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Abstract

Resonance enhancement of the quantum efficiency of new polarized electron photocathodes based on a short-period strain-compensated AlInGaAs/GaAsP superlattice structure is reported. The superlattice is a part of an integrated Fabry-Perot optical cavity. We demonstrate that the Fabry-Perot resonator enhances the quantum efficiency by up to a factor 10 in the wavelength region of the main polarization maximum. The high structural quality implied by these results points to the very promising application of these photocathodes for spin-polarized electron sources.

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Resonance Enhancement of Spin-Polarized Electron Emission from Strain-Compensated AlInGaAs-GaAsP Superlattices

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Abstract. Resonance enhancement of the quantum efficiency of new polarized electron photocathodes based on a short-period strain-compensated AlInGaAs/GaAsP superlattice structure is reported. The superlattice is a part of an integrated Fabry-Perot optical cavity. We demonstrate that the Fabry-Perot resonator enhances the quantum efficiency by up to a factor 10 in the wavelength region of the main polarization maximum. The high structural quality implied by these results points to the very promising application of these photocathodes for spin-polarized electron sources.

Introduction

Strained short-period superlattices have been used to advantage in achieving highly spin-polarized electron photoemission [1]. In these structures, the heavy hole (hh) and light hole (lh) minibands are split due to the effects of both quantum confinement and strain-induced splitting. The enlarged valence band splitting results in a high initial electron polarization in the conduction band under excitation by circularly polarized light. Smearing of the interband absorption edge and light-heavy-hole mixture processes lead to a polarization (P) in the bandedge absorption of less than 100 %. These mechanisms set a sizeable limitation for the maximum polarization of emitted electrons [2, 3]. The initial polarization can be increased by choosing strongly strained structures with a higher valence band splitting.

The thickness of the strained photocathode working layer, however, exceeds the critical thickness for strain relaxation resulting in structural defects, smaller residual strain and lower polarization. Critical thickness considerations limit the number of superlattice (SL) periods in the working layer and thus the quantum efficiency of the structures. To overcome this problem, two types of photocathodes have been proposed. The use of a strain compensated SL, whereby the composition of the SL barrier layers is chosen to have opposite (tensile) strain from that of the quantum well layers, allows the total working layer to be considerably thicker [4]. Another way to increase the quantum efficiency (QE) is to integrate the SL working layer into a Fabry-Perot optical cavity [5]. The key feature of such structures is a Distributed Brag Reflector (DBR) at the back side of the photocathode that reflects the incoming circularly polarized light back to the surface where approximately 0.3 of the intensity is reflected into cathode again and so on.

In the present work we combine these two approaches and develop a novel photocathode structure that integrates a working layer based on the strain-compensated InAlGaAs-GaAsP SL into a Fabry-Perot optical cavity. We investigate polarized electron emission from the photocathodes with and without a DBR mirror and report a tenfold enhancement of quantum efficiency due to optical enhancement from the Fabry-Perot cavity without degradation of electron polarization.

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1. Experiment

The photocathode structures were grown on a *p*-type (100) GaAs substrate by Metal Organic Vapor Phase Epitaxy using trimethyl group III reagents and arsine. The photocathode design is shown in Fig. 1. It consists of a DBR mirror containing 22 pairs of alternating $\lambda/4$ plates of $Al_{0.19}Ga_{0.81}As$ and AlAs. On the top of this mirror, a 500nm thick $Al_{0.35}Ga_{0.65}As$ buffer layer is grown that serves as the substrate for the strained SL. The superlattice contains 20 pairs of compressively-strained $(Al_{0.16}Ga_{0.84})_{82}In_{18}As$ quantum well layers and tensile-strained $GaAs_{0.83}P_{0.17}$ barrier layers. The layer compositions were designed to optimize the effect of strain magnitude and compensation on electron polarization. On top of the SL working layer, a 6-nm thick GaAs surface layer was deposited with Zn-doping concentration enlarged from 7×10^{17} cm^{-3} in the working layer to 1×10^{19} cm^{-3} to achieve negative electron affinity by the well known procedure of surface activation. Two samples have been prepared with and without a DBR layer.

As cap		
GaAs	QW	6nm
$(Al_{0.16}Ga_{0.84})_{82}In_{18}As$	SL 20X	4nm
$GaAs_{0.83}P_{0.17}$		6nm
$Al_{0.35}Ga_{0.65}As$	Buffer	500nm
GaAs		20nm
AlAs	DBR 22X	71nm
$Al_{0.19}Ga_{0.81}As$		58nm
GaAs (100) – Substrate , Zn		

Fig. 1. Composition of the photocathode.

