Development of Polarized Electron Sources using AlGaAs-GaAs Superlattice and using Strained GaAs

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Abstract

We have developed two types of polarized electron source.

1) A $Al_{0.35}Ga_{0.65}As$-GaAs superlattice grown by the MBE method was examined. The maximum polarization of 71.2 ± 1.1(stat.) ± 6.1 (sys.)% was obtained at a photon wavelength of 802nm at room temperature.

2) A strained GaAs layer grown on the $GaP_{0.17}As_{0.83}$ base layer by the MOCVD method: The maximum polarization of 85.0 ± 1.1(stat.) ± 6.3(sys.)% was obtained at a photon wavelength of 860nm at room temperature.

1. Introduction

For a future linear collider such as JLC (Japan Linear Collider(1)), highly polarized electron beam is strongly needed(2). In order to overcome the 50% upper limit of a spin polarization from bulk GaAs photocathode illuminated by circularly polarized light, a degeneracy of a heavy-hole(hh) state and a light-hole(lh) state should be removed(3). We have examined two types of the photocathode ; one is a AlGaAs-GaAs superlattice whose periodic structure of quantum wells and potential barriers can remove the degeneracy. Another is a strained GaAs grown on a thick GaPAs base layer. The lattice-mismatch between the GaAs and the GaPAs causes uniaxial stress on the GaAs and also can remove the degeneracy.

2. AlGaAs-GaAs Superlattice Photocathode

The AlGaAs-GaAs superlattice photocathode is made by the Molecular Beam Epitaxicy (MBE) method. The structure of the photocathode is described in table 1.

Table 1. Structure of the Superlattice Sample.

As (~2μm, for surface passivation)	
Be-doped AlGaAs-GaAs Superlattice (0.1μm)	
Be-GaAs	(19.8Å: 7 monolayers, $p=6.2x10^{18}/cm^3$)
Be-$Al_{0.35}Ga_{0.65}As$	(31.1Å: 11 monolayers, $p=4.0x10^{18}/cm^3$)
Be-doped $Al_{0.35}Ga_{0.65}As$ (1μm, $p=5.0x10^{18}/cm^3$, for barrier)	
Be-doped GaAs buffer layer (500Å, $p=7.7x10^{18}/cm^3$)	
Zn-doped GaAs Substrate (400μm, $p=2.0x10^{19}/cm^3$, orientation:(100))	

The superlattice parameters, thickness of each layer (AlGaAs and GaAs) and a fraction of aluminum, are optimized to get large energy split between hh and lh and high mobility at room temperature. The thickness of GaAs and AlGaAs layer are 19.8Å and 31.1Å respectively. Total thickness of the superlattice layers is 0.1 μm. The aluminum fraction is set to be 0.35. The resultant energy split is estimated to be 44meV which is greater than the thermal noise of 26meV at room temperature.

The superlattice surface is activated to Negative Electron Affinity (NEA) by applying a cesium gas. In order to estimate an effective Sherman function, we use several Au foils with different thickness in the Mott analyser. Measured left-right asymmetries as a function of the foil thickness with laser wavelength of 792nm are shown in Fig.1. We can reliably estimate the left-right asymmetry at zero foil thickness and evaluate the effective Sherman function at given foil thickness.

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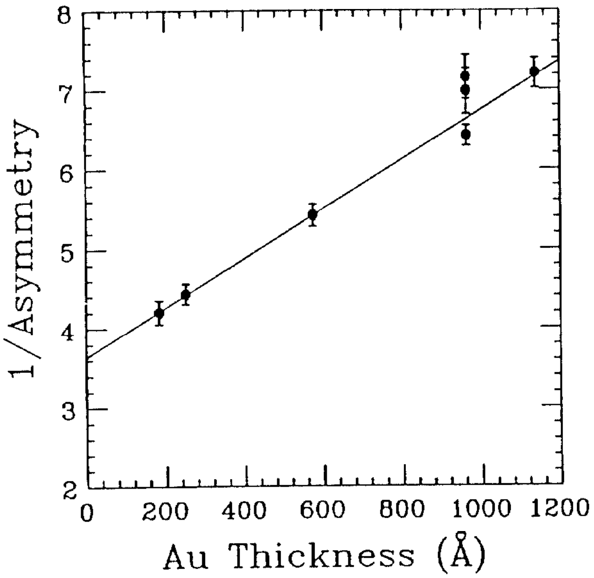

Figure 1. Inverse of the left-right asymmetry.

