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Jefferson Lab IR demo FEL photocathode quantum efficiency scanner

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Abstract

Jefferson Laboratory's Free Electron Laser (FEL) incorporates a cesiated gallium arsenide (GaAs) DC photocathode gun as its electron source. By using a set of scanning mirrors, the surface of the GaAs wafer is illuminated with a 543.5nm helium–neon laser. Measuring the current flow across the biased photocathode generates a quantum efficiency (QE) map of the 1-in. diameter wafer surface. The resulting QE map provides a very detailed picture of the efficiency of the wafer surface. By generating a QE map in a matter of minutes, the photocathode scanner has proven to be an exceptional tool in quickly determining sensitivity and availability of the photocathode for operation. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

1.1. IR FEL

TJNAF's IR FEL [1] is depicted in Fig. 1. The injector consists of a gun with a cesiated gallium arsenide (GaAs) photocathode, which is illuminated by a frequency doubled, mode-locked Nd:YLF drive laser. The electrons produced by the gun are accelerated by a potential difference of a few hundred kilovolts and enter a 10-MV superconducting radio frequency (SRF) cryomodule. The electron bunches enter the linac in phase with the radio frequency (RF) of an SRF linac and are accelerated to energies in the range of 35–50 MeV. After passing an isochronous and achromatic chicane around the output-coupled laser cavity mirror, the 42-MV electrons enter an IR wiggler. The wiggler consists of a line of magnets with alternating polarity (NSNS, etc.) that causes the electron beam to wiggle (hence the name) and produces the photons that bounce between the mirrors of the optical system. Then the electron bunch leaves the wiggler and passes through another chicane around the highly reflective laser cavity mirror. The electrons proceed around the beam transport and reenter the linac. Unlike the beam's first trip through the linac, it is now out of phase with the RF and is decelerated to 10 MV and sent to a beam dump. The deceleration process allows extensive energy recovery and is responsible for making TJNAF's FEL highly efficient.

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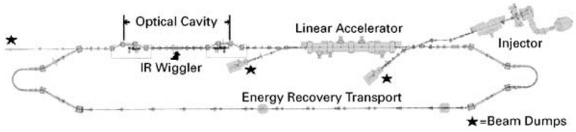

Fig. 1. IR-FEL.

1.2. Motivation

The primary motivation for fabricating the photocathode scanner was to monitor the quantum efficiency (QE) degradation of the photocathode wafer. Experience has shown that photocathode QE falls not only with use, but also as a function of time. With our current periodic operational schedule, there was a need to determine the state of the wafer before each run.

2. Setup

2.1. Optics

A JDS Uniphase helium–neon laser (model 1675) is used to illuminate the photocathode during scans. This laser was chosen mainly because its output wavelength of 543.5 nm closely matches the 527 nm output of the Drive Laser. This single mode 1mW laser also has good pointing stability of $<0.03\,\mu$rad and a small power drift of $\pm 2.5\%$ over an 8-h period [2]. After the laser (Fig. 2), a lens is used to focus the laser spot down to a 0.25 mm radius on the wafer to increase resolution. To reduce space charge effects caused by the focused beam and the low acceleration voltage of 66 V DC, a neutral density filter is used to attenuate the power that is incident on the cathode. A first-surface mirror directs the beam to the two oscillating mirrors of a General Scanning Inc. DX series, closed loop optical scanner. The resulting raster beam travels up through one of the four vacuum viewports in the Light Box assembly to the Light Box Mirror. This mirror reflects the beam to the wafer. The Light Box Mirror is a pyramid-shaped optic with four reflective surfaces and a clear bore through its center for the electron beam to pass. Each of the four surfaces faces a viewport, two of which are used for the Drive Laser input and output. At the third viewport, opposite the scanner, there is a CCD camera mounted to image the photocathode surface. Because of this arrangement, it is necessary to slightly misalign the scanned beam to the Light Box to avoid saturating the camera.

