PROGRESS REPORT

Development of Polarized Photocathodes for the Linear Collider

Personnel and Institution(s) requesting funding

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Collaborators

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Collaborating personnel will work on the project but are not requesting funding here.

Project Leader

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Project Overview

The development of high current polarized photocathodes is very important for the International Linear Collider (ILC) project. Physics requirements call for highly polarized electron beams with at least 90% polarization.

A Wisconsin - SLAC collaboration has developed and studied polarized photocathodes which have been used for the SLAC SLD and fixed target programs. A more recent goal is the development of photocathodes with a polarization in excess of 90% which meet the ILC charge requirements. This work started as a SLAC -Wisconsin collaboration (E. Garwin, T. Maruyama of SLAC and R. Prepost of Wisconsin) and has evolved into a formal SLAC collaboration called the Polarized Photocathode Research Collaboration (PPRC).

Early research efforts focused on the development of strained photocathodes since electron spin polarization higher than 50%, approaching 100%, is theoretically possible using cathode structures which have less crystal symmetry than unstrained GaAs . Excellent performance was achieved with strained GaAs epitaxial layers grown on a GaAsP buffer layer. The 1994-1998 SLC operation with the SLD detector and subsequent fixed target experiments E-143, E-154, E-155, and E-155X used strained gallium arsenide cathodes which produced at least 80% polarization at the source. More recently, a newly developed high current polarized photocathode used for SLAC experiment E-158 achieved a polarization of about 85-90% with a charge approaching that required for the ILC.

We have continued R&D efforts on cathode structures to address certain issues, specifically: 1) fundamental properties of materials, and 2) higher polarization. One limitation of singly strained heterostructures is that the thickness of the active layer is limited to about 0.1μm. A larger thickness of the active layer results in serious degradation of the strain. Superlattice structures can in principle overcome the inherent thickness limitation of single heterostructures. Therefore one of the main goals of this R&D program is to systematically study several superlattice structures and to find a parameter set for maximum electron polarization.

One change since year 1 of this continuing proposal is the technology choice for the cold accelerator. The accelerator bunch spacing is 300 ns compared to the 1.4 ns that was proposed for the warm machine. The warm machine choice required photocathodes that had to recover from a trapped charge induced photovoltage in less than 1.4 ns. The recovery time from trapped charge is greatly reduced with a high p-type doping level for the first 100 nm of surface. We worked extensively on this problem and developed a high gradient doped strained GaAs structure which nominally met the NLC bunch separation requirements. However, high doping levels result in some depolarization since one of the major mechanisms for depolarization is spin-flip electron-hole scattering. The ILC bunch spacing of 300 ns no longer requires such a rapid recovery from trapped charge and the photocathodes no longer require a surface high doping level.

Two superlattice structures have been chosen for study. The structures are quite different. Although both superlattice structures alternate potential wells with potential barriers, the InAlGaAs/GaAs structure has a strained InAlGaAs barrier while the GaAs/GaAsP superlattice has a GaAs strained well.

The InAlGaAs/GaAs superlattice structure of about 18 periods was proposed by the Russian St. Petersburg group of Y. Mamaev. The Mamaev group had CDRF funds in partnership with SLAC to study and grow certain superlattice structures. The two year CDRF grant ended Nov. 2004 and resulted in this interesting structure which required additional study. This particular structure has an lattice matched buffer layer which should result in higher quality with less dislocations and a smaller conduction band offset which should result in greater electron transport. We need to confirm the polarization and QE results of this superlattice photocathode with a structure that has been grown by a commercial vendor. Once the results have been confirmed, we can investigate parameter optimization.

The second superlattice photocathode selected for investigation is GaAs/GaAsP. We have previously studied this structure and obtained excellent results with a peak polarization of about 86%. We believe the parameters have not yet been fully optimized and will study the polarization dependence on doping levels. To this end, several samples have been ordered from a commercial vendor.

Work will also continue with studies of low-temperature atomic hydrogen heat cleaning of the photocathode structures. Lower heat cleaning temperatures result in less dopant loss, less dopant diffusion, and less degradation of strain.

Another effort which is now underway is the development of a laser with the ILC pulse structure for testing our photocathode structures.

Progress Report

InAlGaAs/GaAs Superlattice Three samples were ordered from SVT Associates in Minneapolis. One sample was grown using the St. Petersburg parameters and the other two samples were grown to have InAl fractions both above and below the target original values. After X-ray measurements and commercial Secondary Ion Mass Spectroscopy (SIMS) analysis the polarization and QE of these structures were measured in the SLAC test system. The results do not show the 92% polarization measured in St. Petersburg. The maximum polarization

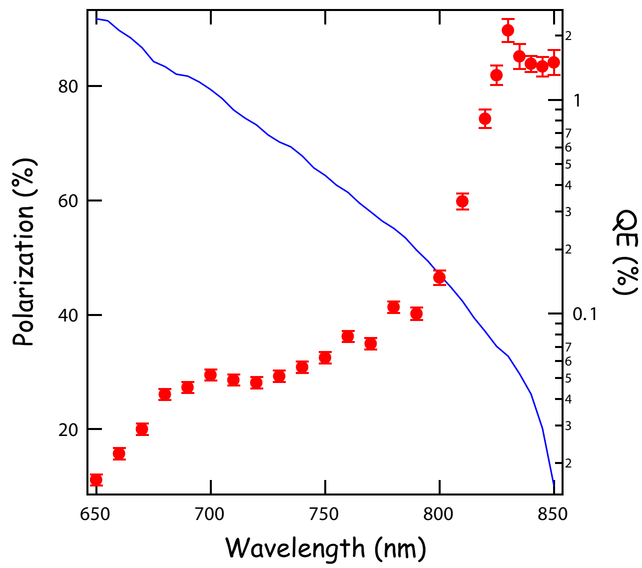

Figure 1: $In_{0.20}Al_{0.21}Ga_{0.59}As/GaAs$ Superlattice Photocathode Polarization and QE Results. The solid line is QE and the points with error bars are polarization.

