SLAC–PUB–7922
PPRC-TN-98-3
August 1998

HIGHLY EFFICIENT NEAR-THRESHOLD SPIN-POLARIZED ELECTRON EMISSION FROM STRAINED SUPERLATTICES*

A.V. Subashiev, Yu.A. Mamaev, Yu.P. Yashin
and A.N. Ambrazhei

Technical University, St.Petersburg, 195251, Russia

J.E. Clendenin, T. Maruyama, G.A. Mulhollan

Stanford Linear Accelerator Center, Stanford, CA 94309, USA

A.Yu. Egorov, V.M. Ustinov, A.E. Zhukov

Ioffe Physico-Technical Institute, RAS, St.Petersburg, 194021, Russia

Abstract

Electron photoemission from strained GaAs / $\mathrm{Al_xIn}_y\mathrm{Ga_{1-x-y}As}$ superlattice with near zero offset at a conduction band was investigated. Low value of the offset was provided by appropriate composition in the strained AlInGaAs layers. After three activations, the Quantum Yield(Y) at the polarization peak was about 0.6%, which corresponds to the best values whenever measured. In the samples with lower Y (0.21%) the polarization of up to 86% was measured, which evidence the validity of the structures for the application in the polarized electron sources.

Presented at the
International Conference on Physics of Semiconductors XXIV
(ICPS-24)
Jerusalem, Israel, August 2-7, 1998

---

*Work supported by Department of Energy contract DE–AC03–76SF00515.

HIGHLY EFFICIENT NEAR-THRESHOLD SPIN-POLARIZED ELECTRON EMISSION FROM STRAINED SUPERLATTICES

A.V. SUBASHIEV, YU.A. MAMAEV, YU.P. YASHIN
AND A.N. AMBRAZHEI
Technical University, St.Petersburg, 195251, Russia

J.E. CLENDENIN , T. MARUYAMA, G.A. MULHOLLAN
SLAC, Stanford, CA 94309, USA

A.YU. EGOROV, V.M. USTINOV, A.E. ZHUKOV
Ioffe Physico-Technical Institute, RAS, St.Petersburg, 194021, Russia

Electron photoemission from strained GaAs / $\mathrm{Al_xIn_yGa_{1-x-y}As}$ superlattice with near zero offset at a conduction band was investigated. Low value of the offset was provided by appropriate composition in the strained AlInGaAs layers. After three activations, the Quantum Yield(Y) at the polarization peak was about 0.6%, which corresponds to the best values whenever measured. In the samples with lower Y (0.21%) the polarization of up to 86% was measured, which evidence the validity of the structures for the application in the polarized electron sources.

1 Motivation

The development of new sources of highly polarized electrons is motivated by their successful and growing applications in high energy physics, atomic physics and studies of thin film and surface magnetism[1]. A major breakthrough in achieving electron polarization > 50 % was made in early 1991 with a negative electron affinity (NEA) cathodes consisted of strained InGaAs layer on GaAs buffer substrate[2]. The strain-induced valence-band splitting results potentially in 100 % electronic optical orientation under excitation by circularly polarized light at the interband absorption edge. Polarized electron sources (PES) having significantly higher polarization and electron beam intensity would have an enormous impact on the physics capabilities of future electron-positron colliders and of surface studies installations[3]. Further improvements of the GaAs strained layer cathodes are limited by the controversial character of the demands on the cathode heterostructure parameters. An alternative source of highly polarized electrons is a semiconductor superlattice (SL) in which the valence band splitting is a consequence of hole confinement in the SL quantum wells. The difference in the light and heavy hole masses results in a splitting of the miniband spectrum in the valence band that can (in the case of deep and narrow quantum wells for holes) exceed the splitting in a stressed GaAs layer. The main advantage of SL-based photoemitters is the possibility to vary the properties of the active layer over a wide range by the appropriate choice of layer composition, thickness, and doping[4,5].