The electron spin polarizations as a function of laser wavelength are shown in Fig.2. The maximum polarization of 71.2±1.1(stat.)± 6.1(sys.)% is obtained with photon wavelength of 802nm at room temperature$^{(4)}$. The quantum efficiency is measured to be 2.7 ± 10^{-6} at 802nm. A practical quantum efficiency of 2.1 ± 10^{-4} is obtained at the wavelength of 772nm with the polarization of 64.3%.

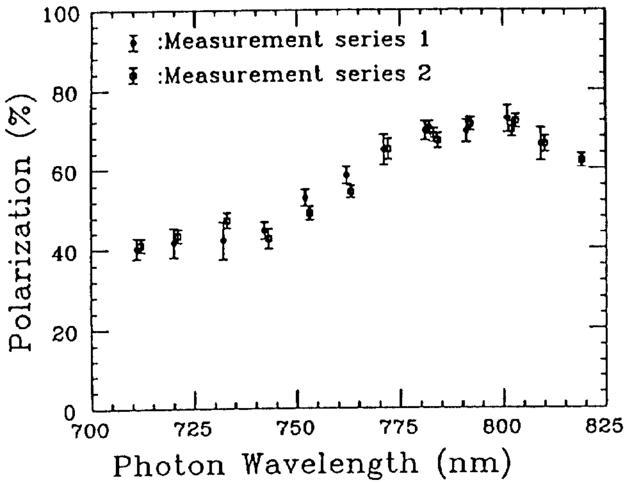

Figure 2. The polarization obtained from the superlattice.

3. Strained GaAs Photocathode

The sample is made by Metal Organic Chemical Vapor Deposition (MOCVD) method. The structure of the sample is described in table 2. The GaAs epitaxial layer with 800Å thickness is grown on the 2.0 μm thickness GaPAs layer which is also grown on the GaAs substrate.

Table 2. Structure of the Strained GaAs Sample.

Zn-doped GaAs (t~800Å, $p\geq5\times10^{18}/cm^3$)
Zn-doped GaP_xAs_{1-x} (x=0.17±0.01) (t~2μm, $p\geq5\times10^{18}/cm^3$)
Zn-doped GaAs Substrate(t=350μm, $p\geq5\times10^{18}/cm^3$, Orientation: (1 0 0))

The phosphor fraction is set to be 0.17 and the resultant lattice-mismatch and energy split are estimated to be 0.7% and 50 meV, respectively. The energy spectrums of electrons observed in the left hand side detector are shown in fig.3. Three curves in the figure correspond to the spectrum with right handed, left handed, and linear polarized light respectively.

