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A Polarized Electron PWT Photoinjector for the ILC

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In order to provide maximum physics benefits, the International Linear Collider (ILC) must have a highly polarized electron beam with a low emittance. High electron spin -polarization (>85%) is attainable with a modern GaAs photocathode illuminated by a circularly polarized laser. Low emittance is achievable with an rf photoinjector, and can be further improved with a round-to-flat beam transformation. A low-emittance rf gun may simplify or eliminate the complicated and expensive electron damping ring downstream. DULY Research has been developing an rf photoelectron injector called the Plane Wave Transformer (PWT) which may be particularly suitable as a polarized electron injector for the ILC. A unique feature of the PWT is that it has a much larger vacuum conductance than conventional rf guns, which makes it possible to easily pump the structure to a vacuum level better than 10^{-11} Torr at the photocathode. In contrast with other normal-conducting L-band gun designs which require operatio n at a high peak field (=35MV/m) in order to achieve a low normalized transverse emittance, an L-band PWT gun can achieve a low emittance at a lower operating peak field (~20MV/m). The low peak field in the PWT gun is beneficial for the survivability of GaAs photocathode because electron backstreaming is greatly mitigated.

1. INTRODUCTION

Currently a dc-gun based polarized electron source [1] can provide the low beam emittance required by the ILC [2], but only with a complicated and expensive damping ring [3]. DC guns are also prone to ion back bomdardment, which is extremely harmful to the GaAs cathode. An L-band, Plane Wave Transformer (PWT) electron photoinjector with an activated Gallium Arsenide (GaAs) cathode has been proposed by DULY Research Inc. (U.S. Patent No. 6,744,226) as a possible polarized electron source for the International Linear Collider [4]. The normal-conducting PWT photoinjector (Fig. 1), comprising a "quasi-open" multi-cell, p-mode, standing-wave structure, can operate in a high vacuum and a relative low peak field, both important for maintaining long lifetime of the GaAs photocathode with good quantum efficiency. The PWT can achieve a much lower transverse emittance than a polarized electron photoinjector based on a dc-gun and sub-harmonic bunchers, while operating at a lower peak field than other rf guns. Some, though not all, of the PWT features may be separately achievable with either dc-based guns or other rf guns; however, the combination of all the features that are essential for the ILC polarized electron source may be unique for the PWT photoinjector. The simplicity of the PWT construction and its operation would also help increase reliability of the polarized electron injector.

In order to demonstrate the feasibility of the PWT photoinjector as a polarized electron gun for the ILC, two critical experiments are needed. The first is to show that an activated GaAs photocathode could indeed survive in the rf cavity. The high vacuum and the low peak field in the PWT should drastically improve results of an earlier Russian measurement [5] in which the GaAs cathode became unusable after just a few rf cycles in a conventional rf gun. The second is that an ultra-low vertical emittance could be achieved for a high-aspect-ratio beam from the PWT after a round-to-flat-beam transformation [6]. This would reinforce and amplify the recent success at the Fermilab/NICADD Photoinjector Laboratory where a 100-to-1 aspect-ratio beam was demonstrated experimentally with a conventional L-band, 1.6-cell gun using the flat-beam transformation [7]. Prior to a flat-beam transformation, however, it is important that a round electron beam has sufficiently small transverse emittances that are angular-momemtum correlated. We show in this paper that an L-band PWT rf gun can in principal achieve such a condition. Future work will consider a round-to-flat-beam transformation to further minimize the vertical emittance for the PWT to meet the ILC requirements.

2. CHARACTERIZATION OF THE PWT PHOTOINJECTOR

2.1. Ultra High Vacuum

A 4-wavelength long version [4] of the PWT gun, comprising 7+2/2 cells, i.e. a first half cell, followed by 7 full cells, and finally another half cell, has enough room for 1 or 2 side-coupled rf port(s), a pumping chamber as well as a primary focusing coil surrounding the PWT tank. The PWT cells are formed between copper circular disks supported by 6 pipes running parallel to the beam axis and carrying water to disk internal cooling channels. The PWT disk assembly is suspended with pipes and the end plates inside a large stainless steel cylindrical tank. The DULY design of the PWT tank includes a perforated section (or “sieve”) (Fig. 2) inside the pumping chamber. Open pumping paths between the disks and the tank contribute to the PWT’s large vacuum conductance. Out-gassing rates are reduced by a careful choice of materials, cleaning procedures and high-temperature bake-out. With several NEG pumps or an SNEG coated vessel providing a high pumping speed at low pressure, the vacuum pressure at the GaAs photocathode can be as low as 10^{-12} Torr, up to 2 orders better than the conventional 1.6-cell gun. A specially designed load lock system (Fig. 3) allows the transport, manipulation and reactivation of the GaAs cathode without a vacuum break to the PWT.

