# THE ILC POLARIZED ELECTRON SOURCE *

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*Abstract*

The SLC polarized electron source (PES) can meet the expected requirements of the International Linear Collider (ILC) for polarization, charge and lifetime. However, experience with newer and successful PES designs at JLAB, Mainz, Nagoya and elsewhere can be incorporated into a first-generation ILC source that will emphasize reliability and stability without compromising the photocathode performance. The long pulse train for the ILC may introduce new challenges for the PES, and in addition 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 load-lock system. The outline of the R&D program currently taking shape at SLAC and elsewhere is discussed. The principal components of the proposed ILC PES, including the laser system necessary for operational tests, are described.

## INTRODUCTION

The TESLA CDR [1] and the U.S. Linear Collider Technology Options Study [2] provide baseline documents for the design of an International Linear Collider. Table 1 summarizes the basic parameters relevant to an ILC polarized electron source and compares them to the performance achieved with the SLC source system.

Table 1: 500 GeV Linac source parameters of the ILC polarized electron source (using an L-band injector) compared to the SLC source.

| **Parameter** | **ILC** | **SLC** |
|---|---|---|
| Number e- per µbunch at IP | $2*10^{10}$ | $5*10^{10}$ |
| Number of micro bunches | 2820 | 1 |
| Micro bunch separation | 337 ns | - |
| Micro bunch charge at source | 6.4 nC | 16 nC |
| Micro bunch length at source | 2 ns | 2 ns |
| Average current in µbunch at source | 3.2 A | 8 A |
| Energy stability | < 5 % rms | 1 % rms |

The main emphasis of the ILC injector R&D will be the generation of the required pulse train and providing the required charge without compromising the polarization. For the source development we assume an electron number twice that required at the ILC interaction point.

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## DRIVE LASER SYSTEM

A laser system must be developed for the ILC polarized injector. The laser wavelength must match the bandgap of the cathode material. For GaAs, a wavelength of ~ 800 nm is necessary. The laser system must be tunable from ~ 750 to 850 nm. This accommodates photocathode development and allows matching of the bandgap as the cathode is operated at different temperatures. The laser system must also provide the time structure of the ILC pulse train. The basic components of the laser system will be an oscillator that operates at a harmonic frequency of the micro bunch repetition rate. Both micro – and macro bunch structure will be generated from the oscillator by electro-optical methods. For efficient amplification of the pulse train, pulse length adjustments using temporal stretching is necessary. We anticipate the laser system will be based on a Ti:Sapphire oscillator and Ti:Sapphire amplifier. Other laser materials such as Cr:LiCAF will also be considered. The emission spectrum maxima of Cr:LiCAF and Ti:Sapphire are almost identical. Cr:LiCAF can be directly diode pumped. However, suitable high power pump laser diodes are not now commercially available and final amplifiers would rely on flashlamps. Pump sources for Ti:Sapphire are CW or QCW diode pumped and frequency doubled Nd:YAG, Nd:YLF or Nd:$YVO_4$ lasers. Pump lasers for Ti:Sapphire that are Q-switched at several MHz are commercially not available. Therefore, final amplifiers for a Ti:Sapphire system would also rely on flashlamp pumping. Laser technology based on Ti:Sapphire is much more mature compared to other options. An ILC source laser system based on Cr:LiCAF will require an significant amount of R&D but may result in a system that can be operated at lower cost compared to Ti:Sapphire. In general, Cr:LiCAF has not been used as an amplifier medium in a commercial or industrial laser system.

The laser/gun system should be designed to produce at least twice the charge required at the IP. Using a wavelength of 800 nm and a quantum efficiency of 0.5 percent, a micro-pulse must have an energy ~ 2 µJ to produce an electron number of $4*10^{10}$. Due to the space charge limit, the current SLAC gun requires a laser pulse of > 600 ps to generate the ILC beam current. If gun development results in improved HV operation, shorter laser pulses can be used. The benefit is the reduced or eliminated need for temporal laser pulse stretching, which is a process always associated with pulse energy losses.

Laser systems developed for the TESLA Test Facility [3] are able to provide the required time structure. However, wavelength and pulse lengths are designed to operate in conjunction with $Cs_2Te$ cathodes and RF guns.

