TITLE: Polarized Electron Photoemission Studies of Spin Relaxation in Thin GaAs Epitaxial Films

TITLE: Nanostructures: Physics and Technology International Symposium [9th], St. Petersburg, Russia, June 18-22, 2001 Proceedings

9th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 18–22, 2001

NC.12p

Polarized elecrton photoemission studies of spin relaxation in thin GaAs epitaxial films

Yuri A. Mamaev†, Yuri P. Yashin†, Arsen V. Subashiev‡, Anton N. Ambrajei† and *Alexander V. Rochansky*†

† Laboratory of Spin-Polarized Electron Spectroscopy, State Technical University, 195251, St Petersburg, Russia
‡State Technical University, 195251, St Petersburg, Russia

Abstract. The results of systematic study of polarized electron emission from unstrained GaAs thin epitaxial layers with varying thickness are presented. Excitation spectra of the polarized photoemission reflect the optical spin orientation of the electrons produced by the circularly polarized light excitation and spin relaxation kinetics. The interpretation of the spectra and their temperature dependencies shows the importance of valence band wrapping and correlation between the spin and the momentum of an electron. For thin overlayers the residual polarization losses occur in the band-bending region.

Optical spin orientation in GaAs in known to give information on the spin relaxation mechanisms and the electron kinetics. With the aim to clarify the mechanisms of photoelectron polarization losses, we have performed a set of the polarized electron emission experiments with unstrained GaAs epitaxial thin films.

The GaAs overlayers with the thickness 70, 100, 150, 500, 1000 and 1500 nm were MBE-grown at the top of n-doped GaAs wafer. An advantage of n-doped GaAs wafer is the elimination of the back scattering of photoexcited electrons from the overlayer/wafer interface, which leads to the lowering of an effective lifetime of electrons prior the emission. At the same time the study of electron emission from the overlayers with various thickness allowed us to investigate the emission of electrons as a function of the electron extraction time from the GaAs film.

In the modulation doped GaAs overlayers the main part of a layer was low p-doped (5×10^{17} cm^{-3}), which should help to suppress Bir–Aronov–Pikus (BAP) spin relaxation mechanism, while the top 10 nm were heavily p-doped (5×10^{19} cm^{-3}) with the aim to achieve high quantum yield at the NEA surface. The working GaAs overlayer was capped with As to prevent the layer pollution by the air. With the aim to study temperature dependence of electron spin dynamics, the electron polarization and yield spectral dependencies were measured at the temperatures 300 and 130 K for freshly activated samples and in the course of the photocathode surface degradation.

All measurements have been performed at the computer-controlled set-up [2] at the residual pressure $1-2 \times 10^{-10}$ Torr, circularly polarized light monochromaticity being equal $\Delta\lambda = 2$ nm. Thermal cleaning procedure (at the pressure not exceeding $3-5 \times 10^{-9}$ Torr) consisted of the sample heating with gradual increase of temperature up to 560–580 degrees centigrade, one hour exposition at 560–580 degrees centigrade and than cooling for one hour till room temperature. NEA has been achieved by cesium and oxygen deposition. During the course of experiments Mini–Mott detector was calibrated both with the energy — loss extrapolation procedure [3] and with GaAs/AlGaAs derivative standard for polarimeter calibration [4].

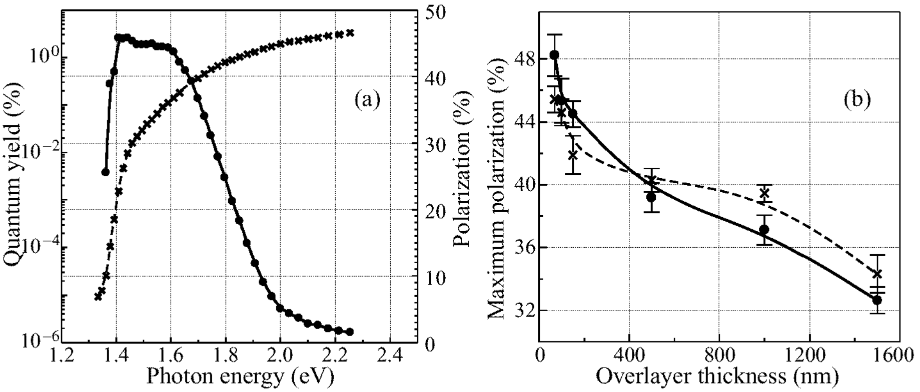

Fig. 1. Electron spin polarization (circles) and quantum yield (crosses) as a function of excitation energy for the GaAs unstrained sample (overlayer thickness 100 nm) at room temperature (a) and maximum polarization values at various GaAs overlayer thickness for freshly activated cathodes (b). Solid line and circles — room temperature; dash line and crosses — $T = 130$ K.