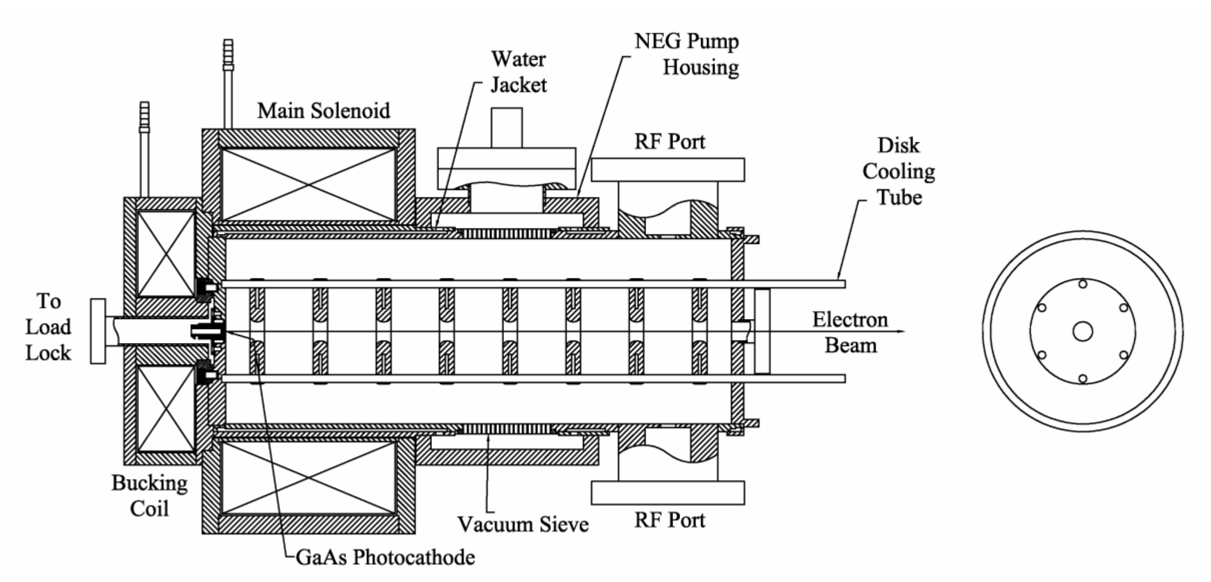

Fig. 1: Schematic of an L-band PWT polarized electron photoinjector.

2.2. Low Transverse Emittance

The emittance compensating focusing system of the PWT comprises a pair of solenoids. In addition to the main coil outside the PWT tank, there is a small bucking coil surrounding the cathode assembly. The currents in the main and bucking coils are easily adjustable to provide either a magnetic null on the cathode surface for an uncorrelated beam, or in the case of a flat beam transformation [7], a non-zero longitudinal magnetic field on the cathode for the generation of an angular-momentum-dominated beam. This design gives large flexibility in the operation of the PWT to achieve an ultra low transverse emittance. Using a set of 3 skewed quadrupoles to transform an initially angular-momentum-dominated round beam into a flat beam with a high aspect ratio, the vertical transverse emittance can be further reduced possibly by two orders of magnitude or more [6].

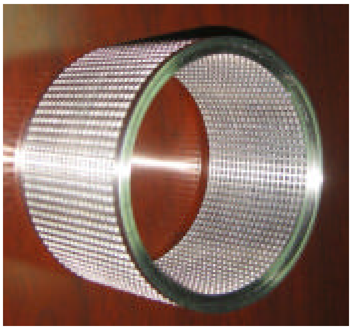

Fig. 2: PWT tank sieve inside the pumping box.

