PROGRESS REPORT FY06 **April 13, 2007**

Development of Polarized Photocathodes for the Linear Collider

Personnel and Institution(s) requesting funding

Richard Prepost, University of Wisconsin, Madison WI 53706

Collaborators

A. Brachmann, SLAC
J. Clendenin, SLAC
R. Kirby, SLAC
T. Maruyama, SLAC

Project Leader

R. Prepost
prepost@hep.wisc.edu
608 262-4905

Project Overview

In prior years a Wisconsin-SLAC collaboration developed polarized photocathodes which were used for the SLAC SLD and fixed target programs. Currently, the R&D program goal is the development of a polarized electron source (PES) which meets the ILC requirements for polarization, charge, lifetime, and pulse structure. There are two parts to this program. One part is the continued improvement of photocathode structures with higher polarization. The second part is the design and development of the laser system used to drive the photocathode. The long pulse train for the ILC introduces new challenges for the PES. More reliable and stable operation of the PES may be achievable if appropriate R&D is carried out for higher voltage operation and for a simpler photocathode load-lock system.

The collaboration with SLAC is through the Polarized Photocathode Research Collaboration (PPRC). Senior SLAC personnel include T. Maruyama, J. Clendenin, R. Kirby, and A. Brachmann.

The research to date has been successful in achieving higher polarization and higher QE, but the goal of $> 90\%$ polarization has not been achieved. The polarization appears saturated at 85% and a material-specific spin-depolarization mechanism appears to be present. Consequently, we have embarked on a program to study several types of superlattice structures.

After several years of intensive photocathode R&D, strained GaAs/GaAsP superlattice structures have emerged as the primary candidates for use with the ILC polarized electron source. Strained superlattice structures, consisting of very thin quantum well layers alternating with lattice-mismatched barrier layers are excellent candidates for achieving higher polarization since three issues are addressed. First, due to the difference in the effective mass of the heavy-holes and light-holes, the superlattice exhibits a natural splitting of the valence band, adding to the strain-induced contribution to the splitting. Secondly, each of the superlattice layers is thinner than the critical thickness. Thirdly, superlattice structures also have the additional advantage that they can overcome the inherent critical thickness limitation of single heterostructures, permitting a much thicker active layer for photoemission. The superlattice structures studied to date have all been designed with a high doping profile in a thin (10 nm) layer near the surface. The high surface doping density is necessary to achieve high QE and to reduce the the surface-charge limit problem, while the lower doping density in the remaining 100 nm of the superlattice is required to reduce depolarization to a minimum. The surface-charge-limit problem was serious for the machines with warm accelerating structures which have a short bunch spacing of the order of nanoseconds. The relatively long bunch spacing of 300 ns for the cold ILC greatly reduces the surface-charge-limit problem and since there is an indication that the high surface doping density is limiting the peak polarization, the high-gradient-doping profile is being reevaluated.

Progress Report for FY06

Several types of new superlattice structures have been tested. A description of the progress follows.

InAlGaAs/GaAs Superlattice This structure is designed to have a flat conduction band, i.e. electrons do not have to tunnel through barriers as they diffuse to the surface. This structure was developed and tested by the Mamaev group at St. Petersburg University and showed a very high polarization of 92%. Samples from St. Petersburg were sent to SLAC to be measured by our group, but did not show the high polarization observed at St. Petersburg. The maximum polarization obtained for these samples with our measurements was consistent with 85% polarization. However, the measurements were made with a relatively high sample heat-cleaning temperature of 550° C. High temperature heat-cleaning generally results in performance degradation of the samples. The St. Petersburg samples were grown using Molecular Beam Epitaxy (MBE) which enabled them to arsenic cap the sample and use a lower heat cleaning temperature. To continue our study of this structure, two samples were ordered from SVT Associates in Minneapolis. 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 did not show the 92% polarization measured in St. Petersburg. The samples obtained from SVT were grown with chemical vapor deposition techniques (MOCVD) which precludes arsenic capping and consequently a high heat cleaning temperature of 550°C again had to be used. We plan to obtain more samples and use a hydrogen cleaning technique which can be done at the lower temperature of 450°C.