Figure 1(a) shows the electron spin polarization $P(h\nu)$ and quantum yield $Y(h\nu)$ as a function of excitation energy for the GaAs unstrained sample with overlayer thickness 100 nm at room temperature. The typical features of $P(h\nu)$ and $Y(h\nu)$ curves are clearly seen, i.e. high spin polarization P near the photothreshold, then rather wide plateau, followed by decreasing of P when $h\nu$ is close to $E_g + \Delta$, where spin-orbit splitting $\Delta = 0.3$ eV. The maximum value of P is about 46% for 100 nm films.

In general, the polarization of the optically oriented electrons can be lost [1]:

(i) at the electrons creation under circular light excitation; (ii) during the thermalisation; (iii) in course of electrons transport to the band-bending region (BBR); (iv) in the BBR; (v) during the escape to vacuum through the NEA surface barrier. The processes at different stages of the photoemission have strongly different time scales, and are essentially independent, so that the polarization P of the emitted electrons can be expressed as a product of the factors reflecting each step of the emission process [6],

$$P(h\nu) = P_0(h\nu) R_{\text{th}} R_{\text{tr}} R_{\text{BBR}} R_{\text{emi}}, \tag{1}$$

where $P_0(h\nu)$ is the electron polarization in the conduction band at the excitation moment, the factors R_{th}, R_{tr}, R_{BBR}, and R_{emi} describe spin relaxation during each of the subsequent stages of emission as listed above.

The wide plateau is a sequence of a suppression of the BAP spin relaxation mechanism due to low doping at the main part of the GaAs overlayer. It also a manifest of negligible polarization losses at the step (ii) of the photoemission.

The dependence of the polarization in the polarization maximum on the layer thickness d is presented in Fig. 1(b). As it is evident from Fig. 1(b), the maximum polarization value grows upon the reduction of GaAs overlayer thickness and for the most thin overlayer practically reaches 50%, which is the theoretical maximum value of P_{max} in equilibrium. This dependence can be used to evaluate the polarization losses in the step (iii) and to estimate the spin relaxation time in the layer.

At the small layer thickness $d \ll l$ (l is the diffusion length) the corresponding depolarization factor can be written as

$$R_{\text{tr}} = \frac{\tau_s}{\tau_{\text{esc}} + \tau_s}, \tag{2}$$

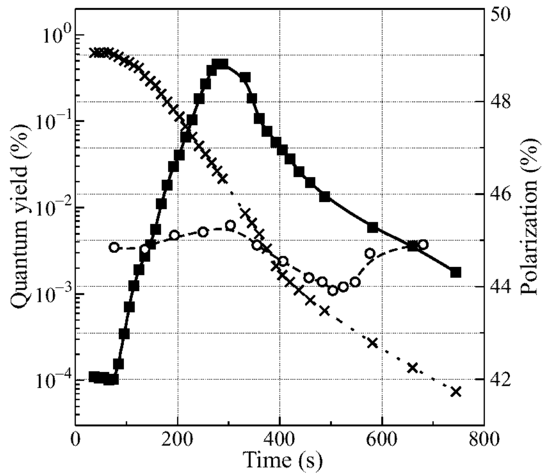

Fig. 2. Polarization (circles and squares) and Quantum Yield (crosses) evolution upon the degradation of the GaAs sample surface at $T = 130$ K for the near-threshold (open circles) excitation ($\Delta = h\nu\ E_g = 15$ meV) and excitation at 190 meV above the energy gap (solid squares).

where τ_s is the spin relaxation time in the active layer. The escape time from the active layer equals $\tau_{\mathrm{esc}} = d/S$, S being the surface recombination velocity. The comparison with the experiment gives the estimate for the spin relaxation time $\tau_s \approx 50$ ps in line with the luminescence data, while the temperature dependence is found to be slower than that for the D'yakonov and Perel' (DP) mechanism.