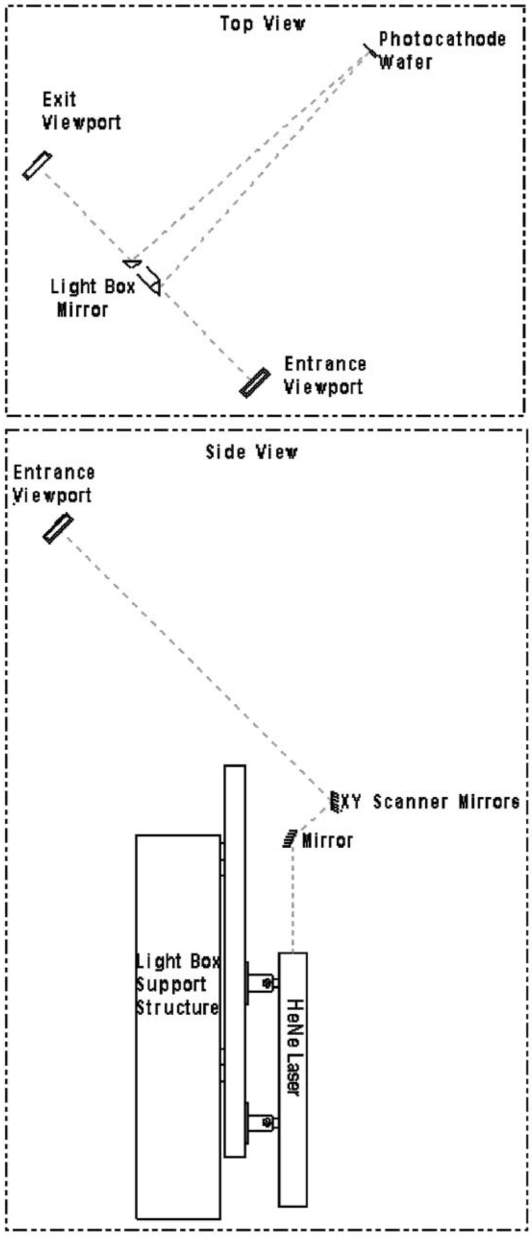

Fig. 2. Photocathode scanner optical layout.

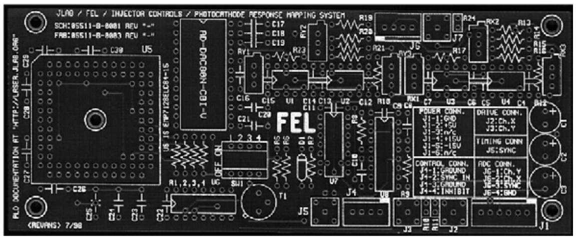

Fig. 3. Photocathode raster board.

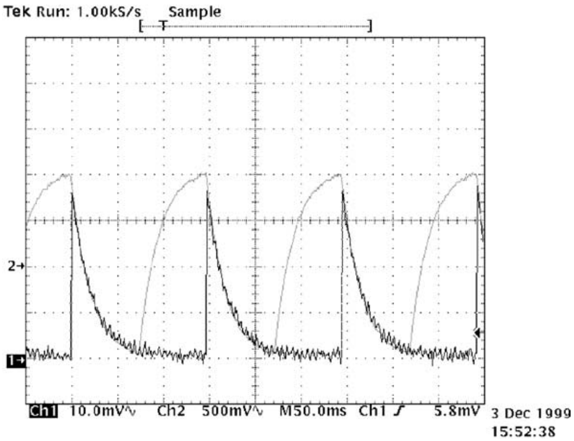

Fig. 4. Photocathode scanner raster output.

2.2. Electronics/data acquisition

A custom-made electronics board (Fig. 3) was designed to both provide the two raster signals to the scanner controller and to output an analog representation of the laser position on the cathode. This raster board uses a PLD chip to output up to 240 discrete steps for the slow X-axis and a continuous ramp for the fast Y-axis. After processing through a digital-to-analog chip, the scope trace of Fig. 4 is the AC output of the raster board with the slow axis on the first channel and the fast axis on the second. With a period of 150 ms, the entire cathode is scanned in 36 s. The second custom board (Fig. 5) is centered around an Analog Devices 759N logarithmic amplifier. The 759N is configured to output 1.5 V for every decade of input current; and with six decades of range, it is sensitive from nanoamps to a milliamp. By biasing the photocathode at 66 V DC, the

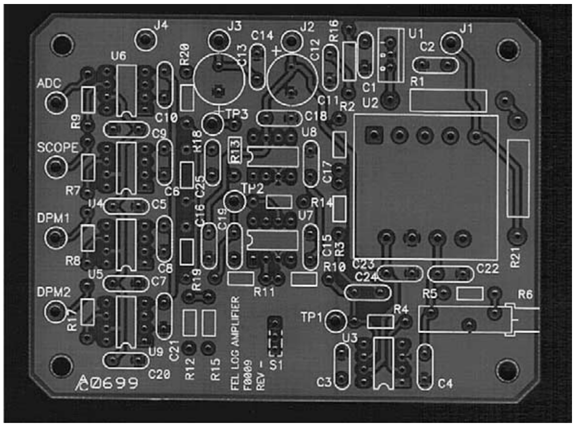

Fig. 5. Scanner logarithmic amplifier board.

current flow resulting from its illumination is measured. The X and Y coordinate positions and the current flow from the cathode are sent to three channels on a VMI VME-3123 digitizer. This 16-channel, 16-bit, analog-to-digital digitizer with a simultaneous "sample and hold" for each channel is able to process 200 k bytes/s/channel.

