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Development of Spin Polarized Electron Source using AlGaAs-GaAs Superlattice

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Abstract

We have studied how the polarization of photoemisson from AlGaAs-GaAs superlattice depends on the thickness of the superlattice. The polarization of three samples whose thicknesses were 0.4, 0.1 and 0.05μm was measured as 51.0, 69.9 and 73.9% respectively. From the extrapolation to zero thickness we interprete that 24.5% depolarization occured at the surface of the superlattice. We also demonstrated that depolarization in the interior of the superlattice is considerably reduced by lowering the Be dopant concentration.

Introduction

We are developing a polarized electron source for e^+e^- linear colliders like a Japan Linear Collider (JLC[1]) by the use of a photoemission from GaAs semi-conductor. The polarized beam is induced by a circularly polarized laser light, which has characteristics of high pulse-intensity and of pulse-to- pulse spin reversibility.

On the other hand, the polarization from bulk GaAs is limited to 50% because of the degeneracy between a heavy- and a light-hole bands. Three ideas were proposed to remove the degeneracy and overcome the 50% limit, such as a superlattice, chalcopyrite, and a strained crystal[2].

In the 1980's, however, no experiments with such materials could achieve the polarization over 50%. Since 1990 the 50% limit has been overcome by KEK, Nagoya Univ. and SLAC group by using superlattice and strained crystals [3,4,5].

As a next step on approach to 100% polarization we have performed systematic experiments to study the mechanisms of depolarization in a superlattice. We report the polarization measurements obtained as a function of the total thickness of AlGaAs-GaAs superlattice and the density of Be-doping. We also report the analysis on the depolarization occurring in the interior and the surface of the crystal.

Experiment

We prepared three samples of $Al_{0.35}Ga_{0.65}As$-GaAs which is grown by molecular beam epitaxy at 520°C. The structure of the samples is described in Table 1.

Table 1. Structure of the variable thickness Samples

As	(1-2μm, for surface passivation)
Be-doped Superlattice	(Total thickness=0.4, 0.1, 0.05μm)
GaAs	(19.8Å, p=6.2×10^{18}/cm^3)
$Al_{0.35}Ga_{0.65}As$	(31.1Å, p=4.0×10^{18}/cm^3)
Be-doped $Al_{0.35}Ga_{0.65}As$	(1μm, p=5.0×10^{18}/cm^3)
Be-doped GaAs	(500Å, p=7.7×10^{18}/cm^3)
Zn-doped GaAs	(400μm, p=2.0×10^{19}/cm^3)

The total thicknesses of the superlattice are 0.4, 0.1 and 0.05μm. All GaAs and AlGaAs layers except the substrate were doped with Be at a concentration of $5\times10^{18}/cm^3$ to produce an negative electron affinity (NEA) surface. The thicknesses of the

GaAs and AlGaAs layers were chosen to be 19.8Å and 31.1Å, respectively⁶⁾. This structure produces an energy differential between the tops of the heavy-hole and light-hole bands of $44meV$, which exceeds by a substantial margin the thermal noise of $26meV$ at room temperature.

In order to investigate the effect of doping on depolarization we prepared a fourth sample in which Be concentration was reduced to about $5\times10^{18}/cm^3$ in the bottom 0.088 μm of the $0.1\mu m$ superlattice. But in the top $0.012\mu m$ we reverted to the high dopant concentration in order to retain the NEA surface. In all other respects this sample was the same as the first three.

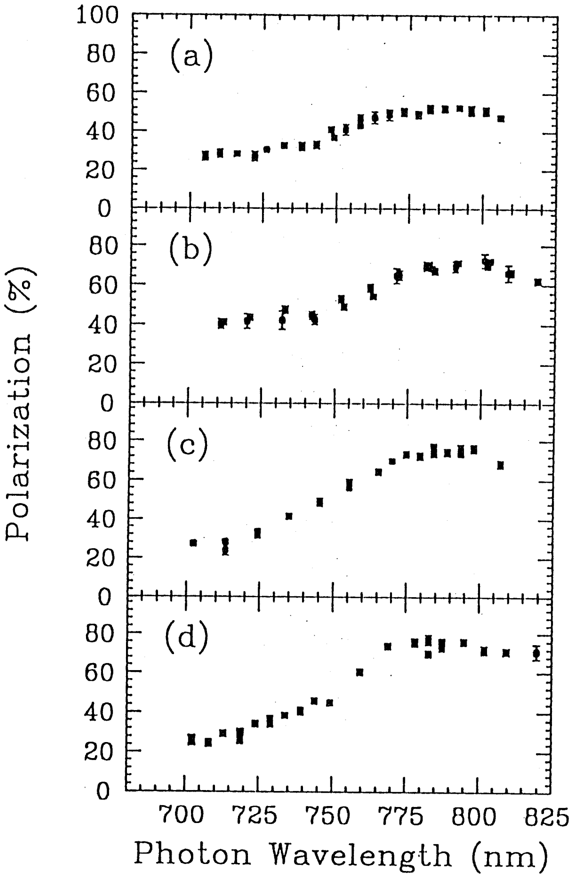

Fig.1 The electron polarization as a function of the laser wavelength. The total thickness and dopant concentration of the superlattice samples are (a) $0.4\mu m$, $\sim5\times10^{18}/cm^3$, (b) $0.1\mu m$, $\sim5\times10^{18}/cm^3$, (c) $0.05\mu m$, $\sim5\times10^{18}/cm^3$, and (d) $0.1\mu m$, $\sim5\times10^{19}/cm^3$

