HIGHLY-POLARIZED ELECTRON EMISSION FROM STRAIN-COMPENSATED AlInGaAs-GaAsP SUPERLATTICES[*]

V. Subashiev, L. G. Gerchikov, Yu. A. Mamaev, Yu. P. Yashin

St. Petersburg State Polytechnic University

Politekhnicheskaya 29, St. Petersburg, 195251, Russia

E-mail: arsen.subashiev@gmail.com

J. S. Roberts, P. A. Houston

Department of Electronic Engineering University
Sheffield, UK

D.-A. Luh, T. Maruyama, J. E. Clendenin

Stanford Linear Accelerator Center
Menlo Park, California 94025, USA

Abstract

New results from experimental and theoretical studies of spin-polarized electron emission from InAlGaAs-GaAsP superlattice photocathodes with opposite strain in the quantum well and barrier layers are presented. The measured values of maximum polarization and quantum yield for the structure with a 0.18 μm-thick working layer are close to the best results reported for strained superlattice photocathode structures, demonstrating the high potential of strain compensation for future photocathode applications. An analysis of the photoemission spectra is used to estimate the parameters responsible for the polarization losses.

Contributed to the
Polarized Electron Sources and Polarimeters International Workshop (PESP 2004)
7-9 October 2004, Mainz, Germany

Highly spin-polarized electron photoemission from strained short-period superlattice (SL) structures have been the subject of a number of studies; e.g., see refs.[1-3]. In these structures, the heavy-hole (hh) and light-hole (lh) minibands are split due to the difference in the hh and lh confinement energies in the SL quantum wells, which adds to the separation due to strain alone. The enlarged valence band splitting results in a high initial electron polarization in the conduction band under excitation by circularly polarized light. However, the thickness of the stressed photo-cathode working layer necessary for achieving a high value of quantum yield exceeds the critical thicknesses for strain relaxation, which results in structural defects, smaller residual strain and thus lower polarization. To overcome these problems the use of strain -compensated stuctures with the composition of the SL barrier layers chosen to have opposite (tensile) strain from that of the quantum well layers was proposed[4]. Thus considerably larger strain values in the SL wells can be achieved with no limitations on the overall thickness of the SL structure[5], which should ensure high electronic polarization. Here we present the results of the studies of these SLs.

The SL structures were grown by metal-organic vapor phase epitaxy (MOVPE), which provides high structural quality and low defect densities at the interfaces[6]. The working layer consisted of 8 to 30 pairs of compressively strained $In_xAl_yGa_{1-x-y}As$ quantum well layers alternated by tensile strained $GaAs_zP_{1-z}$ barrier layers. On top of the SL working layer a 6-nm thick GaAs surface layer was deposited with Zn - doping concentration enlarged to 1×10^{19} cm^{-3}.

The range of available compositions of the $In_xAl_yGa_{1-x-y}As$ QW layer is restricted to x values which give maximum valence band splitting while retaining a high structural quality (i.e. $x \approx$ 16-18 %) and the y values that result in the SL band gap larger than that in GaAs ($y \geq 12$ %). The phosphorus content in the $GaAs_zP_{1-z}$ barrier layers should provide sufficient deformation to compensate strain in the wells. However at large z values the SL becomes of a type II for the light holes so that the energy splitting of the hh1- lh1 minibands is lowered. To test this variation three sets of samples with $z =$8, 17 and 18 % various working-layer thicknesses were studied.

The experimental $Y(h\nu)$ and spectra $P(h\nu)$ (for pre-activation heating temperature T_h close to optimal) for the photocathode based on $In_{0.18}Al_{0.14}Ga_{0.68}As$- $GaAs_{0.83}P_{0.17}$ SL containing 20 periods with 5 nm-thick wells and 4-nm barriers is presented in Fig. 1. The parameters of the photocathode, i.e. the maximum polarization value , $P_{max} = 84\%$, and yield at the maximum, $Y(h\nu)= 0.4\%$, are close to the best results reported for any strained superlattice photocathode structures, evidencing the high potential of strain compensation. The spectral dependence of $P(h\nu)$ shown in Fig. 1 is typical for all considered samples. It includes a high - polarization peak at the band-edge absorption and a second peak at higher energies with a well pronounced dip