One can see that at the thickness less than 400 nm $P_{\mathrm{max}}(300\,\mathrm{K}) > \mathrm{P}_{\mathrm{max}}$ (130 K). This observation can be explained by more effective spin relaxation in BBR at 130 K, since at low temperature the BBR quantum well is deeper, than at $T = 300$ K [5] and DP mechanism becomes more effective at the step (iv) [6].

At the thickness d more than 400 nm the value of P_{max} for cool cathode exceeds one at room temperature. This feature is typical as well for the bulk cathodes and is explained by faster spin relaxation in the working layer (in the step (iii)) prior the emission into vacuum.

Data of Fig. 1(b) were obtained for freshly activated cathodes, i.e. $P(h\nu)$ and $Y(h\nu)$ curves were measured just after activation of NEA surface. The increase of the work function, which occurs upon the degradation of the sample surface, leads to the cut-off the photoelectrons which are captured in the BBR and thermalised at the bottom of the conduction band.

Hence, the only "hot" electrons, which have not yet undergo spin relaxation due to steps (ii)–(iv), can escape into vacuum. This experiment enables us to evaluate the polarization losses in these steps. Figure 2 shows that in the case of photoexcitation at about 200 meV above the photo-threshold polarization is growing up upon the surface degradation, which is explained by the higher polarization of hot electrons. The GaAs valence band wrapping effect and the relationship between the spin and the momentum of an electron just after excitation can lead to the electron polarization of up to 67% [7]. It was first time illustrated by Mirlin [7], who measured the hot photoluminescence circular polarization of up to 35%. High polarization was achieved with specially designed and modified GaAs sample. Valence band wrapping and the relationship between the spin and the momentum of an electron are essential for high-polarization photoemission. High polarization obseved in this case suggests that for thin overlayers the residual depolarization occurs due to spin relaxation in the band bending region.

The presented analysis of the polarization losses in the photoemission processes in the unstrained GaAs thin layers shows the perspectives for the polarization increase in the highly polarized electron sources based on the strained GaAs layer and the short-period semiconductor superlattices [1]. Since the losses in BBR and in the emission in vacuum are not enhanced for these cases the limiting factors are found to be associated with the polarization losses in the excitation and in the electron extraction in BBR.

Acknowledgments

This work was supported by the Russian State Program "Physics of Solid State Nanosrtuctures" under grant 97-1091, Russian Foundation for Basic Research under grant 00-02-16775, INTAS under grant 99-00125 and SNSF under grant 7IP 062585.

References

[1] A. V. Subashiev, Yu. A. Mamaev, Yu. P. Yashin and J. E. Clendenin, *Phys. Low-Dim. Structures* **1/2**, 1 (1999).
[2] Yu. P. Yashin, A. N. Ambrajei and Yu. A. Mamaev *Instruments for Experimental Techniques* **43** (2), 245 (2000).
[3] T. J. Gay, M. A. Khakoo, J. A. Brand, J. E. Furst, W. V. Meyer, W. M. K. P. Wijayaratna and F.B. Dunning, *Rev. Sci. Instrum.* **63** (1), 114 (1992).
[4] G. Mulhollan et al., *Proceedings of the 16th IEEE Particle Accelerator Conference (PAC 95) and International Conference on High-energy Accelerators (IUPAP)*, Dallas, Texas, 1995, p. 1043.
[5] C. Herman, H.-J. Drouhin and G. Lampel, *Spectroscopy of Nonequilibrium Electrons and Phonons* ed C. V. Shank and B. P. Zakharchenya, Elseiver Science, B.V., 1992, Ch. 9.
[6] A. V. Subashiev and J. E. Clendenin, *Journ. Modern Physics* **A 15** (1), 2519 (2000).
[7] D. N. Mirlin, *Optical Orientation*, ed F. Meier and B. P. Zakharchenya, North-Holland, Amsterdam, 1984, Ch. 4.