2 Choice of the SL layer composition

The main advantage of the $\mathrm{Al_xIn_yGa_{1-x-y}As/GaAs}$ SL proposed here comes from the band line-up between the semiconductor layers of the SL. The Al content determines the formation of a barrier in the conduction band, while adding In leads to conduction band lowering, so the conduction band offset can be completely compensated by appropriate choice of x and y, while barriers for the holes remain uncompensated. Therefore the use of superlattices with the optimized quarternary alloy composition can provide a high vertical electron mobility and simultaneously a small spin relaxation rate while also maintaining a large enough valence-band splitting.

Four different SL - photocathodes were studied : (1) - 15 pairs of GaAs (4nm) and AlInGaAs (4nm) SL with uniform Be doping at $3\mathrm{x}10^{18}$ cm^{-3} and x=0.18 y=0.18 as well as 17- pairs SL with (2) x=0.16, y=0.18, (3) x=0.18, y=0.18, and (4) x=0.18, y=0.2 AlInGaAs layers. In samples (2-4) the doping $5\mathrm{x}10^{17}$ cm^{-3} in the bulk (to reduce depolarization effects) but $6\mathrm{x}10^{18}$ cm^{-3} in the final 8 nm (to increase the QE) was used. The SL samples were MBE-grown on GaAs (100)-oriented substrates. The characterization of the samples was done using luminescence and X-ray diffraction techniques.

The schematic of the position of the band edges for x=0.20, y=0.18 is shown at the inset of Fig. 1. Using linear interpolation for the deformation potential, elastic constants and band offsets we have found that the conduction band offset appears to be anomalously small for $x = 1.1y$. The choice of the layer thickness is dictated by the need to split the hole minibands. The splitting grows when barriers are broad enough and wells are narrow and deep. Still the thickness of the strained $\mathrm{Al_xIn_yGa_{1-x-y}As}$ layer should be less than the critical thickness $h_c(d) \approx 8$ nm. The overall critical thickness for the superlattice with alternating layers of equal thickness can be estimated as $H_c = h_c(L/2)$, where L is the SL thickness. In accordance with X-ray data the chosen thickness of the SL samples (0.12-0.13 μm) exceeded H_c much less than in the case of a cathode structure with one strained GaAs layer.

3 Experimental results

The spin polarization of photoelectrons was measured using the Mott analyzers both at the laboratory of spin-polarized electron spectroscopy of St.-Petersburg Technical University and at the Stanford Linear Accelerator Center. We have

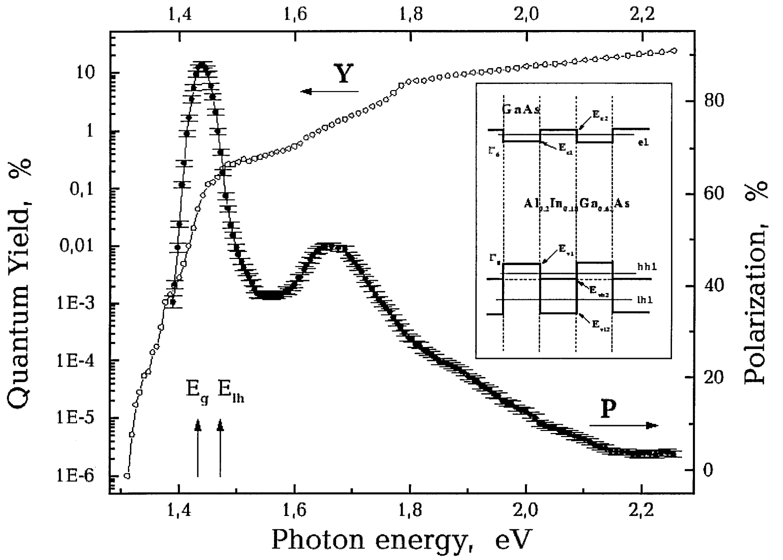

Figure 1: Yield and polarization spectra for SL sample #4. The inset shows the calculated band structure for x=0.20, y=0.18.

found the polarization results to be similar despite the somewhat different techniques of sample preparation, activation, and vacuum.