InAlGaAs/GaAsP Superlattice This structure is designed to be strain compensated, i.e. the wells and barriers of the superlattice have almost equal and opposite strain, giving the benefits of the large heavy-hole light-hole splitting obtained from strain and a more ideally strained sample. Samples were obtained from the University of Sheffield in the UK. However the polarization measured by our group was only ∼80%, not competitive with our best superlattice structures. No new samples are on order.

InGaP/GaAs Superlattice The goal in the design of this structure was to study the effect of lower spin-orbit coupling parameters. Samples were obtained through an SBIR award to SVT Associates. Three wafers were grown, two with a strained barrier, and one with a strained well. The highest polarization achieved was only 70% showing no improvement compared to our best photocathodes.

Photocathode Laser with the ILC Pulse Structure In preparation for operating our developed photocathodes with the ILC pulse structure, Axel Brachmann of SLAC is developing a system to produce the required ILC 300 ns bunch spacing. The system uses a low power

YAG/TiSapphire 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, 3 MHz structure as the first step in this program. SLAC has obtained the required Pockels cells. At a later date, an amplification stage will be added, giving sufficient power for photocathode photoemission.

Remaining FY06 Project Activities and Deliverables

Spin Relaxation Measurements using Faraday Rotation To date we have not had a technique to measure the spin relaxation time constants of the photocathode structures under test. To this end an apparatus to measure the photocathode polarization as a function of time using the Faraday Effect is under construction. The technique uses a pump-probe technique that first pumps electrons into the conduction band (pump pulse) with circularly polarized light to produce polarized electrons. The rotation of the linear polarization direction of a second linearly polarized light pulse (probe pulse) is measured as a function of the time delay between the pump and probe pulses. The rotation of the linear polarization angle due to the Faraday Effect is proportional to the degree of electron polarization and thus the electron polarization can be mapped as a function of time giving the spin relaxation time. The main apparatus component is a short pulse mode-locked Ti-S laser capable of producing pulse widths considerably shorter than the spin relaxation times to be measured. The laser wavelength spread also must be such that only the heavy-hole to conduction band transition is excited, required to produce the high polarization. To date we have acquired a TiSapphire mode locked laser from KM labs and commissioning tests are under way. We plan to start making Faraday Rotation measurements in Spring-Summer 07. The direct measurement of spin relaxation times will help to identify the parameters most directly related to maximum photocathode polarization and lifetime.

InAlGaAs/GaAs Superlattice Studies The InAlGaAs/GaAs superlattice structure has a flat conduction band unlike other structures which have conduction band barriers for electron transport. As explained in the previous section, the lower measured polarization by our group relative to the polarization measurements made in St. Petersburg on the same structure is likely due to a higher heat cleaning temperature. We will obtain more wafers from the Mamaev group and implement low temperature atomic hydrogen cleaning.

InGaN Photocathode Studies The large band gap of InGaN offers the potential for structures with improved negative electron affinity (NEA) potentially yielding high quantum efficiency (QE) with a long lifetime. These are no other studies of the use of GaN based structures as a polarized photocathode. Preliminary samples were obtained through an SBIR award to SVT Associates. These studies will continue.

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 plan to place an order for two samples with different doping levels from SVT Associates.

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 during FY07/08 and later add the amplification stage to drive real photocathodes. There is currently SLAC SBIR program with KM Labs to develop a suitable amplifier.

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

1. **Purchase of GaAs/GaAsP photocathode structures from a commercial vendor** The vendor presently used is SVT Associates. Additional samples are required to complete the study of differing doping concentrations. This item accounts for about half of the $20k equipment items.
2. **Facility Equipment** The remaining $10k of the equipment budget is for laser upgrade of the photoluminescence facility. FY05 funds were used to acquire a Pockels cell driver for the development of a laser with the ILC pulse structure. Funds from FY05 and FY06 have been used to purchase a Mode-Locked TiSapphire laser from KM Labs to be used for the Faraday Rotation Studies.
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.

FY06 Budget - Institution: University of Wisconsin

Item	FY07
Other Professionals	0
Graduate Students	0
Undergraduate Students	0
Total Salaries and Wages	0
Fringe Benefits	0
Total Salaries, Wages and Fringe Benefits	0
Equipment	20
Travel	3
Materials and Supplies	8.6
Total direct costs	31.6
Indirect costs(1)	3.0
Total direct and indirect costs	34.6