obtained for these samples with our measurements is consistent with 85% polarization and no significant dependence on the InAl superlattice fraction. However, the present measurements were made with a relatively high sample heat-cleaning temperature of 550 C. High temperature heat-cleaning temperatures generally result in performance degredation of the samples. The St. Petersburg samples were grown using Molecular Beam Epitaxy (MBE) which enables one to arsenic cap the sample and use a lower heat cleaning temperature. The samples grown by our own vendor were grown with chemical vapor deposition techniques (MOCVD) which preclude arsenic capping. Consequently, we must heat-clean the samples at a significantly higher temperature to get a satisfactory QE. We plan, in the future, to reduce the heat-cleaning temperature using atomic hydrogen cleaning.

The QE and polarization results for the three InAlGaAs/GaAs samples were very similar and did not show any difference for the three sets of different InAl fractions. The QE and polarization results for one of the samples is shown in fig. 1.

GaAs/GaAsP Superlattice We have continued to study the GaAs/GaAsP superlattice with the goal of optimizing the parameters with respect to doping concentration. Higher doping generally leads to depolarization effects and we would like to explore lower p-type doping levels. As stated earlier, the cold technology choice has greatly reduced the peak charge requirements and lower doping levels can be used. The GaAs/GaAsP superlattice structures which have been used for SLAC experiments have yielded 86% polarization and there should be a possibility for higher polarization. we have placed an order for two samples with different doping levels from SVT Associates. Unfortunately, the quoted delivery time of six weeks has not been met and we still do not have the samples. We expect to receive the samples by the end of Feb. 06.

Photocathode Laser with the ILC Pulse Structure In preparation for operating our developed photocathodes with the ILC pulse structure, Axel Brachmann of SLAC is in the process of putting together a system to produce the required ILC 300 ns bunch spacing. The system uses a low power YAG/TiSaphire mode locked laser operating at 76 MHz which will be Pockels Cell switched to produce about a ms pulse with a 3 MHz microstructure. We have purchased a commercial Pockels Cell driver from Bergmann Messgerate Entwicklund KG capable of providing the 1 ms, 3MHz structure as the first step in this program. SLAC has ordered the required Pockels cells with delivery expected in March 06. At a later date, an amplification stage will be added, giving sufficient power for photocathode photoemission.

Next year Project Activities and Deliverables

InAlGaAs/GaAs Superlattice Studies We will implement low temperature atomic hydrogen cleaning of the photocathode samples. We believe the present high temperature heat-cleaning (550 C) utilized for these samples has degraded the electron polarization. This may explain the lower measured polarization relative to the polarization measurements made in St. Petersburg on the same structure.

GaAs/GaAsP Superlattice The samples should arrive within the next few months and we will then be able to study the effect of the p-type doping levels on the electron polarization. Depending on the results of polarization and QE measurements we may want to order additional samples.

Laser with ILC Pulse Structure The Pockels cell driver required for production of the ILC pulse structure has arrived. The short term plan is to set up the laser system without the final stage amplifier and late in FY06 or in FY07 to add the amplification stage to drive real photocathodes. We are currently looking for a suitable amplifier to be purchased later this year.

GaAs/AlInGaAs Superlattice SLAC has an approved Phase I SBIR with SVT Associates for the growth of this structure. Once the samples arrive, X-Ray measurements and SIMS analyses will have to be done in order to characterize the sample parameters.

Subsequent year (if any) Project Activities and Deliverables

Subsequent year activities will require the submission of a new proposal, since FY06 is the last year of the current three year grant. However, with a new proposal we anticipate that the work will continue to focus on the study of superlattice structures, the development of a laser with the ILC pulse structure, and the study of applying photocathode bias voltages to possibly enhance QE and polarization. This latter effort has recently started, and is in the first stage of devising a technique to apply bias voltages to photocathodes in a cathode test system.

Budget Justification: The items in the budget shown below are justified as follows:

1. **Purchase of photocathode structures from a commercial vendor** The vendor presently used is SVT Associates. This vendor has the facilities for MBE growth with Be doping. This item accounts for about half of the $20k equipment items. The main goal of this proposal is the study and development of high polarization photocathodes.

2. **Facility Equipment** The remaining $10k of the equipment budget is for laser upgrade of the photoluminescence facility and for the development of a laser with the ILC pulse structure.
3. **Characterization Studies** The materials and supplies part of the budget in amount $8.6k is for the X-ray and SIMS analyses which have to be done for every new structure sample. Payment is required for any X-Ray analysis done at either Wisconsin or Stanford and the SIMS analyses are done by a commercial vendor.
4. **Travel** The $3k budgeted for travel is for Prepost trips to SLAC.
5. **Indirect Costs** The $3k amount for indirect costs is based on the University of Wisconsin 26% overhead rate for off-campus projects. Only the Materials/Supplies and Travel items are subject to the indirect cost charge.

Two-year budget, in then-year K$

Institution: University of Wisconsin

Item	Next year	Subsequent year	Total
Other Professionals	0	0	0
Graduate Students	0	0	0
Undergraduate Students	0	0	0
Total Salaries and Wages	0	0	0
Fringe Benefits	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0
Equipment	20	20	40
Travel	3	3	6
Materials and Supplies	8.6	8.6	17.2
Total direct costs	31.6	31.6	63.2
Indirect costs(1)	3.0	3.0	6.0
Total direct and indirect costs	34.6	34.6	69.2