SLAC-PUB-13514
January 20, 2009

Polarized Photocathode R&D for Future Linear Collliders

F. Zhou, A. Brachmann, T. Maruyama, and J. C. Sheppard

SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA.

Abstract. It is a challenge to generate full charge electrons from the electron sources without compromising polarization for the proposed ILC and CLIC. It is essential to advance polarized photocathodes to meet the requirements. SLAC has worldwide unique dedicated test facilities, Cathode Test System and dc-Gun Test Laboratory, to fully characterize polarized photocathodes. Recent systematic measurements on a strained-well InAlGaAs/AlGaAs cathode at the facilities show that 87% polarization and 0.3% QE are achieved. The QE can be increased to ~1.0% with atomic hydrogen cleaning. The surface charge limit at a very low current intensity and the clear dependence of the polarization on the surface charge limit are observed for the first time. On-going programs to develop photocathodes for the ILC and CLIC are briefly introduced.

Presented at Workshop on sources of polarized electrons and high brightness electron beams, Jefferson Lab, Newport News, October 1-3, 2008

Work supported in part by US Department of Energy contract DE-AC02-76SF00515

Polarized Photocathode R&D for Future Linear Collliders

F. Zhou, A. Brachmann, T. Maruyama, and J. C. Sheppard

SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA.

Abstract. It is a challenge to generate full charge electrons from the electron sources without compromising polarization for the proposed ILC and CLIC. It is essential to advance polarized photocathodes to meet the requirements. SLAC has worldwide unique dedicated test facilities, Cathode Test System and dc-Gun Test Laboratory, to fully characterize polarized photocathodes. Recent systematic measurements on a strained-well InAlGaAs/AlGaAs cathode at the facilities show that 87% polarization and 0.3% QE are achieved. The QE can be increased to ~1.0% with atomic hydrogen cleaning. The surface charge limit at a very low current intensity and the clear dependence of the polarization on the surface charge limit are observed for the first time. On-going programs to develop photocathodes for the ILC and CLIC are briefly introduced.

Keywords: photocathode, photoemission, polarized beam.
PACS: 85.60.Ha, 79.60.-i, 29.27.Hj.

CHALLENGES OF THE ILC AND CLIC: HIGH-CURRENT HIGH-POLARIZATION ELECTRON SOURCES

Extensive developments on high-current high-polarization electron sources for the proposed International Linear Collider (ILC) and CERN Compact Linear Collider (CLIC) are being carried out at the SLAC and JLAB in the United States. Table 1 summarizes the major parameters of the polarized electron sources for the linear colliders. The major challenge for the ILC electron source is to generate full charge 1-ms-long macropulse without compromising polarization while the one for the CLIC is to generate a train of only-100-ps-long full-charge micropulses. In principle, the full charge production could be limited by space charge and/or surface charge effects in the linear colliders. A high quality polarized photocathode is required to overcome the surface charge limit, while a high-voltage dc-gun is needed to suppress the space charge effect. In addition, the high average beam current from the dc-gun sources for the linear colliders may cause serious ion-back bombardment onto the cathode, which may badly affect the QE lifetime due to the deterioration of the cathode. It requires us to explore solutions to reduce ions onto the cathode, such as cryo-pumping – condensing the ions onto the wall by cooling down the gun to a very low temperature, typically at 20-30 K. The major goals of the photocathode developments at the SLAC for the ILC and CLIC: 1) demonstration of full charge production without space charge and surface charge limit; 2) >85% polarization; 3) ~1% QE and long QE lifetime.

TABLE 1. Major parameters of the ILC and CLIC high-current high-polarization electron sources.

Parameters	**ILC**	**CLIC**
Electrons Per Microbunch	3×10^{10}	6×10^{9}
Number Of Microbunch	2625	312
Width Of Microbunch	1 ns	100 ps
Time Between Microbunches	360 ns	500.2 ps
Width Of Macropulse	1 ms	156 ns
Macropulse Repetition Rate	5 Hz	50 Hz
Charge Per Macropulse	12600 nC	300 nC
Average Current From Dc-Gun	63 μA	15 μA
Peak Current Of Microbunch	4.8 A	9.6 A
Current Intensity (1cm Radius)	1.5 A/cm^2	3.0 A/cm^2
Polarization	>80%	>80%

COMPLETE EXPERIMENTAL CHARACTERIZATIONS OF A STRAINED-WELL InAlGaAs/AlGaAs

Strained-well InAlGaAs/AlGaAs structures designed and manufactured by St. Petersburg in Russia have the following advantages [1]: 1) larger valence band splitting due to the combination of deformation and quantum confinement effects in the quantum well; 2) a sharp band-bending-region; and 3) a reasonably thick working layer without strain relaxation. The measurements in Russia show that the structures have excellent performance – 1% QE and 90% polarization. To cross-check the Russian data and also provide all key performance of the cathode including charge limitation, polarization, QE and QE lifetime, the InAlGaAs/AlGaAs structures have been characterized at the SLAC cathode and gun test facilities.

