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# Development of Polarized Photocathodes for the Linear Collider

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### 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 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. 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.

## Technical Progress and Final Results

The items below describe progress and results from superlattice parameter studies, the development and first results for measuring spin relaxation times using a newly developed Faraday Rotation apparatus and progress on developing a polarized source laser system with the ILC pulse structure.

### GaAs/GaAsP Superlattice: Study of Superlattice Parameters

The best results to date for a polarized source have come from a GaAs/GaAsP superlattice. In this study the superlattice parameters were systematically varied to optimize the photoemission characteristics. The heavy-hole and light-hole transitions were reproducibly observed in the quantum efficiency spectra, enabling direct measurement of the band energies and and energy splitting. Eleven samples obtained from SVT Associates were obtained with varying P fraction, number of superlattice periods and GaAs well and GaAsP barrier width parameters. The P fraction determines the lattice mismatch between the well and barrier components of the superlattice. The superlattice period studies were performed to determine the maximum thickness of the superlattice before significant strain relaxation. The well and barrier thickness studies resulted in a shifting of the wavelength of the peak polarization. Over a wide range of parameters the spin polarization remained constant at about 86%, indicating that the valence heavy-hole light-hole band splitting for a range of well thicknesses was sufficient. The complete results have been published in Ref.[1].

### 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. The photocathode performance was found highly dependent on the superlattice parameters and in particular, the superlattice electron confinement energy appears to be an important parameter. The results are described in Ref.[2].

### GaAs/GaAsP Superlattice: Surface Layer Doping Concentration

We have continued to study the GaAs/GaAsP superlattice with the goal of optimizing the parameters with respect to the surface layer doping concentration. High surface doping generally leads to depolarization effects and thus we have studied lower p-type surface doping levels. As stated earlier, the cold technology choice has greatly reduced the peak charge requirements and lower doping levels that still support the required charge may be possible. The GaAs/GaAsP superlattice structures which have been used for SLAC fixed target experiments have yielded 86% polarization with a p-type surface layer doping of $5 \times 10^{19}\text{cm}^{-3}$ and there should be a possibility for higher polarization with a lower GaAs surface layer doping level. For this study we have obtained four samples from SVT Associates with varying p-type doping in a 5 nm GaAs cap surface layer of a GaAs/GaAsP 14 period superlattice. The p-type doping levels studied were $5 \times 10^{19}, 2 \times 10^{19}, 1 \times 10^{19},$ and $5 \times 10^{18}\text{cm}^{-3}$. The results are shown in Fig.1. and show no significant trend for higher polarization with reduced surface layer doping.

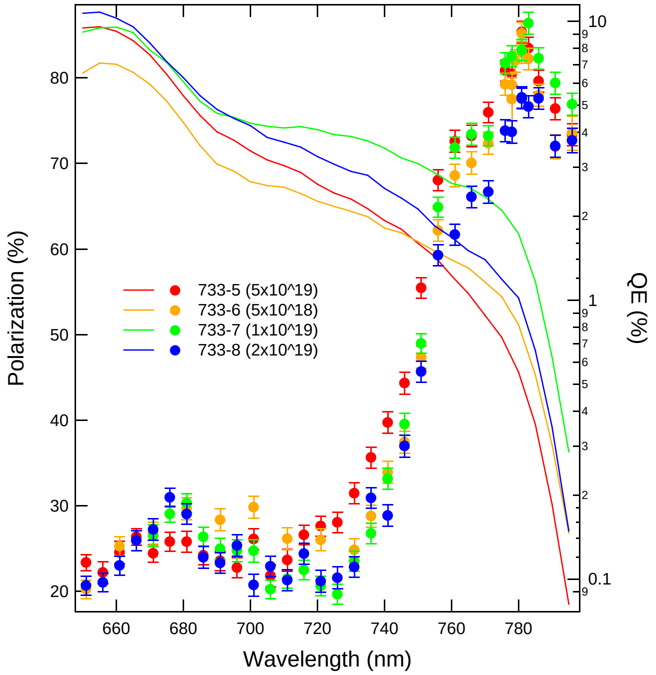

Figure 1: Polarization and Quantum Efficiency vs. Wavelength for different GaAs surface layer p-type doping levels

## Photocathode Laser with the ILC Pulse Structure

In preparation for testing 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. The low power stage output enters a high power amplification stage. However the commercial pump laser for the amplification stage has not yet met the required power level specifications and further progress awaits finding a vendor for the pump laser that can meet the required power specifications.

