JEFFERSON LAB POLARIZED SOURCE *

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The CEBAF accelerator at Jefferson laboratory (JLab) can deliver CW electron beams to three experimental halls simultaneously. Most of the physics program requires polarized beams. Many experiments, both polarized and unpolarized, require a high average beam intensity as well. This paper presents the current status of the polarized electron source at JLab, gives results of lifetime, quantum efficiency, beam polarization achieved and also discusses issues associated with parity violation experiments.

1. Introduction

At Jefferson Lab, polarized electrons are produced from a 100 kV GaAs photoemission electron gun. To deliver beam to the three physics halls simulatenously, we use three separate laser systems illuminating a common area of the photocathode. Each laser sends an optical pulse train at 499 MHz locked to the RF of the accelerator, which operates at 1497 MHz. The laser light incident onto the photocathode is circularly polarized by a Pockels cell. The electron polarization is flipped pseudo-randomly at 30 Hz. Feedback systems have been implemented on the optics table to maintain high beam quality.

Most experiments conducted at JLab use a polarized beam. A large fraction of the nuclear physics program requires high average beam intensities (100 μA), for both polarized and unpolarized experiments. The laser system at the source has to be modified accordingly to accomodate these different requirements.

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As the laboratory has met increasingly demanding requirements (three hall simultaneous operation, polarized beam, parity violation), physics experiments have become more and more challenging for the polarized source in terms of intensity, polarization and beam qualities. The main effort of the polarized source group at JLab is directed at obtaining long operating lifetimes of the source with high beam intensity and polarization, as well as ensuring high quality beam parameters for the three halls.

2. Guns

For production beam delivery we use strained layer GaAs photo-cathodes from Bandwidth Semicondutor (previously Spire Corporation) with the standard SLAC specifications. After a brief exposure to atomic hydrogen the semiconductor is activated to build a negative electron affinity (NEA) on the semiconductor surface. This activation is performed in the gun chamber by applying successive doses of Cesium and Nitrogen Trifluoride. Typical quantum efficiency is 0.2% at 840 nm (1% at 780 nm). The polarization of the photoemitted electron beam is 70-80% as measured in the injector and in the halls via Compton, Moller and Mott scattering [1]. Since 1998, the CEBAF injector is equipped with two identical polarized guns, each using a high polarization strained-layer GaAs. Each gun being the other's spare, either gun can deliver beam simultaneously to the three halls. One can switch from one gun to the other within a few minutes (check of beam steering and RF phases). Beam current requirements for the nuclear physics program range from a few nanoamps to 100 μA.

3. Lifetime

A critical parameter in operating such high current polarized electron guns is the photocathode lifetime. We define the operational lifetime of a source as the amount of charge emitted from this source before the quantum efficiency has decreased to 1/e of its initial value. Vacuum quality, high voltage design, and the active surface area of the photocathode are believed to play significant roles to understanding lifetimes [2]. The lifetime is of crucial importance in a CW machine because it determines the frequency at which the cathode has to be treated during operation.

Since the last upgrade of our source in 1998 the vacuum conditions in both guns have been excellent ($\sim$5x10^{-12} Torr). The active surface has been reduced to an area of $\sim$5 mm diameter and the cathode lifetime has increased dramatically [3]. Two regime of operations are distinguished:

- during low beam current delivery (<100 μA from the cathode), lifetime as high as 600 C was measured,
- during higher current operation ($\sim$200 μA), the lifetime is reduced to approximately 300 C.

A single photocathode, used for production for more than one year required only three NEA activations. During low current operation beam was delivered continuously to all three halls for three months without any treatment of the cathode, therefore maximizing the availability to the physics program.

4. Lasers

In order to drive the electron source one needs a robust laser system. Diode lasers provide a stable and reliable option. They are easy to use, have small noise at the frequency of the helicity reversal ($\sim$0.1 % at 30 Hz) and require little maintenance. Since the early days of CEBAF polarized beam operation, diode lasers have been used for most of the physics program: for low current and high polarization experiments, by matching the laser wavelength to the cathode bandgap ($\sim$840 nm) or, when polarization is not needed, by reducing the wavelength ($\sim$780 nm) to take advantage of the higher quantum efficiency for high current experiments. However, some physics experiments [4] [5] require both high current and high polarization. Diode lasers are then inadequate because of their power limitation (< 100 mW), limiting the available electron beam current to $\sim$100 μA at 780 nm. Titanium Sapphire (Ti:Sap) lasers provide a means to obtain higher output power ($\sim$500 mW) at high polarization wavelengths. Homebuilt Ti:Sap systems, pumped by a high power DC Nd:YVO_4 and mode-locked using seed light from a gain switched diode laser [6] were driving the polarized source during experiments requiring high current and high polarization during 2001. The homebuilt Ti:Sap lasers have exhibited more noise than diode lasers ($\sim$1% at 30 Hz) and required a higher level of maintenance. Recently, Ti:Sap lasers with an active accousto-optic modulator (AOM) and passive internal mode-locking are being pursued.