The structures were characterized by photoluminescence measurements, which included mapping of the structure surface. Both structures showed very good structural quality. The excitation spectra of the polarized photoemission from these structures were measured at room and at lowered (130 K) temperatures for different activation regimes. Studies of polarization growth during assisted degradation were used to identify polarization losses in the band bending region (BBR).

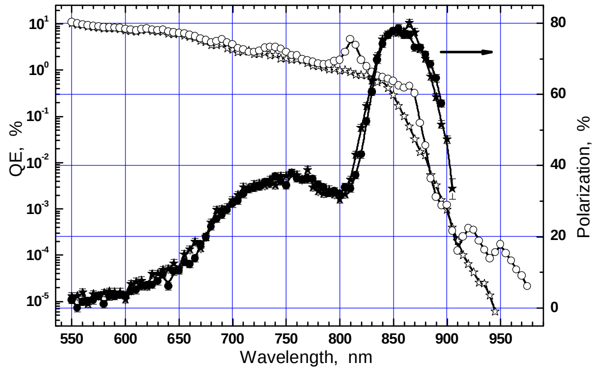

Fig. 2. Polarization (solid symbols) and quantum efficiency (open symbols) spectra of the emitted photoelectrons from photocathodes with (circles) and without (stars) DBR.

2. Results and Discussion

The polarization and quantum efficiency data as a function of wavelength are shown in Fig. 2 . The polarization spectra with and without the DBR layer are almost identical. The structures show all the typical features of SL emission including high-polarization peak at the band edge absorption and a second peak at higher energies with a well-pronounced dip between them. However these samples have different quantum yield spectra. While the sample without a DBR exhibits a typical smooth QE (λ) behavior with a cutoff below the absorption edge, the quantum yield spectrum of the sample with a DBR has additional resonance features.

To illustrate this fact, we plot in Fig. 3 the ratio of quantum efficiencies for these two samples together with the polarization curve for the DBR sample. Resonance peaks correspond to the increase of the electromagnetic field in the working layer when resonance conditions for the Fabry-Perot optical cavity are fulfilled. The largest resonance peak of quantum yield enhancement at λ=870nm practically coincides with the main polarization maximum of electron emission. Thus the DBR layer in the present sample increases the quantum efficiency of polarized electron emission by factor 10.

It worth to noting that the resonance enhancement of quantum yield is not accompanied by a decrease of electron polarization. This fact manifests the high structural quality of this photocathode. Since the resonance standing wave in a Fabry-Perot cavity is very sensitive to a phase shift near the resonance, even a small difference in the refraction indexes in in-plane directions as the result of a small anisotropy of the inplane lattice strain leads to a completely unpolarized wave in the working layer [6].

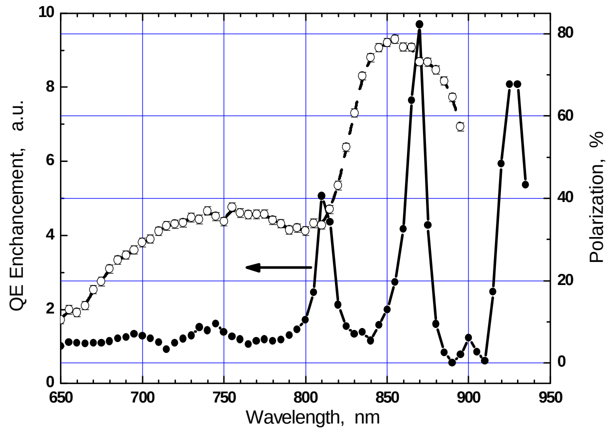

Fig. 3. Resonance enhancement of quantum efficiency (solid circles) and polarization of electron emission (open circles) from photocathode with DBR.

3. Conclusions

We have developed a novel type photocathode based on InAlGaAs-GaAsP strain compensated superlattices integrated into a Fabry-Perot optical cavity of high structural quality. We demonstrate a tenfold enhancement of quantum efficiency at the polarization maximum due to the multiple resonance reflection from DBR layer. The obtained results demonstrate the advantages of the developed photocathode as a perspective candidate for spin polarized electron sources.

Acknowledgments

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