## 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 has been developed. 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.

The apparatus has been commissioned and first measurements have been made with a 2 micron thick GaAs photocathode sample. The Faraday Rotation apparatus layout is shown in Fig.2. The Argon 20 W laser provides the pump excitation for the Titanium Sapphire mode-locked laser which produces both the pump and probe pulses using a variable delay line between the circularly polarized pump and the linearly polarized probe pulses. The rotation of the linear polarization direction is measured after transmission through the sample by separately measuring the horizontal and vertical components of the transmitted linear polarization.

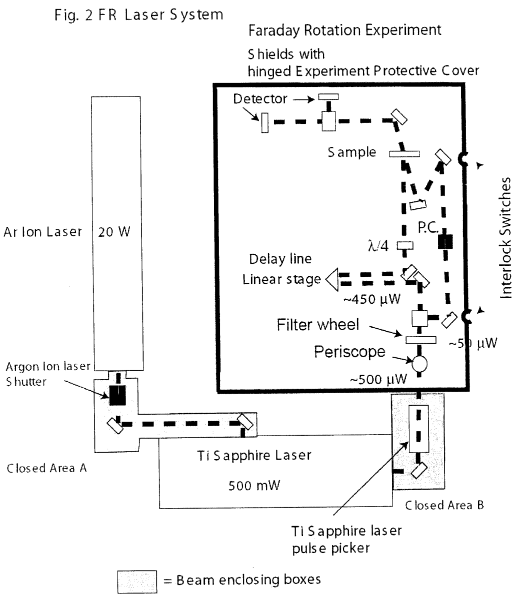

Figure 2: Layout of the Faraday Rotation Pump-Probe Apparatus

The spin relaxation result for a room temperature 2 micron GaAs photocathode is shown in Fig. 3. The plot shows a quantity proportional to the spin polarization as a function of the delay between the pump and probe pulses. The calibration of the delay line is such that 1 mm of path length difference between the pump and probe pulses corresponds to a time difference of 3.33 ps. A fit to the data yields a spin relaxation time of 12.6 ps is in reasonable agreement with previously measured values published in Ref.[3] and[4].

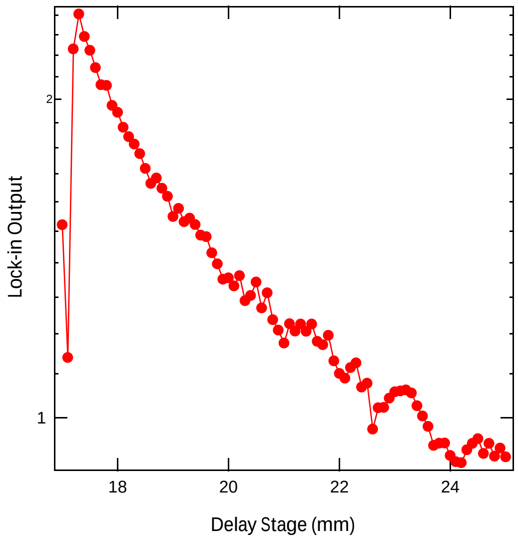

Figure 3: A quantity proportional to the spin polarization of a room temperature bulk GaAs photocathode as a function of the delay stage path difference between the pump and probe pulses. A delay stage difference of 1 mm corresponds to a time delay of 3.33 ps. A fit to the data yields a spin relaxation time of 12.6 ps.

## References

[1] “Systematic Study of Polarized Electron Emission from Strained GaAs/GaAsP Superlattice Photocathodes”, T. Maruyama et al., Appl. Phys. Lett. **85**, 2640 (2004).

[2] “Polarization Possibilities of Small Spin-Orbit Interaction in Strained-Superlattice Photocathodes”, T. Maruyama, A. Brachmann, J.E. Clendenin, E.L. Garwin, R. Prepost and A. Moy, Proceedings of the 17th International Spin Physics Symposium, edited by K. Imai et al., Kyoto, Japan, Oct.2-7 2006. p. 1045.

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[4] R.J. Seymour and R.R. Alfano, Appl. Phys. Lett. **37**, 231 (1980).