OBSERVATION OF SIGNIFICANT QUANTUM EFFICIENCY ENHANCEMENT FROM A POLARIZED PHOTOCATHODE WITH DISTRIBUTED BRAGG REFLECTOR*

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Abstract

Polarized photocathodes with higher Quantum efficiency (QE) would help to reduce the technological challenge associated with producing polarized beams at milliampere levels, because less laser light would be required, which simplifies photocathode cooling requirements. And for a given amount of available laser power, higher QE would extend the photogun operating lifetime. The distributed Bragg reflector (DBR) concept was proposed to enhance the QE of strained-superlattice photocathodes by increasing the absorption of the incident photons using a Fabry-Perot cavity formed between the front surface of the photocathode and the substrate that includes a DBR, without compromising electron polarization. Here we present recent results showing QE enhancement of a GaAs/GaAsP strained-superlattice photocathode made with a DBR structure. Typically, a GaAs/GaAsP strained-superlattice photocathode without DBR provides a QE of 1%, at a laser wavelength corresponding to peak polarization. In comparison, the GaAs/GaAsP strained-superlattice photocathodes with DBR exhibited an enhancement of over 2 when the incident laser wavelength was tuned to meet the resonant condition for the Fabry-Perot resonator.

INTRODUCTION

The nuclear physics research at Jefferson Lab requires high energy and high current polarized electron beams that originated from a low energy polarized electron source. Superior quality photocathodes producing both high QE and electron polarization are key to critical elements to guarantee the successful implementation of the existing physics programs and are also of vital importance in satisfying the demand of future machines such as the medium-energy electron-ion colliders (MEIC) [1] currently under intensive study. Although polarization over 85% has been achieved, the QE is still relatively low, usually ~ 1%. In this report, we present the characterization and study of a new type of strained-superlatice photocathode designed to significantly improve the QE while still maintaining high electron polarization.

As shown in Fig. 1(a), usually the incident laser beam makes only a single pass through the active layer of a

standard GaAsP/GaAs photocathode structure, with most of the laser energy deposited in the substrate, leading to unwanted cathode heating. For high current applications where the laser power can reach Watt-levels, this may serve to evaporate the cesium from the surface and reduce the QE [2].
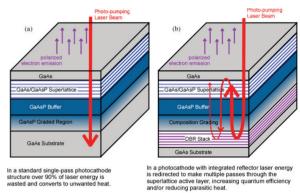

Figure 1: Illustration of (a) a standard strained-superlattice photocathode with a single-pass laser beam, and (b) the photocathode combined with a DBR mirror for confining the unabsorbed laser beam within the active layer.
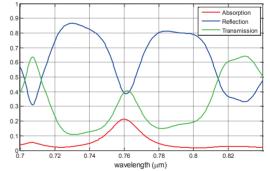

Figure 2: Calculation of absorption, reflectivity and transmission of a photocathode with DBR structure.

To overcome this issue, a new structure was proposed [3] by combining the device active layer with a semiconductor-based mirror structure as illustrated in Fig. 1(b), where a Fabry-Perot (FP) cavity around the active layer is formed using a distributed Bragg reflector (DBR) as a bottom mirror and surface-to-vacuum reflection as the top mirror (Fig. 1b). Such an optical configuration allows effectively confinement of the laser beam inside the active layer region and therefore increases the amount of light absorbed by the photocathode without increasing the pump laser power. A calculation of absorption, reflectivity and transmission of a DBR photocathode at

different wavelengths is shown in Fig. 2. The multiple peaks indicate the possible enhancement effect by the DBR and are not seen from a standard strained-superlattice photocathode. Several samples of strained-superlatice GaAsP/GaAs cathodes both with and without DBRs were designed and fabricated. In the following sections, results of characterization of QE and polarization are presented.

Figure 3: Schematic of the vacuum test chamber used to measure QE versus laser wavelength. IP: ion pump, NEG: non-evaoprable getter pump, PM: laser power meter. A schematic of the low voltage Mott polarimeter can be found in reference [5].

EXPERIMENTAL SETUP, MEASUREMENTS AND RESULTS

Two different experiment setups were used for our experiment. The first is a simple UHV chamber used only for QE measurement. A schematic of the chamber assembly is shown in Fig. 3. The photocathode wafer was diced and mounted on to the bottom of a stalk using a tantalum cap in a clean area before moving into the chamber. The upper part of the chamber consisted of a photocathode mounting stalk, one NEG pump and a residual gas analyzer (RGA) for leak checking, while the bottom part of the chamber was primarily occupied by a cesium source strips, nitrogen triflouride (NF_3) supply, horizontal glass hydrogen cleaner (not used for this work), two ion pumps (IPs), and two viewing windows. A rough pump could be connected to an overboard IP with quick-flanges and Conflat flanges. After loading a photocathode sample, the entire assembly was baked at 250 °C for 30 hours to reduce the presence of water vapor in the system. The pressure level was in the range of 10^{-11} Torr or below when the system cooled to the room temperature. The light source was a super-continuum laser (NKT Photonics, SuperK) tunable from 400nm to 850nm providing milli-Watts of output power. The collimated laser beam, relatively high power and broad wavelength coverage of this laser greatly eased the difficulty of

optical alignment and significantly reduced the measurement error using a traditional monochromator with a high power lamp. The laser beam was directed into the chamber through the window at the bottom of the chamber. A laser power meter was placed below the window. The transmission of the window was carefully evaluated across the entire wavelength range to eliminate the large discrepancy we have observed from vendor data. The cathode was activated by following the standard yo-yo procedure with cesium and NF_3.
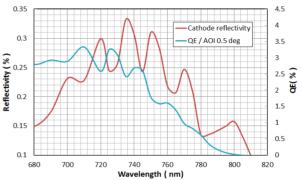

