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# COMPARISON OF ALINGAAS/GAAS SUPERLATTICE PHOTOCATHODES HAVING LOW CONDUCTION BAND OFFSET[*]

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The main advantage of superlattice (SL) structures as spin polarized electron emitters is the ability to provide a large splitting between the heavy hole (HH) and light hole (LH) valence bands (VB) over a large active thickness compared to single strained layers. Two important depolarization mechanisms in these structures are the scattering effects during the transit of the electrons in the active region and the depolarization that takes place in the band bending region (BBR) near the surface. In this paper, we systematically study the effects of the electron mobility and transit time by using an InAlGaAs/GaAs SL with a flat conduction band (CB). Initial results by the SPTU-SLAC collaboration using such structures grown by the Ioffe Institute showed polarization and quantum yield (QE) of 92% and 0.2% respectively. We report measurements using similar structures grown by SVT Associates. The results (polarization up to 90%) are also compared with simulations.

## 1. Introduction

High polarization electron sources are an important part of the International Linear Collider effort at SLAC. In previous work, polarization on the order of 90% was achieved with the GaAs/GaAsP SL [1], [2].

The main spin depolarization mechanisms in these structures are:

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1. Interband absorption smearing $\delta$ due to bandedge fluctuations;
2. Hole scattering between the HH and LH states that causes a broadening $\gamma$ of the LH band;
3. Spin precession due to an effective magnetic field generated by the lack of crystal inversion symmetry and spin orbit coupling;
4. Electron-hole scattering (negligible comparing to 3);
5. Less polarization selectivity in the BBR;
6. Scattering and trapping of electrons in the BBR.

The first two mechanisms are related to the HH-LH splitting for supporting the spin selection rules. A systematic study on the GaAs/GaAsP structure [2] showed that after a certain splitting level, no increase of polarization could be obtained. Mechanisms 5 and 6 are related to the effects of the BBR and will be independently studied in the future. Mechanisms 3and 4 are material related and they take place during the transport of electrons in the photocathode active region. In the GaAs/GaAsP SL, the electrons tunnel through high barriers in order to reach the cathode surface. In order to lower the barriers in the CB without lowering the barriers for the holes in the VB (to preserve the HH-LH splitting), a quaternary alloy InGaAlAs/GaAs SL was designed and tested at St. Petersburg University, and polarization as high as 91% was achieved with an optimized structure [3]. The measurements were repeated at SLAC on samples grown by SVT Associates. The results are presented in this paper and they are compared with simulations.

## 2. Design of Flat Conduction Band SL Structures

The model for the emitted electron polarization [4] indicates that polarization is inversely proportional to the electron transit time in the active region. Motivated by this concept, flat CB structures based on $In_xAl_yGa_{1-x-y}As/GaAs$ strained barrier SL were designed. The x (In) percentage lowers the bandgap, controls the CB offset $\Delta E_C$ and induces compressive strain in the barriers in order to achieve the desirable HH-LH splitting. The y (Al) percentage controls the size of the SL bandgap and preserves high barriers for the holes in the VB. The goal is to design a structure with as flat a CB as possible, while maintaining a substantial (>30meV) VB splitting. The CB gets anomalously flat for $x=1.1y$. The VB splitting is determined by the induced strain in the barriers controlled by the Indium percentage and the quantum confinement of the wells controlled by the barrier/well sizes. For the $Al_{0.21}In_{0.20}Ga_{0.59}As/GaAs$ SL with 1.5nm wells and 4nm barriers the HH-LH splitting is >50meV.

## 3. Experimental Results

The parameters of the measured samples are shown in Table 1. The first 3 samples are grown by SVT Associates and the last 3 by the Ioffe Institute. All samples have 1.5nm quantum well width, 4nm barrier width, 18 periods, and $4\times10^{17}cm^{-3}$ Be doping. The BBR thickness is 6nm. For comparison the GaAsP/GaAs SL has 89meV LH-HH splitting, $\Delta E_C$=97meV.

