IMPROVED ELECTRON YIELD AND SPIN-POLARIZATION FROM III-V PHOTOCATHODES VIA BIAS ENHANCED CARRIER DRIFT*

Gregory A. Mulhollan, John Bierman, Saxet Surface Science, Austin, Texas
Axel Brachmann, James E. Clendenin, Edward Garwin, Robert Kirby, Dah-An Luh, Takashi Maruyama, SLAC, Menlo Park, California
Richard Prepost, UW-Madison/PD, Madison, Wisconsin

Abstract

Spin-polarized electrons are commonly used in high energy physics. Future work will benefit from greater polarization. Polarizations approaching 90% have been achieved at the expense of yield. The primary paths to higher polarization are material design and electron transport. Our work addresses the latter. Photoexcited electrons may be preferentially emitted or suppressed by an electric field applied across the active region. We are tuning this forward bias for maximum polarization and yield, together with other parameters, e.g., doping profile. Preliminary measurements have been carried out on bulk and thin film GaAs. As expected, the yield change far from the bandgap is quite large for bulk material. The bias is applied to the bottom (non-activated) side of the cathode so that the accelerating potential as measured with respect to the ground potential chamber walls is unchanged for different front-to-back cathode bias values. The size of the bias to cause an appreciable effect is rather small reflecting the low drift kinetic energy in the zero bias case.

BACKGROUND AND MOTIVATION

Solid state photoemission sources of spin-polarized electrons form the core of investigative tools in physics subfields including solid state, atomic, nuclear and high energy. Spin-polarized low energy electron spectroscopy and spin-polarized inverse photoemission allow the probing of the surface magnetic structure and exchange-split band structures respectively. High energy and particles physics have benefited from the use of polarized electron sources for fixed target and collider configurations permitting the testing of the standard model with greatly reduced requirements on integrated beam interaction luminosity compared to systems not using spin polarized leptons. Future high energy facilities will benefit from increased electron spin-polarization to acquire data with better statistics (smaller error bars) for a given run time, utilize machine time for shorter periods to achieve equivalent statistics and suppress unwanted W^+W^- pair production for polarizations in excess of 90% [1].

Advances in electron spin-polarization from III-V based photoemitters have come in several jumps. Initially the electron spin-polarization was limited to 25-35%. In the first uses of GaAs as a source, polarization calibrations were often confused by the variable quantum yield achieved from the bulk GaAs single crystals; the emitted electron spin-polarization varies with the photoemitter surface electron affinity. The first major improvement in the photocathode performance was the use of thin, epitaxially grown GaAs films of micron or less thickness atop an emission barrier sublayer. The thin layer provides an improved polarization by decreasing the residence time of the photoexcited electrons by virtue of a shallow origin compared to bulk materials. This configuration allows spin-polarizations nearing 50% to be achieved. The second major advance was through the use of advanced MBE techniques to lift the $p_{3/2}$ heavy hole-light hole degeneracy by structural deformation of the pseudomorphically grown emitting layer. Electron spin-polarizations approaching 90% have been achieved, but at the expense of quantum yield.

Several factors can contribute to the emitted electron spin-polarization having a value less than unity including: incomplete band separation, depolarization during transport, depolarization in the near-surface region and losses during emission. The worst culprits are the first two in the above list. Band separation may be addressed by improved growth quality and even more complex structures, such as superlattices, which are theoretically less susceptible to defect propagation. Transport induced depolarization may be partially mitigated by operation at cryogenic temperatures or with lowered dopant levels. The solution proposed here is to modify the drift velocity, and thereby the electron residence time after excitation, through the use of a bias across the cathode.

CATHODE DESIGN

The successful cathode design will be tailored to have the greatest possible compatibility with the operation of the SLAC polarized electron gun system so that the optimized emitter may be employed for high charge emission with minimal source hardware modification. Key to the development of this device will be the integration of the transferred electron photocathode technology into the spin-polarized electron photoemitter structure. Bias across the device will be through a metal film lithographically grown

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atop the emitting GaAs layer and a back contact to the substrate GaAs. Similar structures have been fabricated in the past for use in other contexts, but were operated without the ability to test the effects of a bias across the emitter.