Figure 4: QE and photocathode reflectivity versus laser wavelength for a DBR photocathode sample. AOI: angle of incidence. Notice that QE peaks occur at reflectivity minima.
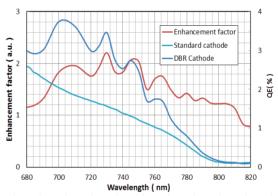

Figure 5: QE versus wavelength for photocathode samples with and without DBR. The QE enhancement factor is shown in red.

Since the structure of the DBR photocathode was designed to enhance the absorption of light at certain resonant wavelengths, we first measured the reflectivity of the photocathode. This was performed by illuminating the photocathode at a small angle, and measuring laser power entering and leaving the vacuum apparatus. The well-collimated laser beam also allowed us to change the beam incident angle to observe the reflectivity dependency on the angle of incidence. One result is shown in Fig. 4. The correlation between each peak of the reflectivity and the valley of the QE curve can be clearly seen, which would not happen with the standard strained-superlattice photocathode. This strongly indicates the resonance behavior happening inside the FP cavity formed by the DBR and the top surface, and it is further

confirmed by the comparison of the QE measurement between the two different cathodes. In Fig. 5, typical QE data are shown for both a DBR and standard strained-superlattice photocathode. The enhancement factor is defined as the ratio of QE values at the same wavelength. The maximum enhancement factor of nearly 2.2 was achieved near 730 nm. A QE enhancement of ~ 1.4 was obtained at the wavelength approximately corresponding to peak polarization, ~ 780 nm. Future photocathodes will be manufactured to precisely center the desired QE enhancement at this wavelength.

To ensure a high level of polarization was maintained with the DBR structure, we also performed systematic polarization measurements using a separate low-voltage retarding-field Mott polarimeter. This polarimeter uses a simple electrode structure and operates from 5 to 30 keV, representing a low energy version of the Mott polarimeter used at the Jefferson Lab accelerator site. Detailed description of the basic physics and the specific configuration of this polarimeter can be found in literature [4, 5]. All the preparation procedures for the photocathode and vacuum chamber were the same as before, including the laser source, although linear polarizers and a quarter waveplate were used to generate the required circular polarization required for spin-polarized electron emission.
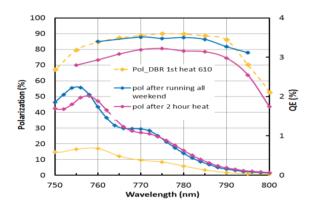

Figure 6: Results of QE and polarization measurement for a DBR cathode in the micro-Mott apparatus under different heating and running conditions.

Typical results of measurement of QE and polarization for a DBR strained-superlattice photocathode are shown in Fig. 6. Since the maximum polarization occurs within the wavelength range from 760 to 790nm, only data points from 750nm to 800nm are plotted in the graph even though a much wider waveband was covered in our QE measurements. The oscillatory behavior indicative of a DBR photocathode can be clearly seen in the QE values, but polarization showed no similar behavior as a function of laser wavelength. The highest polarization ~ 90% was obtained after the first heat treatment, which is required to remove the arsenic cap, but QE was low. QE improved with subsequent heat treatments but polarization was observed to decrease (magenta curve). It is interesting to see excellent polarization and good QE after delivering about 1 micro-Ampere of current for approximately 72

hours (blue curve). Appreciating the polarization dependence on heating and activation history will be the topic of future study.

We also studied a standard non-DBR photocathode inside the micro-Mott apparatus with results shown in Fig. 7. The QE of the DBR photocathode was notably enhanced compared to the non-DBR photocathode, with QE enhancement peaks comparable to those observed using the simple vacuum apparatus, while polarization from both photocathodes was nearly the same, between 80 and 90%. However, we must state that the QE of the standard non-DBR photocathode was lower than similar photocathodes used at CEBAF, 0.6% compared to a typical value of 1%. More photocathodes will be tested in the near future.
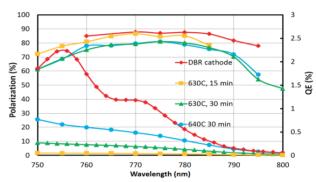

Figure 7: QE and polarization versus laser wavelength for DBR (in red) and standard strained-superlattice photocathodes studied in the micro-Mott apparatus (in, yellow, green and blue).

SUMMARY

We have characterized QE and polarization as a function of laser wavelength for GaAs/GaAsP strained-superlattice photocathodes, with and without a DBR structure. Significant QE enhancement was achieved with the DBR photocathode while polarization was maintained at high levels near 90%. We plan to further optimize the DBR structure, to optimize QE enhancement at 780nm, which is the drive laser wavelength for CEBAF lasers. Beam produced at CEBAF using a DBR photocathode will then be evaluated using the higher precision 5 MeV Mott polarimeter. Other beam properties, such as electron emittance and bunch length, will be studied too.

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