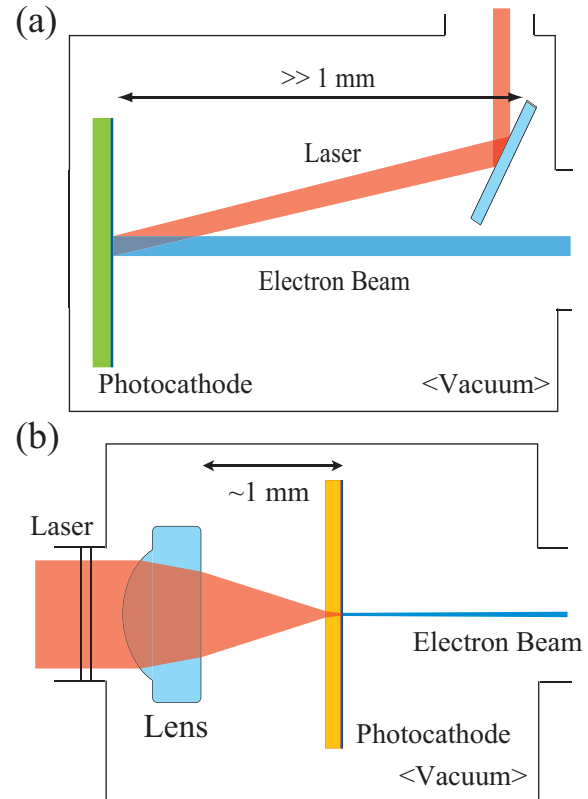Schematic view of T-PCs are shown in Fig. 2. Details of PC design and manufactureing are reported in

Figure 1: Conceptual diagrams of conventional (a) and Transmission (b) Type photocathode.

Ref. [3, 4]. The transmission photocathodes were fabricated by using a low-pressure organometallic vapor phase epitaxy (OMVPE) system at Nagoya University. A commercially available GaP wafer with a Zn dopant of 1.4 $\times$ 10^{17} cm^{-3} was used as a transmission substrate. To control the strain property in the buffer and SL layers, an interlayer was grown on the GaP substrate. Then, a few μm of the GaAsP buffer layer and several tens pairs of GaAsP-GaAs SL layers were grown with a Zn dopant concentration of 1.5 $\times$ 10^{18} cm^{-3}.

Example ESP and QE spectra taken for a T-PC are shown in Fig. 3, where the closed circle and square points indicate ESP and QE, respectively. A maximum ESP of 90% with QE of 0.4% has been achieved by this PC sample at a wavelength of 783 nm. These performances are comparable to conventional reflected-PC [5, 6]. In manufacturing this sample, an Al$_{0.4}$Ga$_{0.6}$As layer was employed as a
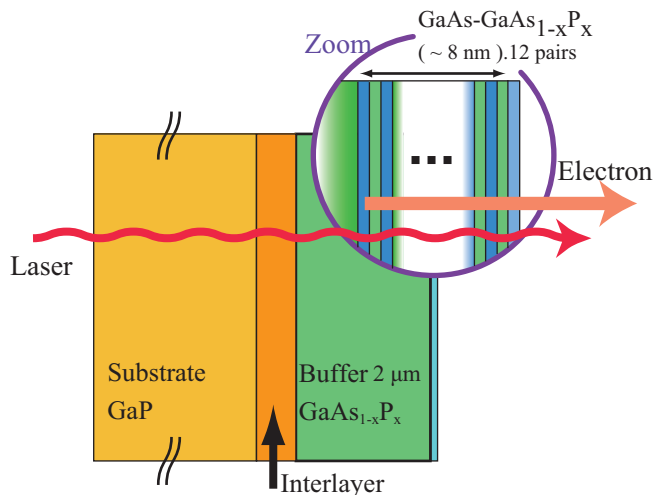
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03 Linear Colliders, Lepton Accelerators and New Acceleration Techniques

T02 Lepton Sources

Figure 2: Schematic view of transmission pthotocathode
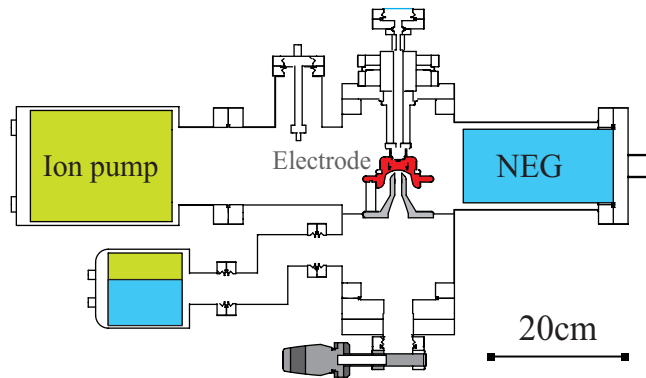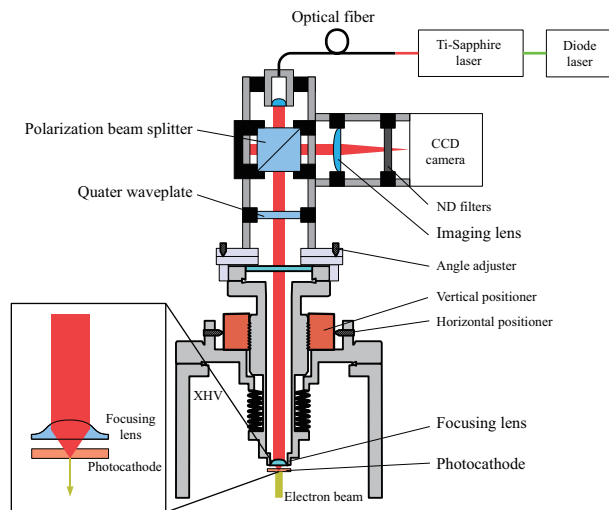