Polarization and quantum efficiency were firstly measured at the SLAC Cathode Test System (CTS) [2]. The CTS is an ultra-high vacuum system equipped with a load-lock chamber through which samples can be introduced without venting the system vacuum. Polarization measurements are made using an electron transport column, an electrostatic 90° spin-rotator and a 20 kV Mott polarimeter. Prior to the cathode installation, the sample is processed via standard chemical and heat cleaning methods. The CTS measurements for the InAlGaAs/AlGaAs sample demonstrate 0.3% QE and 87% polarization. The sample used at the SLAC is not a fresh one and may have some degradation of near-surface region and As-cap. The degradation could not be removed by the standard chemical and heating cleaning techniques. However, the QE of the InAlGaAs/AlGaAs cathode was recovered to 1% with atomic hydrogen cleaning [3].

The SLAC Gun Test Laboratory (GTL) [4] is capable of characterizing all parameters including the surface charge limit, QE and QE lifetime, and polarization. The GTL beamline consists of an ultra-high vacuum, high-voltage electrostatic dc-gun, a load-lock chamber for cathode transfer and activation, and a beamline with magnetic components for electron beam transport. With the cathode biased at 120 kV, the gun is capable of producing a space-charge-limited current of 15 A from the 20 mm diameter cathode. An electrically isolated, optically coupled nanoammeter is used to measure the average photoemission current. A fast Faraday Cup (FARC) is employed to measure the temporal profile of the electron beam from which the surface charge limitation can be measured. The electron beam is transported to the Mott chamber for polarization measurements. Fig. 1 shows the comparison of polarization spectrum of the InAlGaAs/AlGaAs cathode measured at St. Petersburg and at SLAC. It is shown that the polarization spectrum measured at the SLAC CTS and GTL is very close although there is a constant wavelength shift between them. The shift is probably caused by a wavelength calibration error in the CTS. The maximum polarization measured at the SLAC CTS/GTL is ~87% versus ~91% in measured in Russia. The polarization difference is attributed to systematic differences in the measurement systems.

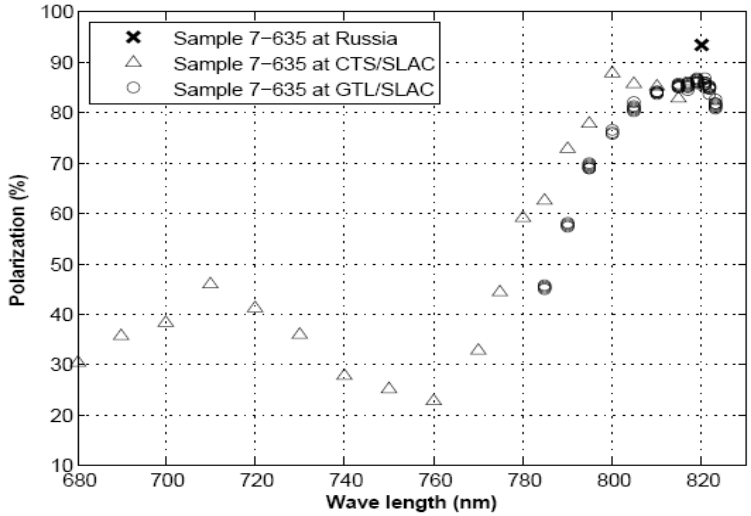

FIGURE 1. The comparison of the polarization spectrum measured at St. Petersburg in Russia, CTS/SLAC and GTL/SLAC.

The surface charge limit on the cathode is seen in Fig. 2 as the drop off of intensity during the current pulse. The limit is caused by the lower doping level in the surface layer, only $7x10^{18}/cm^3$ in the cathode. Further studies show that the onset of surface charge limitation occurs at a very low current intensity, only 0.06 A/cm^2. Increasing the doping level to $2\text{-}5x10^{19}/cm^3$ in the surface layer can effectively suppress surface charge limit [5].

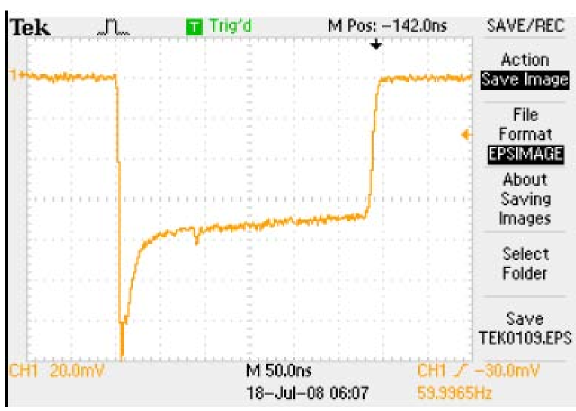

FIGURE 2. Observation of surface charge limit at $2.5x10^{10}$ electrons at 10 mm laser full size on the cathode. The abscissa is time, and the ordinate is the beam signal from Faraday Cup.

