HIGHLY POLARIZED ELECTRON SOURCE DEVELOPMENT IN JAPAN

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Abstract

The development works of the high performance semiconductor photocathodes and the source-guns to produce highly polarized electrons for linear colliders and other accelerators have been conducted by our collaboration. The present status of our four research subjects, (1) superlattice photocathode development, (2) construction of polarized DC-guns, (3) study of surface charge limit phenomenon, and (4) study of field emission dark current problem for the spin RF-gun, are described from the view points of key technologies of photo-emitter polarized electron source.

1 INTRODUCTION

Recently various spin-physics programs that require the polarized electron beams are proposed or have been carried out at several laboratories such as SLAC, Mainz, MIT/Bates, NIKHEF, Bonn and TJNAF etc. Polarized electron beams are also expected to play the essential roles in the future linear colliders. In answer to these needs, the polarized electron source (PES) technologies have also been developed intensively in these several years.

At present, only the GaAs-type PES is being used in physics experiments, and it is based on a combination of two fundamental technologies, laser optical pumping and semiconductor surface with the negative electron affinity (NEA), as shown in Fig. 1.

Important performances required for polarized electron beams include; 1) electron spin polarization (ESP), 2) quantum efficiency (QE), 3) cathode life time, 4) maximum peak current or average current and 5) beam emittance. Among them, the maximum ESP is limited only by the photocathode (PC) properties, those are the fine energy splitting between heavy-hole and light-hole bands in the valence band, and the spin relaxation in the emission process.

All other performances are governed by both properties of the PC and the NEA surface. The NEA surface is made by treating a heavily p-doped GaAs surface with a mono-layer of alkali metal and oxidant (Cs + O_2 or Cs + NF_3) as shown in Fig. 2 [1]. This NEA surface plays indispensable roles in electron emission, and it provides the beam with not only the highest ESP, but also much higher QE than others do without the NEA surface.

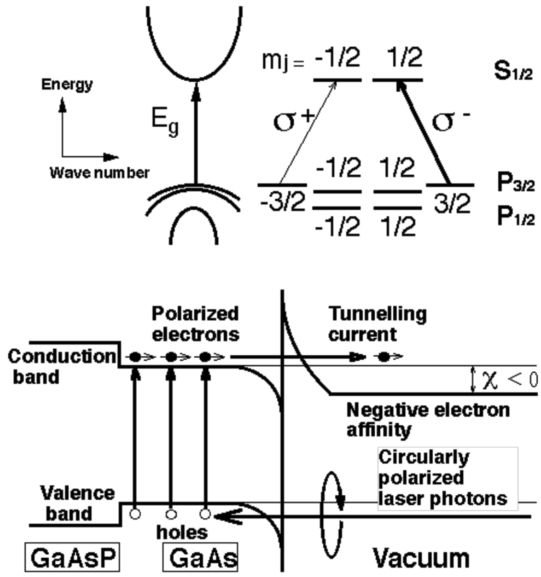

Fig. 1 : Principle of Strained GaAs-type PES

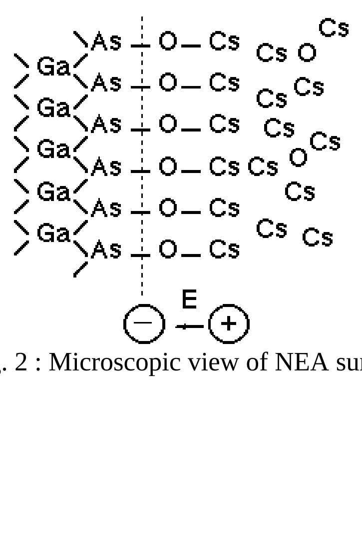

Fig. 2 : Microscopic view of NEA surface

(1997. 8. 1)