In Fig. 1, the measured polarized emission and quantum yield data are shown as a function of the optical excitation energy for SL sample #4. Maximum polarization obtained was 86 %. Quantum yield Y at the polarization maximum is sensitive to activation procedure and vacuum in the setup. The polarization dependence on the excitation energy comes from the initial electron polarization P_0 and also the electron escape time d/S_0 into the band bending region. The falling down of the initial polarization at high-energy side of the maximum starts with the electron excitation from the first light-hole miniband. The decrease of polarization below absorption edge can be attributed to electron excitation in the tail states of the conduction band and rising of the the electron escape time. A sharp decrease of Y and P at the band edge indicates a small tail size for the chosen doping level. Thus, the position of the polarization maximum is close to the SL band gap. In the SL the band gap is larger than that in GaAs layers due to quantization of the heavy hole states and some shift of the conduction band minimum.

In Fig 2, the measured polarization of the emitted electrons for all the

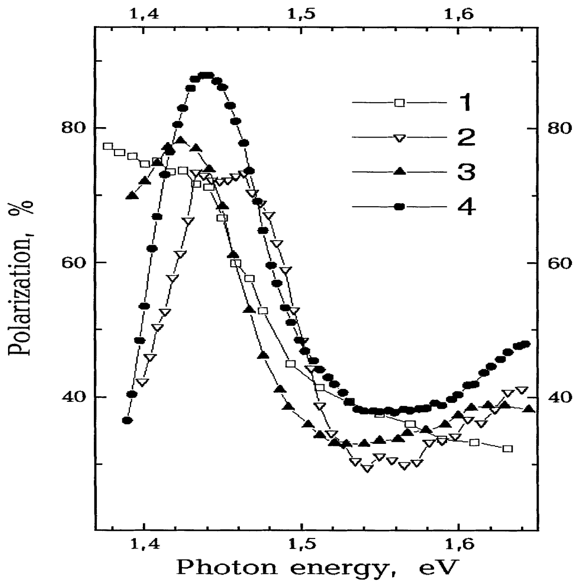

Figure 2: Polarization spectra for all four SL samples.

samples at the absorption edge is presented. The absolute value of maximum shift is consistent with the expected change on the basis of the band edge calculations. The width of the polarization maximum is consistent with the splitting of $\approx$ 40 meV between hh1 and lh1 minibands. One can expect larger splittings of the SL with thicker barriers and thinner GaAs wells. Then, one can expect smaller spin relaxation rate for optimally chosen doping of SL, compatible with needed extracted emission current. Thus, the optimization of the SL structure parameters and doping profile can lead to further improvement of the proposed new SL photoemitter structure.

4 Conclusions

In conclusion, electron spin polarization as high as 86 % has been reproducibly obtained from strained $Al_xIn_yGa_{1-x-y}As/GaAs$ superlattice with anomalously small conduction band offset at the heterointerfaces. The modulation doping of the SL provides high polarization and high quantum yield at the polarization maximum. The position of the maximum can be easily tuned to an excitation wavelength by choice of the SL composition. Further improvement of the emitter parameters can be expected with additional optimization of the SL structure parameters.

Acknowledgements

This work is supported by the U.S. Civilian Research and Development Foundation under Award No. RP1-351, support of Russian State Program "Surface atomic structures", project 95-1.23 and Swiss National Science Foundation under grant 7IP 51742 is also gratefully acknowledged.

References

1. D.T. Pierce, in *Experimental Methods in the Physical Sciences*, Vol. 29 A, (R. Celotta and T. Lucatorto eds.), p. 1, New York, London, Acad. Press, 1995.
2. T. Maruyama, E.L. Garwin, R. Prepost, G.H. Zalapac, J.S. Smith, J.D. Walker, *Phys. Rev. Lett.* **66**, 2376 (1991).
3. J.E. Clendenin, *Int. J. Mod. Phys.* **A13**, 2507 (1998).
4. K. Togawa et al., Surface charge limit in NEA superlattice photocathodes of polarized electron source,: DPNU-98-11 (4 March 1998), submited to Nucl. Instrum. and Meth.
5. A.V. Subashiev, In *Pros. 12-th Intern. Symp. on High-Energy Spin Physics, Amstardam 1996* ed. by C.D.W. de Jager et al. Word Scientific, Singapore, 1997, p. 749.