Therefore, the technology developed at TESLA Test Facility can only be partially integrated into a polarized source using a GaAs cathode and a DC gun.

## POLARIZED GUN DEVELOPMENT

The cathode bias for the SLC polarized electron gun is limited to 120 kV by the need to maximize the QE lifetime of the GaAs crystal. Under these conditions, the maximum dark current is ~50 nA, but typically <20 nA, and there is no HV breakdown. Gas molecules released by the dark current result in a rapid reduction in the quantum efficiency (QE) of the cathode [*]. The dark current is primarily the result of field emission from the stainless-steel cathode electrode. At 120 kV, the maximum field is 7 MV/m at a radius of 6.5 cm, while the field at the crystal is 1.8 MV/m. With only 120 keV of kinetic energy, the electron beam exiting the gun experiences strong space charge forces that set a limit on the minimum dimensions (both spatial and temporal) for the ILC microbunch. For the SLC, a follow on rf bunching system matched the temporal dimension of the bunch to the S-band booster. The gun voltage necessary to allow elimination of the rf bunching system for an ILC L-band injector will be studied. However, even a modest increase in operating voltage will greatly improve the capture efficiency of the injector system.

Several methods have been successfully used to decrease or at least limit the dark current, including increasing the pumping speed near the cathode [4], careful cleaning of the electrode material(s), optimizing the shape of the cathode electrode [5], and use of Mo and Ti for the cathode and anode electrode materials respectively [6]. In addition, a dramatic decrease in dark current has been reported for implantation of stainless-steel with $N_2$ ions [7].

Leakage current along the HV insulator supporting the cathode is a contributing factor to HV breakdown. The insulator for the SLC gun is ceramic whose exact composition is proprietary. Methods to coat ceramics with a high-resistance conducting material compatible with ultra-high vacuum will be investigated.

One can certainly envision a polarized DC gun operating at 500 kV with a corresponding field at the cathode of 10 or even 20 MV/m. However, increasing the DC bias much above 500 kV may prove difficult. For operating at higher beam energies, an rf gun has proven reliable for generation of unpolarized electron beams. The principal issues for a polarized rf gun are the vacuum and back bombardment of the cathode by rf accelerated electrons. The vacuum in a conventional rf gun when operating is at best $10^{-9}$ Torr at the cathode. With a serious R&D program, this value can probably be reduced by 1-2 orders of magnitude, which might prove adequate. Eliminating back bombardment by electrons is more problematic, requiring not just an enormous reduction in field emission but also operating conditions that eliminate or greatly reduce the probability of a field emitted electron hitting the GaAs crystal. These issues will be studied, but probably not on a time scale to affect the initial ILC source.

* The relatively low duty factor of the electron pulse at the ILC source as well as the large spatial dimensions necessitated by space charge effects means ion back bombardment should not be the limiting factor for the cathode QE lifetime.

## PHOTOCATHODE DEVELOPMENT

After several years of intensive photocathode R&D, strained GaAs/GaAsP superlattice structures have emerged as the primary candidates for use on the ILC polarized electron source [8]. Strained superlattice structures consist of very thin quantum well layers (GaAs) alternating with lattice-mismatched barrier layers (GaAsP). Each layer of the superlattice (typically 4 nm) is considerably thinner than the critical thickness (~10 nm) for the onset of strain relaxation, while the transport efficiency for electrons in the conduction band still can be high. GaAs/GaAsP superlattice photocathodes routinely yield at least 85% polarization with a maximum QE of ~1%. The structures are *p*-doped using the high-gradient-doping technique, consisting of a thin (10 nm), very-highly-doped ($5\times10^{19}$ $cm^{-3}$) surface layer with a lower density doping ($5\times10^{17} cm^{-3}$) in the remaining active layer(s). The high surface doping density is necessary to achieve high QE and to reduce the surface-charge-limit problem, while the lower doping density is used to maximize the polarization.

The surface-charge-limit problem was serious for the normal conducting machines with short bunch spacing of the order of nanoseconds. With bunch spacing of ~300 ns, the surface-charge-limit problem for the ILC is much reduced. Since there is an indication that the high surface doping density is limiting the peak polarization, the high-gradient-doping profile should be re-evaluated.