Crystal Name	x	y	ε (%)	Lw (ML)	LB (ML)	δs (meV)	Wc (meV)	Surface	Be dope Inside	Be dope Surface	Pol. (%)	Q.E. (%)	λ (nm)
SL #3	0.0	0.35	0.0	7	11	23	89	GaAs	5×10^{16}	5×10^{16}	68	0.01	780
SL #7									5×10^{17}	4×10^{19}	68	0.5	756
SL #11					25	39	10			4×10^{16}	68	0.9	739
SLS #1	0.15	0.0	1.1	7	11	30	191	GaAs	8×10^{16}	4×10^{19}	84	0.01	910
SLS #2								InGaAs	5×10^{17}		88	0.02	920
SLS #3								GaAs			89	0.004	920
SLS #4								InGaAs	8×10^{16}		91	0.004	908
SLSA #1	0.15	0.35	1.1	6	25	82	8	InGaAs	5×10^{17}	4×10^{19}	73	0.1	745
SLSA #2				5	11	58	112				80	0.7	741
SLSA #3				7		73	73				82	0.1	780

x : fraction of Indium
y : fraction of Alminium
ε : strain of InGaAs layer
Lw : thickness of InGaAs (well) layer
LB : thickness of AlGaAs (barrier) layer
δs : energy splitting between the tops of hh and lh mini-bands
Wc : enegy-broadning of conduction band
Pol. : the maximum polarization
Q.E. : quantum efficiency at the maximum polarzation
λ : laser wavelength which gives maximum polarization

Table 1 : Specifications and Performances of $In_xGa_{(1-x)}As$-$Al_yGa_{(1-y)}As$ superlattice

The NEA surface brings such great advantages, but it also involves serious problems on performances, such as the PC life-time and the peak current limit. For good QE and long PC life-time, the NEA surface must be free of adsorbed residual gases (especially, CO_2 and H_2O) at the sub-monolayer level, which requires the extremely careful treatment of PC in ultra-high-vacuum (UHV) in the 10^{-11} torr range [2]. The experimental solutions of these NEA problems are key technologies for the successful PES operations, and they are discussed again in Sections of 3, 4 and 5.

2 SUPERLATTICE-PC DEVELOPMENTS

In 1991, we first demonstrated that highly polarized electrons can be produced by two different families of new PC, 86% ESP by the thin GaAs layer strained by lattice-mismatch [3] and 70% ESP by the GaAs-AlGaAs superlattice [4]. Since then, three kinds of PC with different superlattice structures, GaAs-AlGaAs, InGaAs-GaAs and InGaAs-AlGaAs have been investigated by us. The specifications and ESP- and QE- performances of these $In_xGa_{(1-x)}As$-$Al_yGa_{(1-y)}As$ superlattice PC's are summarized in Table 1, where total thickness of the superlattice structures is ~0.1µm for all samples. From above studies, the following experimental facts are confirmed[5].

1) The modulation doping technique (the medium Be-density of 5×10^{17}/cc inside the superlattice, and the heavily Be-density of 4×10^{19}/cc at the surface) is much effective to increase the QE and to reduce the depolarization.
2) The higher ESP can be obtained by the strained-layer superlattice than that by unstained one. As an example, the ESP and the QE of SLSA#2 are shown in Fig. 3.
3) The wider band-gap superlattice-PC is more suitable to get the higher QE.

The ESP and QE limitations are not yet settled rigidly for the superlattice structures, and we believe that further studies are needed for full understandings for physical mechanisms which determine these limitations.

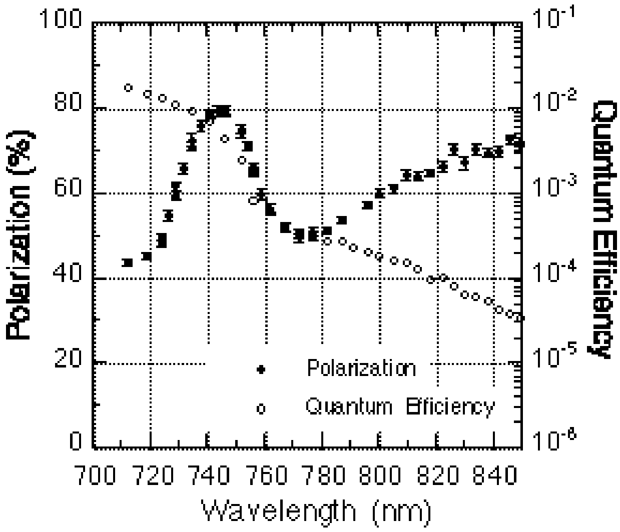

Fig. 3 : ESP and QE dependence on laser wave-length for SLSA#2 strained-layer superlattice PC.