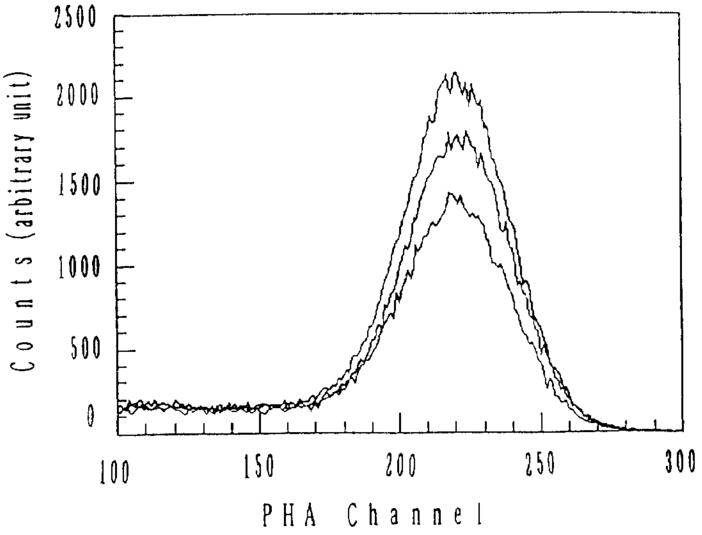

Figure 3. The energy spectrums of electrons.

The measurement of electron spin polarization is done as same as that of superlattice. The quantum efficiency of this photocathode is shown as a function of photon wavelength in Fig.4.

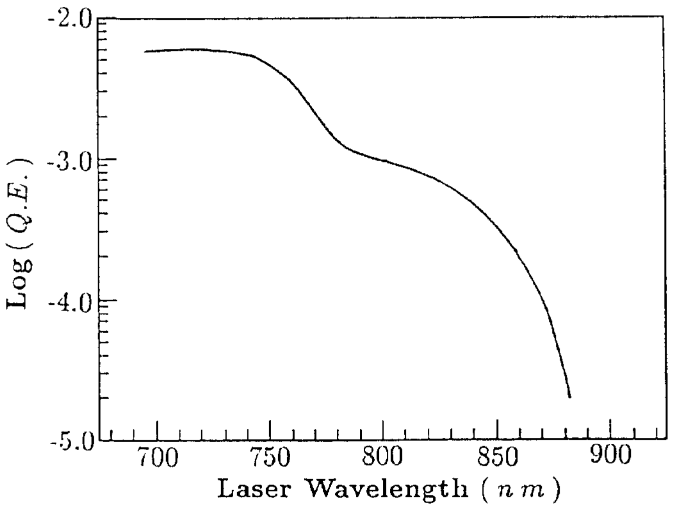

Figure 4. The quantum efficiency of the strained GaAs.

The first and the second rise of quantum efficiency correspond to the threshold of photoemission from GaAs and GaPAs. Fig.5 shows the wavelength dependence of polarization. The maximum polarization of 85.5 ±1.1(stat.)±6.3(sys.) % was obtained(5) at photon wavelength of 860 nm with a quantum efficiency of 4 ± 10^{-4}.

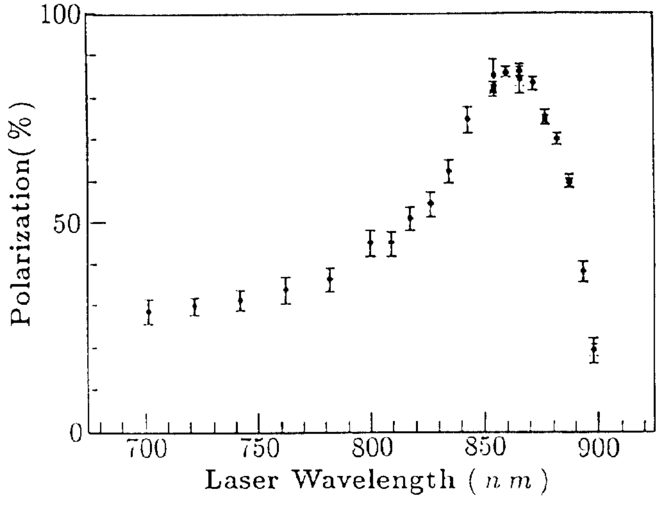

Figure 5. The polarization obtained from the strained GaAs.

4. Conclusions

From those data it becomes clear that the GaAs epilayer strained by the lattice-mismatch of the heterojunction and the AlGaAs-GaAs superlattice are potential candidates of the new photocathode of a polarized electron source, because they have much higher polarization than the GaAs photocathode and reasonable amount of quantum efficiency.

5. References

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