The idea of biasing a photoemitter across its active region is not new. Bell [2] demonstrated the concept in 1974. Photoemitters with a small band gap are not capable of being activated into a state of negative electron affinity. While the surface affinity can be lowered, it cannot be brought below that of the conduction band in the bulk of the material. The quantum yield for near band gap illumination from such materials, while of great technological importance as IR detectors, is quite low. Bell realized that by applying a bias across the active region, that some of the electrons in the conduction band minimum could be promoted or transferred into higher conduction band states whilst drifting toward the surface enabling their emission into vacuum. Thus the name transferred electron photoemitter.

The requirement of a bias structure in intimate contact with the emitter surface can be best met by directly growing the needed structure on top of the cathode using lithographic techniques. A complication may occur if the contact material presents an additional barrier to the emission of electrons or aids their propagation from the surface. The effect depends not only on the contact material, but the GaAs doping type and concentration as well. Common materials used for contacts to GaAs readily mix at the high temperature necessary for cleaning GaAs surfaces in vacuum in preparation for the activation process. Fortunately, tungsten will make an Ohmic contact with p-type GaAs [3] so it can provide the needed electrical connection while still being resistant to interdiffusion into the underlying cathode.

EXPERIMENTAL APPARATUS

Preliminary cathode testing and instrumentation development is performed at Saxet, while additional testing, particularly electron spin-polarization measurements, are performed at SLAC. Much of the lithography-related work is performed at National Nanotechnology Infrastructure Network laboratories located near SLAC (Stanford Nanofabrication Facility) and Saxet (University of Texas Microelectronics Research Center).

A simple modification of the SLAC cathode tray is employed for biased sample measurements. To insure good electrical contact between the cathode and the bias supply, mechanical clamping is employed. Top and bottom connections to the cathode are independent with the bottom contact through the usual platter support and the top connection made by BeCu fingers brought into contact from above after the cathode has been heat cleaned and activated. This design maintains ease of cathode change while being robust under high temperature cycling.

To maximize simplicity in the cathode growth, lithography and measurement phases, contact complexity was localized into the mechanism for the top surface connection. This maintains both the well established cathode preinsertion treatment process and use of the existing cathode support and heating fittings while still permitting the application of differing top and bottom potentials. To satisfy the need for heat cleaning at 600^{o}C, the top contact mechanism is attached to a linear motion feedthrough to allow its displacement away from the cathode during the heat cleaning process. The contactor is maintained at ground potential during the activation process, then brought into contact with the tantalum clamping ring for the bias dependent measurements.

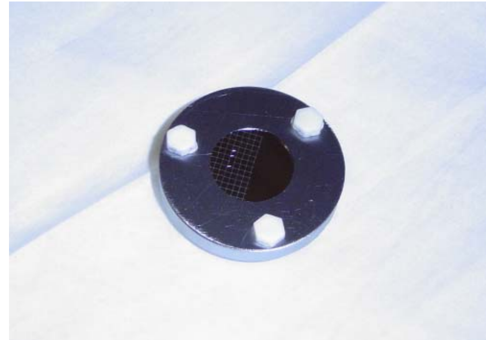

Figure 1: Clamping cathode holder. The platter is molybdenum, the clamping ring is tantalum and the tensioning screws are alumina. Shown with mechanically affixed grid over one half of cathode.

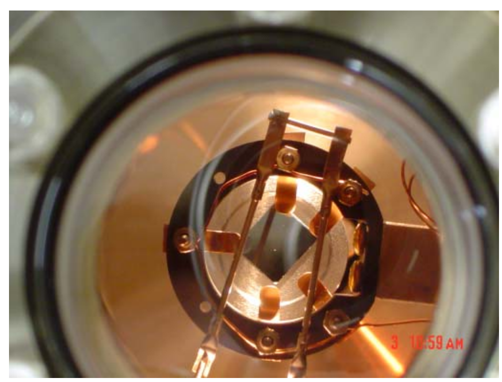

Figure 2: Cathode contacting mechanism in use at Saxet. A similar mechanism is installed in one test chamber at SLAC with a second one to be installed into the polarimeter-equipped chamber at the time of this conference.