between them. These features follow the sequence of the miniband transitions hh1→e1, hh2→e2 and lh1→e1 respectively, the edges of theses transition being close to the energies corresponding to maximal slope in $P(h\nu)$ are shown in Fig. 1 by the vertical lines.
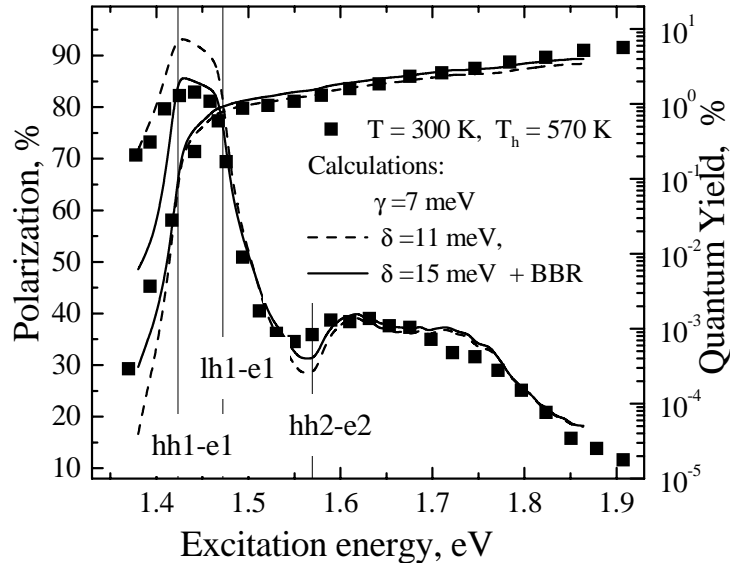

FIG. 1: Polarization and quantum yield spectra of the emitted photoelectrons for $In_{0.18}Al_{0.14}Ga_{0.68}As$-$GaAs_{0.83}P_{0.17}$ superlattice and the calculated energy dependence of $P(h\nu)$ and $Y(h\nu)$ spectra with the valence band smearing and hole scattering (dashed), and with the contribution of the BBR added (solid lines).

To estimate the photocachode parameters, we have calculated optical absorption and the initial polarization of photoelectrons in the working layer as a function of excitation energy using the multiband Kane model[7]. The electron depolarization during the transport to the surface and emission into vacuum was assumed to be 5%[8]. The calculated maximum polarization value at the top of the first polarization maximum is sensitive to the broadening of the absorption edge associated with two main factors. The first is the interband absorption smearing due to the band edge fluctuations, which can be evaluated by fitting the $Y(h\nu)$ dependence. The second factor originates from the processes of hole scattering between the hh and lh states, which leads to a non-zero contribution of the lh1 miniband to the absorption near the edge and that populates the second spin state. The calculated spectra for scattering rate γ =7 meV and smearing energy δ= 11 meV are depicted in Fig. 1 by the dashed line giving the maximum value of electron polarization $P_{max} \approx 92$ %.

Note that a sizeable decrease of the polarization maximum comes from the surface CaAs layer (BBR) since it has smaller band gap and the polarization of electrons excited in this layer does not

exceed 50%. The results of the calculation of the $P(h\nu)$ and $Y(h\nu)$ spectra allowing absorption in a BBR layer with a thickness of 10 nm are shown in Fig. 1 by the solid line. The good agreement with experimental data shows the importance of this contribution to the total polarization losses.

To summarize, newly designed photocathode superlattice structures with strain compensation have been grown and studied as candidates for highly polarized electron emission. These photocathodes are based on InAlGaAs-GaAsP structures grown by MOVPE. The structures are found to be advantageous due to the prevention of strain relaxation and the smaller relative contribution of the BBR region in comparison with strained-well structures.

———————————————————

[1] T. Omori, Y. Kurihara, Y. Takeuchi, M. Yoshioka, T. Nakanishi, S. Okumi, M. Tsubata, M. Tavada, K. Togava, Y. Tanimotol, C. Takahashi, T. Baba and M. Mixuta, Jpn. J. Appl. Phys., **33**, 5676 (1994).

[2] T. Saka, T. Kato, T. Nakanishi, S. Okumi, K. Togava, H. Horinaka, T. Matsuyama, and T. Baba, Surf. Sci. **454-456** 1042 (2000).

[3] T. Maruyama, D.-A. Luh, A. Brachmann, J. E. Clendenin, E. L. Garvin, S. Harvey, J. Jiang, R. E. Kirby, C. Y. Prescott, R. Prepost, and A. M. Moy, SLAC-Pub-10331, Feb. (2004)

[4] Yu. P. Yashin, J. S. Roberts, L. G. Gerchikov, P. A. Houston, A. N. Ipatov, Yu. A. Mamaev, A. V. Rochansky and A. V. Subashiev, *11th Int. Symp. "Nanostructures: Physics and Technology" (NANO 2003)* (St.Petersburg, 2003) p. 61.

[5] J.C. Dries, M.R. Gokhale, K.J. Thomson, S.R. Forrest, *Appl. Phys. Let.***73**, 2263 (1998).

[6] R.P. Green, A. Krysa, J.S. Roberts, D.G. Revin, L.R. Wilson, E.A. Zibik, W. H. Ng, and J. W. Cockburn, Apl. Phys, Lett. v. 83, 1921 (2003).

[7] A.V. Subashiev, L. G. Gerchikov, A. N. Ipatov *Journ. Appl Physics* **96**,1511 (2004).

[8] K. Aulenbacher, J. Schuler, D. v. Harrach, E. Reichert, J. Roethgen, A. Subashev, V. Tioukine, Y. Yashin, J. Appl. Phys., 92, 7536 (2002).