SLAC–PUB–7346
October 1996

A Polarization Study of Strained GaAs Photocathode Structures*

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Abstract

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Contributed to the
Workshop on Polarized Electron Sources and Low Energy Polarimeters
12th Int. Sym. on High-Energy Spin Physics
NIKHEF, Amsterdam, NL, September 6-7, 1996

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

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ABSTRACT

The properties of several types of strained GaAs and GaAsP photocathodes have been studied using x-ray diffraction and photoemission.

The polarized electron source at SLAC has performed extremely well during recent years supplying electrons having a spin polarization of 78% (85%) for high (low) current operation with beam current limited primarily by experimental requirements. However, there is room for improvement in the electron polarization. The less-than-ideal polarizations are a result of both imperfections and depolarizing mechanisms within the photocathode.

The structure of the photocathode used at SLAC in the polarized electron source is shown in Fig. 1. It is a single-strained emitting layer structure grown atop a GaAs substrate. The layers are arranged so as to: first create a smooth layer for later epitaxy, gradually add P content into an initially pure GaAs layer for high quality GaAsP layer growth, form a well ordered GaAsP layer with constant P fraction and finally to strain the 100 nm emitting layer. The in-plane compressive strain in the final layer removes the heavy hole-light hole degeneracy in the GaAs band structure near the Γ point. Emission from the heavy hole band alone has an electron spin polarization theoretical maximum of 100%. All the photocathodes discussed below have this same general structure.

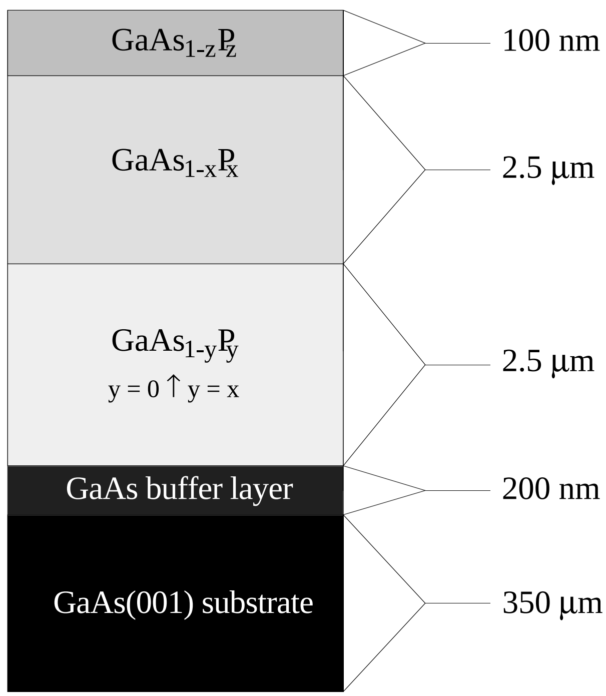

Figure 1: Structure of single-strained layer GaAs photocathode in use at SLAC. All layers are doped with Zn to 5x$10^{18}/cm^3$. The currently used cathode has $z = 0$ and $x = 0.28$.

Imperfections, usually in the form of strain relieving dislocations, contribute to incomplete separation of the heavy and light hole bands. During growth, the dislocations can either propagate from the final strain inducing GaAsP layer or be generated in the strained GaAs emitting layer. It is desirable to fabricate as defect-free as possible both the strain inducing layer and the strained layer. To this end, several different structures have been tested for epitaxial quality. A second type of imperfection can arise in the form of compositional inhomogeneities of the underlying structure. For example, errors in the P content will lead to low strain and hence low polarization. Substitution of a strain inducing layer with a composition easier to control than the GaAsP layers is a possible remedy.

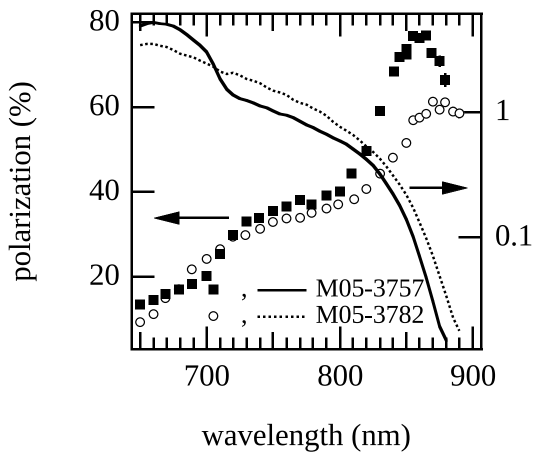

Figure 2: Photoemission data from GaAs strained by GaAsP (M05-3757) and GaInP (M05-3782).

MOCVD grown GaInP has better compositional uniformity across large (≥3") wafers than GaAsP. Several photocathodes with the structure of Fig. 1 excepting the replacement of the GaAsP layers with GaInP of the appropriate stoichiometry were fabricated to test the quality of GaInP as strain inducing layers[1]. A comparison of x-ray and photoemission results from the best of these cathodes compared with the currently used material appears in Figs. 2 and 3. While the final GaAs layer was strained, the overall quality of the GaInP layers, which had P mixing problems at the interface with the final GaAs layer due to the MOCVD chamber chemistry, was morphologically inferior to the GaAsP leading to relaxed strain and low polarization.