Several types of superlattice structures are currently being tested. Recently a strain-compensated InAlGaAs/GaAsP superlattice structure consisting of well and barrier layers with opposite strain has been studied [9], demonstrating an advantage of strain-compensation in incorporating a larger strain. A peak polarization of 92% has been observed in strained InAlGaAs-AlGaAs superlattice structures [10]. It is generally known that materials with a smaller spin-orbit interaction such as InGaP are advantageous in minimizing the spin relaxation. All these recent developments should be investigated.

The conventional way to prepare a surface free of all surface oxides and contaminants is to heat the crystal to 600° C for 1 hour. This high temperature cleaning results in some unwanted reconstruction at the surface and dopant diffusion in the thin, highly-doped layer. To avoid this high temperature heat cleaning, several techniques for low-temperature cathode preparation have been explored. It is possible to deposit a protective layer following fabrication of the photocathode. The material used for the


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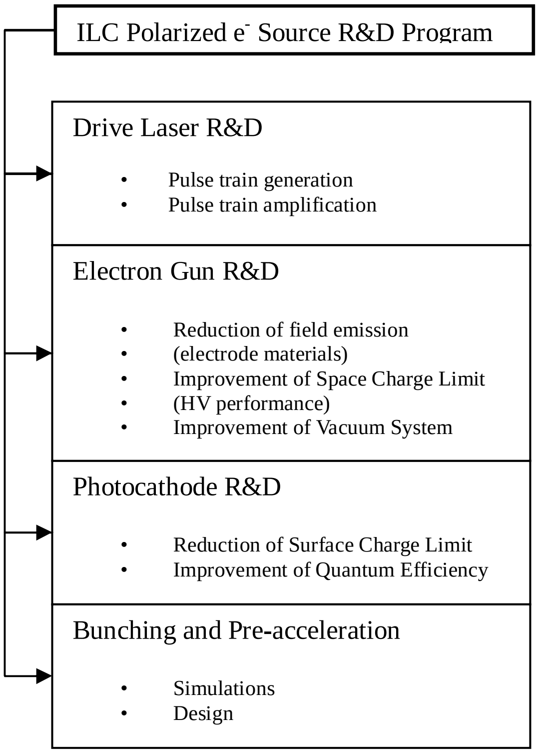


Figure 1: ILC Polarized Electron Source research effort.

protective layer must (a) desorb at less than 450° C and (b) not contaminate the UHV system. The use of a protective As overlayer has been reported. Atomic hydrogen cleaning (AHC) is a well-known technique for removing oxides and carbon-related contaminants at relatively low temperatures [11]. These techniques for low-temperature photocathode preparation should be explored and perfected.

The requirements for the bunching section and pre-acceleration are outlined in the TESLA CDR [1] and the US cold technology option study [2].

## BUNCHER AND PRE-ACCELERATOR SYSTEM

The choice of a low energy DC gun with its inherent space charge problems leads to the need for buncher systems to shorten the bunch length and capture the electrons to prepare them for efficient capture and acceleration in higher frequency higher gradient RF systems. Buncher cavities operate at sub harmonic frequencies of the final frequency. Three systems are used: a 108 MHz prebuncher, followed by a 433 MHz buncher, followed by a 1.3 GHz buncher-accelerator. Buncher systems are surrounded by solenoids to provide strong focusing of the divergent low energy beam. Because of the necessity of these solenoid fields, the buncher cavity systems must be normal conducting. The beam energy coming out of the buncher systems is 12 MeV.

The pre-accelerators accelerate the beam to an energy sufficient for its injection into the standard acceleration modules of the electron injection linac. This is accomplished by two pairs of normal conducting cavities that accelerate the beam to 76 MeV, followed by two standard superconducting modules that accelerate to 500 MeV. Optics focusing and matching is necessary between the sections.

The R&D program to develop the ILC polarized electron source is outlined in Fig. 1.

## CONCLUSIONS

Although existing polarized photoinjectors will meet the basic requirements of the ILC, appropriate R&D is planned in order to incorporate the latest advances in PES technology into the initial ILC source. This will result in a more efficient, reliable, and stable system.

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