5. Helicity correlated effects

Some experiments conducted at JLab use the parity violating weak coupling to probe the nucleon structure. Because of the magnitude of the experimental asymmetry ($\sim 10^{-6}$, or 1 ppm), this program imposes stringent constraints on the helicity correlated beam parameters, such as intensity, position, and energy.

During the first parity violating experiment at JLab the asymmetry in beam current, or charge asymmetry, was corrected at the source on the polarizing Pockels cell. The voltage applied to the cell was varied at 30 Hz to minimize the difference in light intensity between both helicity states (PITA effect). The charge asymmetry averaged to the sub-ppm level over three months of data collection and position differences were ∼20 nm in the hall. The experiment was completed successfully in 1999; helicity correlated charge asymmetry and position differences had minimal contribution to the systematic error of the experiment [7].

To minimize the electron beam charge asymmetry one can orient the residual linearly polarized light, taking advantage of the anisotropy in quantum efficiency of the photocathode. A half-wave plate inserted in one laser path can be remotely orientated. Once the sensitivity of the charge asymmetry to the orientation of the waveplate is calibrated the charge asymmetry in the electron beam is measured in the halls. This measurement determines the correction to be applied to the plate orientation. This slow (approximately one adjustment per hour) feedback ran successfully during 3 months of operation and asymmetries as small as 50 ppm were measured within less than an hour at the end of the physics run.

More recently an intensity attenuator (IA), an idea borrowed from the MIT-Bates accelerator, has been installed. A low voltage Pockels cell, coupled to a polarizer, modulates the light intensity. The sensitivity of the modulation is controlled by the additional use of a $10th$ order wave-plate. Preliminary testing shows that this technique provides stable and sufficient gain to control the charge asymmetry within experiment specifications while keeping insertion loss low. A typical gain is 200 to 300 ppm/V with a dynamic range of $\pm$ 5 V.

For position feedback, a mirror placed on the laser beam path, is modulated at the helicity reversal rate to compensate for the electron beam position differences measured in the halls. The mirror is on a kinematic mount driven by a piezoelectric transducer (PZT) at 30 Hz to correct for both horizontal and vertical motion. This position feedback system shows promising results and will be used during 2002-2003 running. The two halls conducting parity-violating experiments are equipped with independent IA and position feedback systems.

The research program conducted in hall B does not require parity quality beam characteristics. The charge asymmetry is controlled for hall B by modulation of the laser power at the helicity reversal rate.

Eventually, a half-wave plate can be inserted in the laser path to reverse the overall sign of the laser polarization and electron helicity as a global systematic checkout.

6. The G0 experiment

A novel experiment designed to measure the strange quark contribution to the nucleon form factors, G^0, will be running at JLab starting Fall 2002[8]. In order to resolve the time-of-flight of scattered protons, this program imposes a reduced repetition rate of 31.1875 MHz on the electron beam. For the first time, beam is produced and sent through the machine at a sub-harmonic ($16th$) of the fundamental 1497 MHz CEBAF repetition rate. Moreover, an average current of 40 μA is requested implying the generation and transport of a bunch charge 16 times larger than for the same average current at the usual 499 MHz. Being a parity-violating experiment it also demands the excellent beam properties described in the previous section while the other halls receive 499 MHz beam. An AOM mode-locked Ti:Sap laser using a 5 m long optical cavity was built at JLab to meet the G0 demands. This laser met the output power requirements, but its pulse width was larger than desired. The pulse width of $\sim$180 ps exceeded the initial acceptance window of the injector (110 ps), therefore generating large transport losses. A commercial Ti:Sap laser using a GaAs passive mode-locking technique was recently purchased and installed on the polarized source [9]. Pulse widths of 70 ps, comparable to diode generated pulses, have been achieved. It is a turn-key device that appears to require minimal maintenance. This laser is being tested and appears to generate a polarized electron beam with very promising qualities such as high transmission through the injector, low noise (0.2 % at 30 Hz) and good stability. The G0 experiment is scheduled to run several years at JLab.

7. Conclusions and outlook

The polarized physics program is conducted at JLab with strained-layer GaAs wafers. These photocathodes reliably provide good quantum efficiencies and high beam polarization. Excellent operational lifetimes have been achieved over the last few years. The source laser system is constantly being optimized to accomodate the physics program. Great efforts were put in to provide each hall with the abillity to control their helicity correlated asymmetries (beam current and position) independently of the other halls.

An intense research program dedicated to obtaining higher quantum efficiency and beam polarization is also underway in our test facility. We are presently studying our cleaning and activation procedures, testing new samples as well as new load lock gun. Lifetime studies should follow shortly.

The coming years 2002-2003 are high profile years for the JLab polarized source because of the two upcoming parity violating experiments. New laser and feedback systems should ensure a successfull completion of these challenging experiments. Also, this work will help us prepare for the future parity-violation as experiments become more and more demanding (see for example [10]).

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