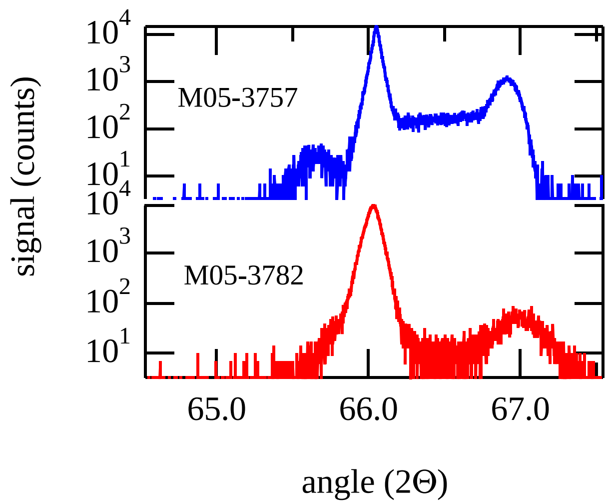

Figure 3: (004) diffraction data (see Fig. 2).

Another plausible source of depolarizaton is photon recycling. In the structure of Fig. 1, photons not absorbed by the emitting layer (about 90% at the band gap) are absorbed in the GaAs substrate. The electrons which are excited across the band gap later decay back into the valence band by emitting photons. These photons can have scrambled polarization and/or be emitted off axis so that they can contribute to the emission of unpolarized electrons. This eventuality was tested by changing the substrate upon which the structure was grown to GaP[2]. As most of this photocathode is transparent to the light corresponding to the band gap of the emitting layer, depolarizing effects due to diffuse reflection at the cathode holder surface were removed by depositing an absorbing metal layer on the polished back face of the GaP substrate. For the strain present in the samples, no improvement in polarization was apparent from the change in substrate.

It is well known that the QE can be improved by increasing the size of the bandgap, for example in moving from GaAs to GaAsP (assuming we stay below the direct to indirect bandgap transition) or by cooling GaAs. The increase in QE is primarily due to the increase in the surface escape probablility[3]. We have tested for this phenomenon in 100 nm thick strained GaAsP, the results of which are shown in Fig. 4. Interestingly, the QE at the peak polarization is equal for both samples and has the same value obtained for strained GaAs (see Fig. 2). A possible explanation of the lack of any QE enhancement is that the peak polarization is always at the same location with respect to bandgap.

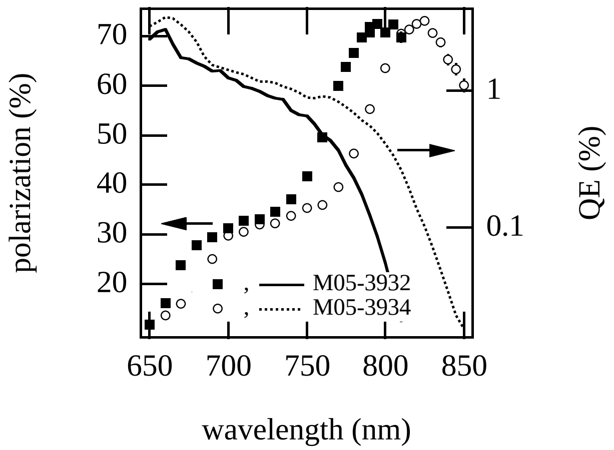

Figure 4: Photoemission data from bandgap shifted GaAsP. Note the value of the QE at the polarization maximum.

Past a critical thickness, epitaxially strained layers relax to the bulk lattice spacing. Strain asymmetry is caused by unequal relaxation along nominally equivalent crystallographic directions. The asymmetry makes electron emission sensitive to the electric field direction of light incident normal to the cathode (see Fig. 5)[4]. Residual linear polarization causes a current asymmetry upon changing the helicity of the light source. This effect was measured in materials of varying strain and tracks well with the wavelength dependence of the polarization.

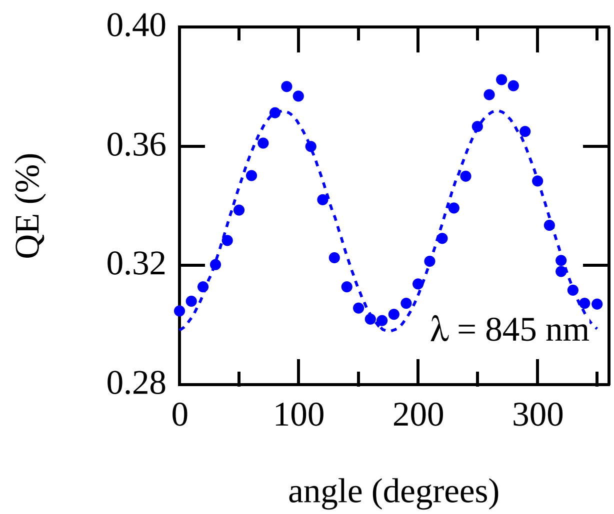

Figure 5: QE as a function of linear polarization azimuthal angle for 100 nm strained GaAs.

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