An As cap for surface passivation was removed by heat cleaning before we started polarization measurement in ultra high vacuum. The measurement was done at room temperature. We illuminated each samples with circularly polarized light from Ti:sapphire laser and accelerated the ejected electrons to $100keV$. We measured the electron polarization by means of a Mott analyzer.

In figures 1(a)-(d) we show the electron polarization as a function of the wavelength of the laser light for the four samples. All four exhibit a plateau at a wavelength of about 770-800nm. In these superlattices the heavy-hole band is closer to the conduction band than the light-hole, and wavelengths above some threshold will be capable of inducing photoemission only from the heavy-hole band. Our interpretation of the polarization plateau is that excitation from the heavy-hole band has become the exclusive source of photoemission. The polarizations averaged over the plateau are 51.0±0.5%, 69.9±0.7% and 73.9±0.6% for the three heavily doped samples in order of decreasing thickness as can be seen in Fig.1(a),(b) and (c).

For the lightly doped sample the polarization averaged over the plateau is 74.8±0.6% as shown in Fig.1(d). The errors just quoted arise from the statistical error in the determination of the electron energy spectrum and are independent. An uncertainty in the Sherman function contributes⁷⁾ an additional error which is 8.7% of the measured polarization and is common to all four measurements. Our polarization results are summarized in Table 2.

Table 2. Measured Polarization of Each Samples

Thickness	doping	average polarization	wavelength of the plateau
(μm)	(/cm^3)	(%)	(nm)
0.4	$\sim5\times10^{18}$	51.0±0.5	775-805
0.1	$\sim5\times10^{18}$	69.9±0.7	775-805
0.05	$\sim5\times10^{18}$	73.9±0.6	775-805
0.1	$\sim5\times10^{19}$	74.8±0.6	765-800

Analysis

We analyze our measurements in terms of a model that considers diffusion of conduction band electrons on one dimension. The model was developed by R.L.Bell⁸⁾ who assumed non-polarized excitation and D.T.Pierce et al.⁹⁾ who generalized

Bell's work to include polarization. We have already reported$^{10)}$ the solution of that model. It was shown in figure 2 as a solid line with the three data points (close circle).

The polarization of 74.8±0.6% obtained by the low doping sample supported above expectation. This value agree with the polarization extrapolated to the zero thickness superlattice, 75.5±0.9%.

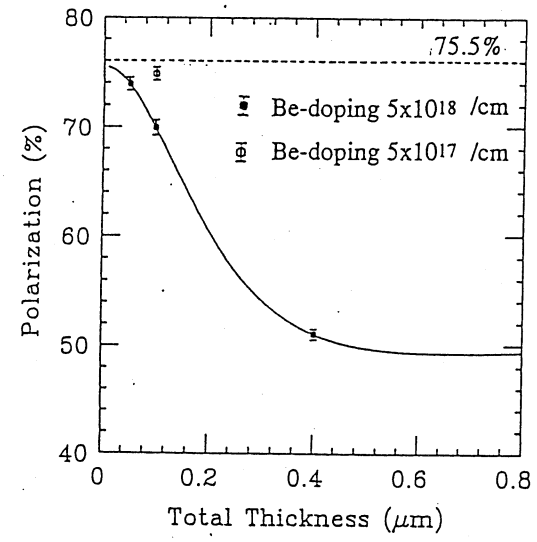

Fig.2 The polarization as a function of the total superlattice thickness. Filled circles (•) show the values for the three samples with a high dopant concentration. An open circles (o) shows the value for the sample witha low dopant concentration.

Conclusion

Three samples of the superlattice whose thicknesses were 0.4, 0.1 and 0.05μm have been tested. The polarization of extracted elctrons are measured to be 51.0, 69.9 and 73.9% at room temperature. By extrapolating these data to the zero thickness, the polarization of 75.5% is obtained. This was interpreted that there was a depolarization of 24.5% when electrons passed the surface of the superlattice.

The lower doping sample, whose doping level was one order of magnitude lower than that of other three samples and thickness was 0.1μm, has been tested. The polarization was measured to be 74.8%. This value reached almost upper limit determined by surface depolarization of 24.5%. It showed that lowering the doping level was effective to reduce the spin relaxation inside the superlattice.

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