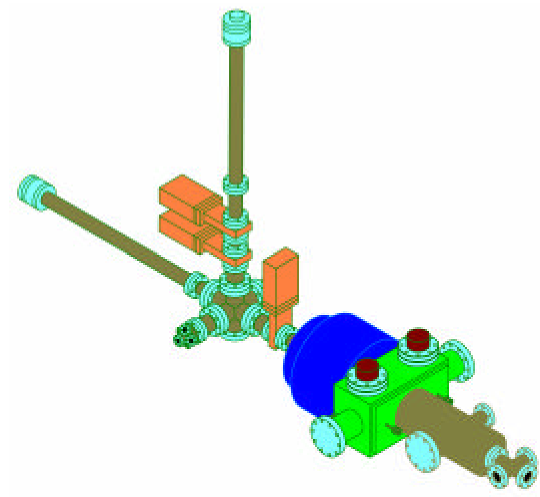

Fig. 3: DULY load lock mounted on a PWT gun.

We have performed some preliminary simulations using PARMELA, ASTRA and HOMDYN to calculate the transverse emittance associated with a round beam generated by an L-band PWT gun, including the GaAs thermal emittance, and subsequently accelerated by four TESLA -type cavities. Given this configuration, the beamline was optimized with ASTRA using the optimizers presented in Ref [8] and the generic optimizer sddoptimize [9]. The results of this optimization for two cases of charges are presented. In Figs. 4 and 5 we present the evolution of the normalized transverse emittance along the beamline for a bunch charge of 3.2 nC (optimum PWT peak field at 23 MV/m), and 0.8 nC (optimum PWT peak field at 21 MV/m), respectively. At the exit of the last TESLA cavity (z=10 m), the transverse emittance is 1.7 microns and 0.6 microns, respectively, for these two cases. Iterative design of the PWT gun is likely to improve the emittance to reach the goal of 0.4 microns for the round beam emittance of the ILC.