The dependence of the polarization on the surface charge limit is clearly observed for the first time. During the observations, only the laser position on the cathode is changed. At different laser positions A and B on the cathode, different levels of the surface charge limit are observed, as shown in Fig. 3(a) and 3(b), respectively. The surface charge limit at the laser position A is more severe than at position B. The beam generated at laser position B has a higher polarization, 2-3% more than at position A, as shown in Fig. 4. At the laser position A, the cathode is driven into saturation, and the electrons photoexcited into conduction band still can escape if they diffuse to a non-saturated region. Thus, these electrons spend a longer time inside the structure so it is likely that they suffer spin greater relaxation than at position B which results in reduced polarization.

(a) (b)

FIGURE 3. Different degree of surface charge limit of the electron beam at different laser position on the cathode; (a) and (b) correspond to the laser position on the cathode at A and B, respectively. The abscissa is time, and the ordinate is the beam signal from Faraday Cup.

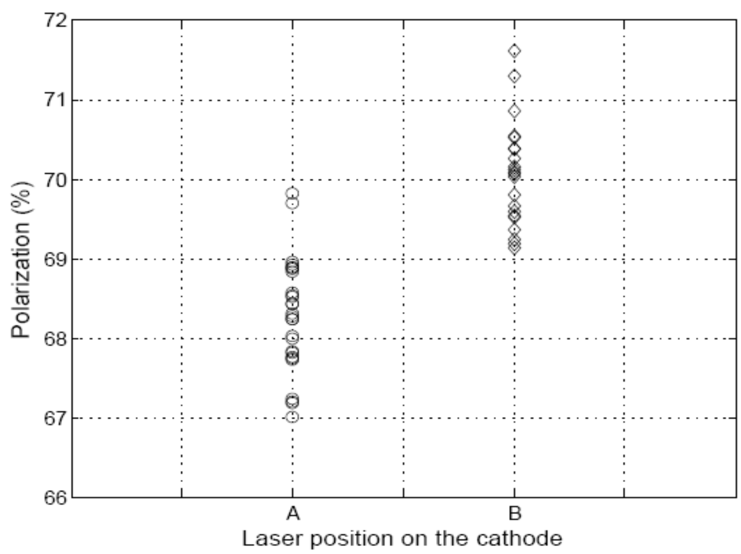

FIGURE 4. Polarizations corresponding to different laser position; data is taken at 800 nm of wavelength.

SUMMARY AND PLANS

It is challenging to generate the ILC and CLIC full charge without compromising polarization. Advancing polarized photocathode technology to increase polarization, QE and QE lifetime along with reduced space charge and surface charge limit is one of the major factors to guarantee the success. Recent measurements at the SLAC test facilities show that the InAlGaAs/AlGaAs can produce 87% polarization, 0.3% QE. The QE can be recovered to ~1% with atomic hydrogen cleaning. Serious surface charge limit is observed at a very low current intensity. The clear dependence of the polarization on the surface charge limit is observed for the first time.

SLAC continues to be actively engaged in the development of improved polarized photocathodes through studies of the doping level in the structure of superlattice and of gradient doping in the active layer of the superlattice. Both QE and polarization are expected to be improved using these two techniques. The ILC laser prototype is expected to come online at the SLAC in 2009. This allows us demonstrate the ILC full charge production. In addition, the studies on ion effects on the QE lifetime are also being pursued.

ACKNOWLEDGMENTS

We would like to thank Jym Clendenin for his contributions and Y. Mamaev for the fruitful collaborations. The work is supported by U.S. DOE contract DE-AC03-76SF00515.

REFERENCES

1. Yu. A. Mamaev, et al., “InAlGaAs/AlGaAs superlattices for polarized electron photocathodes”, SLAC-PUB-11403, August 2005.
2. G. A. Mulhollan, “Low energy polarized electron source test facilities”, 1993 (unpublished).
3. V. Tioukine, “Atomic hydrogen cleaning of superlattice cathodes”, Workshop on sources of polarized electrons and high brightness electron beams, Jefferson Laboratory, Newport News, VA, October 1-3, 2008.
4. P. J. Saez, “Polarization and charge limit studies of strained GaAs photocathodes”, Ph. D thesis, SLAC-R-501, March 1997.
5. T. Maruyama, et al., “A very high charge, high polarization gradient-doped strained GaAs photocathode”, SLAC-PUB-9133, March 2002.