Table 1. Parameters of measured samples

| Sample | In% | Al% | SL BG | BBR dop | LH-HH | $\Delta E_C$ | Polarization % |
|---|---|---|---|---|---|---|---|
| 5506 | 17 | 18 | 1.449 eV | 1e19cm$^{-3}$ | 52meV | 19meV | 82-85 |
| 5501 | 20 | 21 | 1.454 eV | 1e19cm$^{-3}$ | 70meV | 19meV | 84-90 |
| 5503 | 23 | 25 | 1.469 eV | 1e19cm$^{-3}$ | 68meV | 10meV | 75-82 |
| 5-777 | 20 | 23 | 1.471 eV | 1e19cm$^{-3}$ | 60meV | 3meV | 91 |
| 6-329 | 20 | 22 | 1.463 eV | 7e18cm$^{-3}$ | 61meV | 11meV | 76-78 |
| 6-410 | 28 | 35 | 1.542 eV | 7e18cm$^{-3}$ | 90meV | 23meV | 75-82 |

Experimental results (dots, multiple measurements) along with the simulations (solid lines) for samples #5501, #5-777 are shown in Figures 1,2.

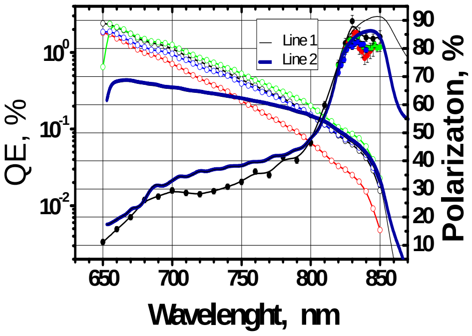

Figure 1. Sample #5501.

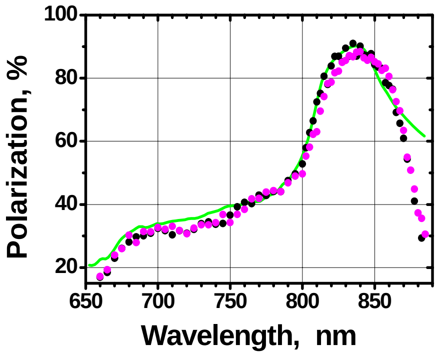

Figure 2. Sample #5-777.

## 4. Discussion and Conclusions

The measured peak polarization is shown in Table 1. By comparing the data with simulation results for samples # 5501 (line 1, Figure 1), 5503 and 5506, we observe a blue shift for the experimental peak. Although longer wavelength photons in general provide more spin selectivity, they also photogenerate electrons primarily in the BBR where there is less polarization selectivity. Also, the electrons photogenerated in the SL structure by longer wavelengths thermalize faster and get trapped more easily in the BBR where they depolarize. Simulation results match the polarization peak height when depolarization is considered to take place in the BBR (line2, figure 1).

All the Ioffe samples were protected by As caps. The highest polarization (91%) was measured when sample #5-777 was heat cleaned at 450°C, while the peak polarization dropped to 85% after heat cleaning at 540°C. The SVT samples where activated after being heat cleaned at 540°C. The effect of the heat cleaning temperature on the polarization suggests that there is a surface factor that contributes to the depolarization. One possible explanation is that the SVT samples have a broader BBR than sample #5-777 due to higher heat cleaning. Samples #6-329 and #6-410 have lower doping at the surface layer and thus, broader BBR than #5-777 and they don’t achieve high polarization

As shown in the (004) x-ray results of Figure 3, the In concentration is slightly higher in the #5501 sample. The deformed SL structure of the SVTA samples can contribute to the lower polarization due to absorption smearing.

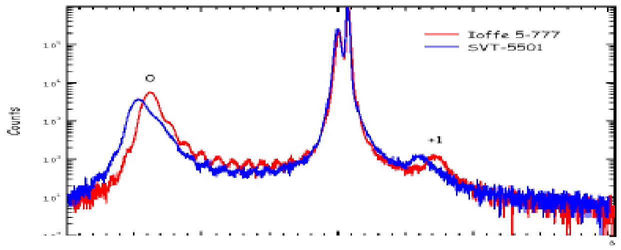

Figure 3. (004) X-Ray analysis of samples 5501 and 5-777. Sample 5-777 has a “cleaner” structure and slightly smaller period (5.01nm) compared to sample 5501 (5.10nm).

The results suggest that although the flat CB samples are promising for high polarization, the polarization seems to depend on surface effects and structural details that are not yet fully understood. Further studies and SIMS analysis of the samples need to take place in order to draw final conclusions about these structures.

## References

1. T. Nishitani, *et al.*, *J. Appl. Phys.*, **97**, 094907 (2005).
2. T. Maruyama *et al.*, *Appl. Phys. Lett.*, **85**, 2640 (2004).
3. Yu. Mamaev *et al.*, *SPIN* 2004, p. 913, SLAC-PUB-10891

4. A.V. Subashiev *et al*., *SLAC-PUB*-7995, PPRC-TN-98-6, Nov 1998.