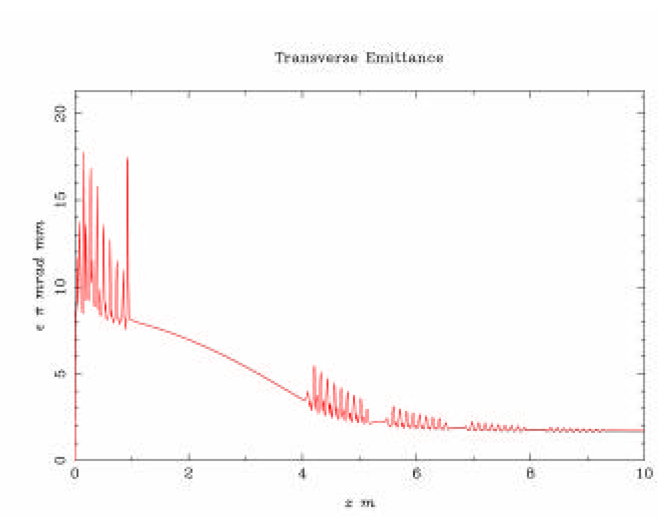

Fig. 4: Transverse emittance vs distance for 3.2 nC

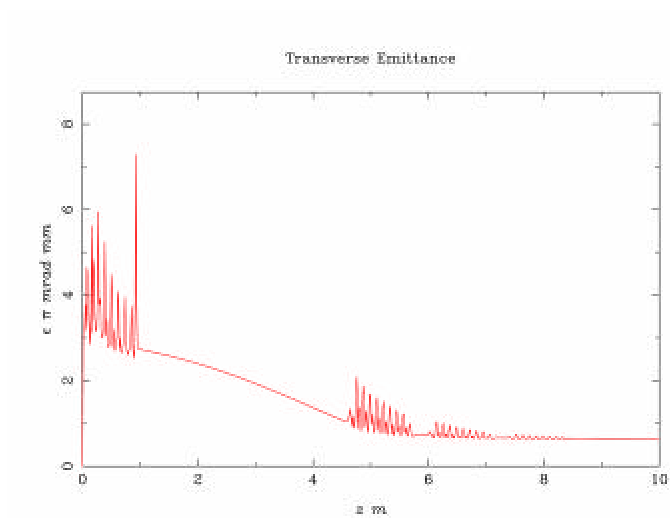

Fig. 5: Transverse emittance vs distance for 0.8 nC

2.3. Low Operating Peak Field

Fig. 6 shows the normalized transverse emittance at the end of simulation (z=10 m) vs peak longitudinal electric field at the cathode for an L-band PWT for a bunch charge of 3.2 nC. At very low peak fields (<18 MV/m), capture of the electron bunch into the rf bucket with a low transverse emittance is difficult due to the space charge effect. However, because of its superior emittance compensation scheme, the PWT beam is effectively focused at a peak field ˜21-23 MV/m, and the transverse emittance improves little as peak field increases further. A lower operating peak field of the PWT would keep many of the backstreaming electrons from hitting the photocathode. Fig. 7 shows the threshold peak electric field for secondary electrons that are emitted from the first iris of the PWT and hitting the cathode, at rf phases of 0 and 90 degrees at the time of emission [10]. These results were obtained with PARMELA, using the full electric and magnetic field maps from SUPERFISH and POISSON. It is seen that operating the gun at 20 MV/m, secondary electrons emitted from the first iris would not hit the cathode. By contrast if the gun were operated at say, 35 MV/m, many secondary electrons would hit the cathode. Simulations were also performed with PARMELA for electrons emitted from the cathode holder and streaming back toward the cathode. In this case, at very large initial rf phases (150-180 degrees) some slow electrons would hit the cathode after the field direction reverses.

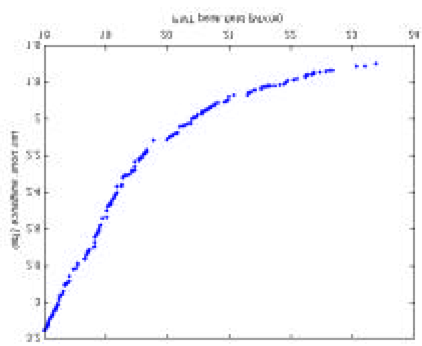

Fig. 6: Normalized transverse emittance vs peak field of an L-band PWT (7+2/2 cell, 3.2 nC).

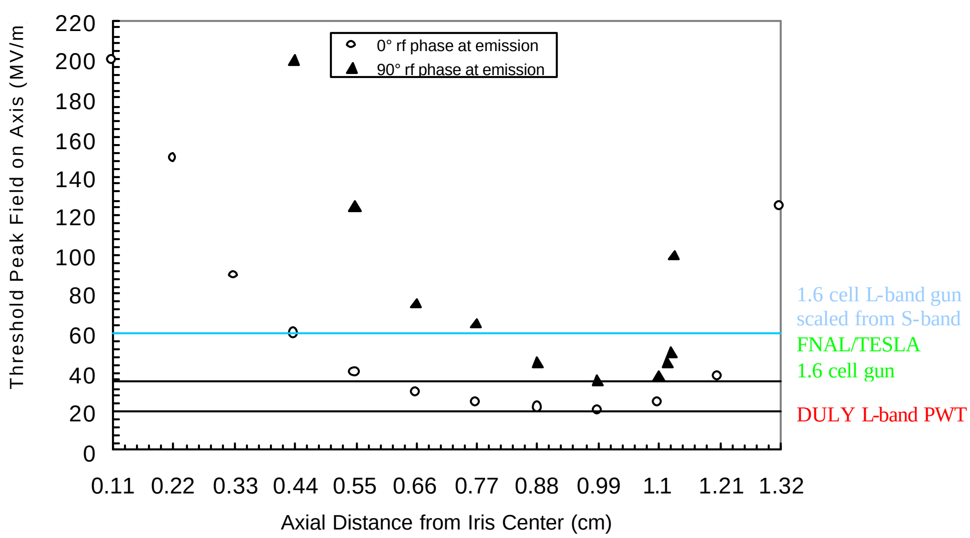

Fig. 7: Peak field threshold for electron back bombardment on cathode (see Ref [10]).

Based on the work in this paper and Ref [4], a short, 1+2/2 cell version of the L-band PWT photoinjector has been proposed by DULY Research Inc. to test the survivability of a GaAs cathode and to measure the vertical emittance of a flat beam at Fermilab, using a high-rep-rate, long-pulse modulator/klystron system capable of 2.5-5 MW of rf power.

Ackowledgments

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