3 CONSTRUCTION OF POL. DC-GUNS

A proto-type of 100keV polarized DC-gun was already constructed, and it have been operated in routine at Nagoya Univ. [6]. At the initial stage, this gun was suffered from the short PC life-time problem due to the large dark currents induced between the high voltage electrodes. This problem was partially solved by using the

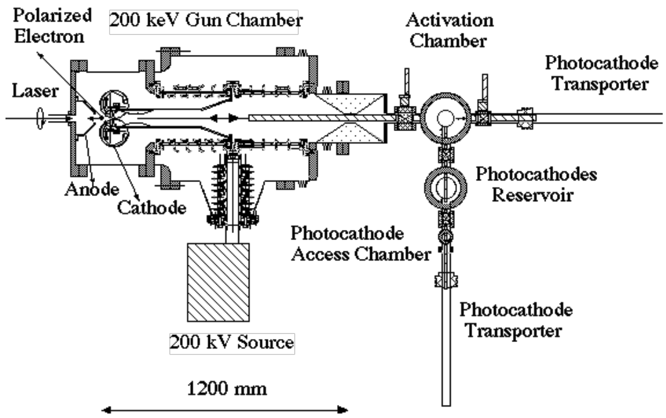

Fig. 4 : Schematic Plan View of 200keV Polarized Gun

clean surface electrodes made by the technology explained later in Section 5.

Another type of 200keV polarized DC-gun is under construction, which is designed for JLC (Japan Linear Collider) and its schematic plan view is shown in Fig. 4. This gun consists of three distinct vacuum chambers; the gun chamber itself, the activation chamber and the PC reservoir. Two transportors are used to move the PC pack between them without breaking the UHV. This activation chamber and the load-lock system is indispensable for reducing the increase of dark currents, which is due to repetitive depositions of Cs atoms into the gun chamber to reactivate the NEA surface. Another advantage of this design is that the load-lock system is kept connected the gun body at the ground potential. The details of requirements and design principles for this gun is given in a book of JLC Design Study [7].

4 SURFACE CHARGE LIMIT PHENOMENON

The maximum current extracted from an NEA activated PC is limited by so called "surface charge limit (SCL)" phenomenon, rather than by the space charge limit one. This phenomenon is caused by the trappings of conduction electrons in the band bending region (BBR) of the NEA surface, and becomes to be so serious problem especially for case which requires the high density multi-bunch beams, such as linear colliders [7]. We have conducted the studies of this problem and could find the solution using both technologies of superlattice structure and heavily p-doping to the surface[6]. The details of this study is reported by K. Togawa et al. in this conference.

5 DARK CURRENT PROBLEM

The activated NEA surface is extremely sensitive to surface contamination. Therefore, in addition to the UHV environment, the creation of contaminants by the field emission dark current induced at the high voltage electrodes must be minimized. For the DC-gun, the average dark current must be kept below 20nA to achieve the good QE and the long PC life-time. The studies to reduce this dark currents from metal surfaces have been conducted by us using a test-apparatus which can provide the UHVenvironment and high DC field gradients for the dummy electrodes treated by various kinds of surface cleaning technologies. The successful result was already obtained for the stainless steel electrode, which could suppress the dark current below 90pA at 34MV/m field gradient for the electrode with ~20ϕ mm diameter and 1mm gap distance [7,8].

As an upgraded design of polarized DC gun, the concept of polarized RF-gun is the attractive idea[7,9]. The key issue to confirm the feasibility of spin RF-gun is the demonstration of survivability of the activated NEA cathode under the high RF-field gradient (≥100MV/m). We have started the study to reduce the dark current from copper surface using the same test apparatus, and the preliminary results from this study is reported by C. Suzuki et al. in this conference.

6 CONCLUSIONS

As conclusions, the several remarks for our research plan are given. Concerning the PC performances, we believe that the superlattice has the most promising abilities (high ESP, high QE, long life-time and high resistance against the SCL phenomenon) for future applications in high energy physics. For the polarized guns for linear colliders, we have the base-line design of 200keV DC-gun whose construction is underway and the feasibility check of polarized RF-gun was started from the fundamental study to solve the dark current problem for copper RF cavity .

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