The Saxet test laboratory is outfitted with a system very similar to the cathode test systems at SLAC. It is a 110 l/s ion- and dual 50 l/s non-evaporable getter (NEG)- pumped stainless steel bakeable chamber equipped with a filament heater station for cleaning the samples as well as channel Cs sources and NF_3 gas inlet via leak valve. Total and partial pressure monitoring is performed by ion-gauge and quadrupole mass spectrometer, respectively. Base pressure is mid 10^{-11} Torr range. Optical excitation for activation is through gas or diode laser with quantum efficiency spectra taken using a computer controlled Spex 1681B 1/4 meter monochromator coupled to a Photon Technology Inc. quartz tungsten halogen (QTH) light housing. Photocurrent is read from a Keithley 6485 picoammeter directly into the LabView control program. Emission and across-sample bias is via dry cells with emission bias fixed at a nominal 72 V. Samples are loaded via a loadlock and transfer arm pumped by a completely hydrocarbon free molecular drag pump station.

The SLAC cathode test laboratory is a facility with two systems for rapidly and accurately measuring quantum yield. The systems have been described in detail in reference [4]. One system has the capability of electron spin-polarization measurements. Sample introduction in both is via a load-lock chamber, thereby preserving the vacuum within the ion and NEG pumped measurement chamber. Optical excitation is via laser or monochromator dispersed QTH or Hg arc lamp. In the second system, polarization is detected via a Mott polarimeter operating at 20 kV. The data acquisition system employs a simple GUI using Visual Basic. Tests take place in both the simpler system and the chamber with polarization analysis as required.

DATA

To date data have been acquired primarily to test the function of the contact mechanism, verify the bulk GaAs response to an applied bias and characterize the behavior of cathode material with a modified doping structure.

Highly doped bulk GaAs was tested in the SLAC cathode test system as part of the initial phase of work. Data are shown in Fig. 3 taken at a wavelength of 670 nm. For a bias which enhances emission (top positive relative to bottom), the yield nearly doubles. For a bias which diminishes emission (top negative relative to bottom), the yield is approximately one half of the zero bias case. Just as seen for the transferred electron photocathodes, the size of the bias required to cause an appreciable effect is rather small.

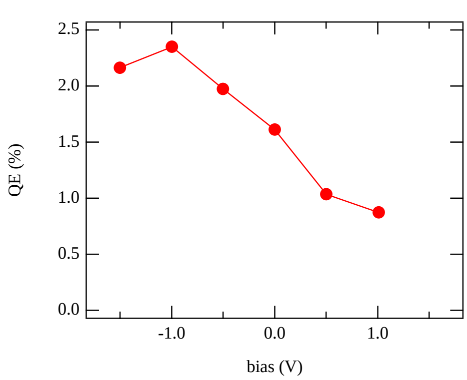

Figure 3: Bias effects on QE from bulk GaAs measured at 670 nm.

The second material tested was MBE grown GaAs/$Al_{0.3}Ga_{0.7}As$/GaAs. The final GaAs layer has the intermediate 100 nm doped at 5×10^{15}/cm^3, with the topmost layer at 1×10^{19}/cm^3. The low doped layer is more resistive and acts as a substantial part of a resistor chain when modeling the cathode as a series resistance. This change in doping also has an effect on the electron transport due to the creation of a barrier at the interfaces of the different doping concentrations. While the bias effects are not as strong as in the case of the homogeneous bulk GaAs, the data in Fig. 4 show a measurable effect, even in the region of emission only from the GaAs overlayer. The effect on polarization readily becomes large even for a small overall change in the population of the emitted electrons.

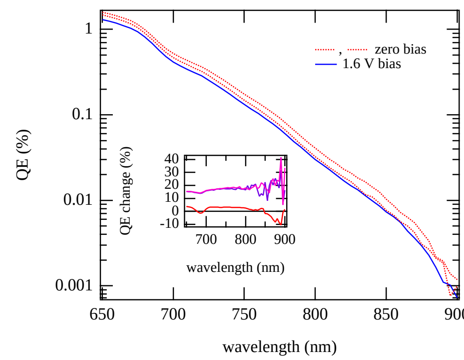

Figure 4: Bias effects on MBE grown GaAs as a function of wavelength at one bias value. Inset shows change for the two different directions of bias.

CONCLUSION

Electron drift components have been modified to affect the quantum efficiency of bulk and thin film GaAs photocathodes. Tuning the lithographically applied contact structure continues and the effects of modified drift on electron spin-polarization will be measured soon. These data will be used to apply the technique to high-polarization photocathode material to minimize polarization losses during the transport process.

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