Figure 4: Schematic view of high brightness electron gun

Figure 3: Observed ESP and QE spectra, indicated by circles and squares, respectively

Figure 5: Schematic view of laser optical system

inter-layer and a Si_3N_4 layer was grown at the back side of PC as an anti-reflection film for the injection laser. More details for this PC are described in Ref. [7].

In order to obtain higher QE, further developments have been made in designing the crystal and superlattice structure.

HIGH BRIGHTNESS GUN

Design and Set up

Two important apparatus performances must met for a high voltage PES gun: an extreamely high vacuum ($< 10^{-10}$ Pa) environment around the NEA-PC and an extremely low dark current (< 10 nA) between the high voltage electrodes. These performances are required to protect the NEA surface and reduce its degradation speed to maintain a long PC lifetime ($>$ several tens hours).

The Schematic view of high brightness electron gun is shown in Fig. 4 The gun chamber was separated into PC room and differential pumping room by the anode electrode. The aperture size of the anode was decided to 1 mm diameter. The base pressure of PC room was maintained the order of 10^9 Pa by using an 100 L/s ion pump and a 2000 L/s non-evaporable getter pump in the beam operation of several micro-amperes.

The accelerating electrodes were designed by using the own simulation code [8]. Since the electrode made of a molybdenum cathode and titanium anode was found to suppress dark currents by our previous study [9], we employed the molybdenum cathode and the titanium anode. The accelerating voltage and the electrode gap were set to be 20 kV and 4 mm respectively. In the experiment of these electrodes, dark currents were successfully suppressed to at most 1 nA at 20 kV and a few nA at 30 kV.

A schematic view of the laser optical system is shown in Fig. 5, where a Nd:YVO$_4$ pumped Ti:sapphire laser was used as a CW light source, and the light was transmitted to a T-PC installed in the gun chamber by an optical single mode fiber. A polarizing beam splitter is mounted at the exit of the fiber to give linearly polarized light, which

is converted to circularly polarized light by a quarter wave plate. The light is then focused on the T-PC surface using an aspherical lens. The position of the lens is adjusted by monitoring the spot size of the reflected light from the T-PC by projecting a magnified focus image of the spot on a charge coupled device (CCD) camera. As a result, a laser spot radius of 0.65 μm half width at half maximum (HWHM) was obtained at T-PC surface. The smallest spot size is near the diffraction limit of 780 nm wavelength light.

Experimental Results

The beam brightness was estimated from a beam size at the PC surface, beam size and charge at the 53.1 cm downstream. The laser spot size could be well measured by a CCD, but the emission area was enlarged due to the diffusion effect inside T-PCs. Then We assumed that the beam radius at the PC surface was 0.90 μm including the diffusion length of 0.25 μm. The data was taken under a emission current of 5.3 μA and an angular current density of 248 mA/sr and a brightness of $2.0 \pm 0.8 \times 10^7$ A.cm^{-2}.sr^{-1} were obtained. This brightness is better by three orders of magnitude, compared for the conventional PES.

The lifetime measurements were carried out with beam current decay mode and the accelerating voltage of 20 kV. The lifetime was defined as the period until the QE value decreased to $1/e$ of the initial value. In the conditions with the initial current of 3 μA and the laser radius of 3.2 μm, the charge density lifetimes 1.8×10^8 C.cm^{-2} was achieved. This value corresponds to the beam lifetime of 36 hours and the charge lifetime of 260 mC.

SUMMARY

In order to achieve high brightness and high polarization performances for polarized electron beams, T-PCs and 20-kV electron guns were developed. By using the 20-kV gun, the advantages for beam brightness and lifetime were demonstarted.

In the T-PCs developments, Various types of T-PC samples with active strained SL layers and a GaP substrate were fabricated and tested. As the recent results, a maximum ESP of 90% with QE of 0.4% has been achieved simultaneously by using the sample that was employed an Al$_{0.4}$Ga$_{0.6}$As interlayer and a Si$_3$N$_4$ anti-reflection film. These performances are comparable to conventional PCs.

The developed T-PCs and 20-kV gun have been already applied a spin polarized low enery electron microscopy (SPLEEM), and we could demonstrate a dynamic observation of magnetic images during the growth of Co on W(110) [10]. Futhermore, the development of Spin-TEM by using same scheme has progressed.

T-PCs could be applied also high energy accelerators, such as a linear collider and an energy recovery linac. To demonstrate promising advantages of T-PCs for these applications, further experiments are required. In the next step, we are prepared for the generation of multi-bunch beams with pico seconds time structure and the emittance measurement in near future.

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