2.3. Software

EPICS code translates the digitized current into a QE% by using the following relationship. In this equation, I is the beam current, P is the laser power incident on the wafer and λ is the laser wavelength.

$$QE\% = \frac{124I(\mu A)}{P(mW)\lambda(nm)}. \quad (1)$$

An EPICS GUI (Fig. 6) allows a user to input the power and wavelength incident on the wafer as well as select the resolution of the plots. While the default settings should be used, it is necessary to have control over these inputs for setup and testing. The GUI allows users to save comments to both current and old saved scans as well as output any of five different types of plots. The first four plots are 2-D plots showing the wafer as seen by the viewport-mounted camera, the wafer oriented as it is physically, and a difference plot of any two files with either of the above mentioned orientations. With any of the 2-D plots, a color

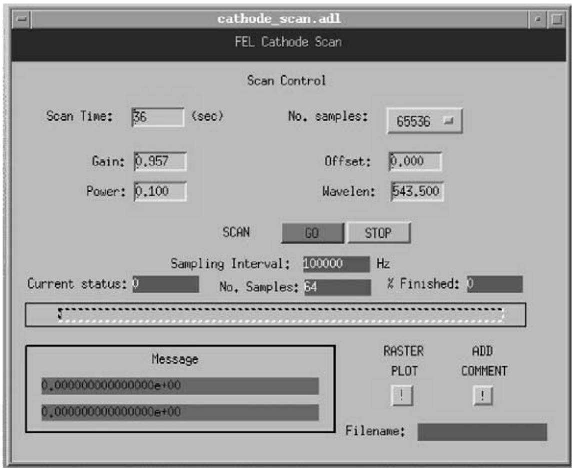

Fig. 6. Photocathode scanner GUI.

scale represents the QE%, and by right-clicking with the mouse on any section of the plot, a specific QE% can be obtained. The last is a 3-D plot that is rendered using MATLAB and can be rotated about either axis. This 3-D plot is also color-scaled to represent the QE%.

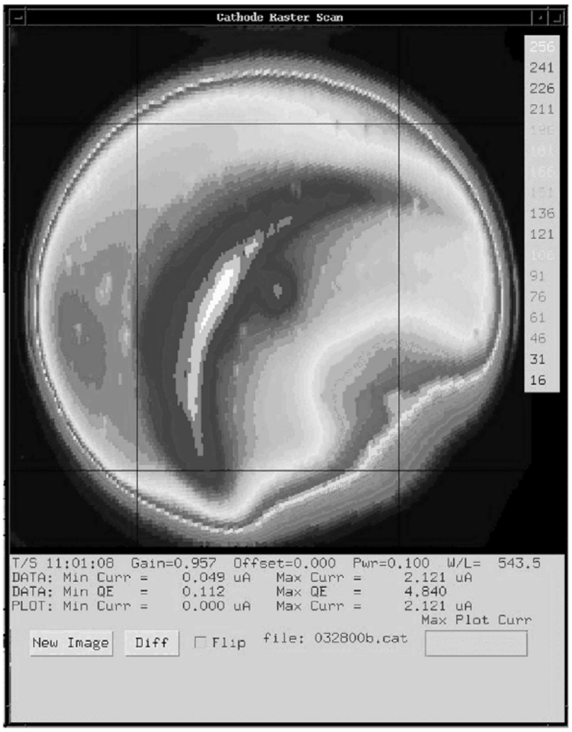

Fig. 7. 2-D photocathode plot.

3. Testing and results

Several tests and measurements were performed to validate the reliability and accuracy of the photocathode scanner. A measurement of the laser power incident on the wafer was obtained with a sensitive, calibrated power meter placed in front of the input vacuum viewport. The attenuation of the viewport and Light Box Mirror was previously measured by replacing the wafer with a power meter. To confirm the absence of space charge effects, it was simply a matter of inserting neutral density filters in the beam path until the current dropped linearly with laser power. The logarithmic amplifier, digitizer, and software accuracy were verified in one step by substituting the biased wafer with a measured precision resistor. The last test performed was to verify the orientation of the plots. This was accomplished by masking sections of the input viewport and comparing its results with the image from the viewport camera. A sample of a 2-D scan can be seen in Fig. 7. For this scan, the maximum QE was 4.84%, located slightly to the left of center. Fig. 8 is a 3-D plot of the same file, rotated clockwise approximately 50° and tilted to show a near vertical profile.

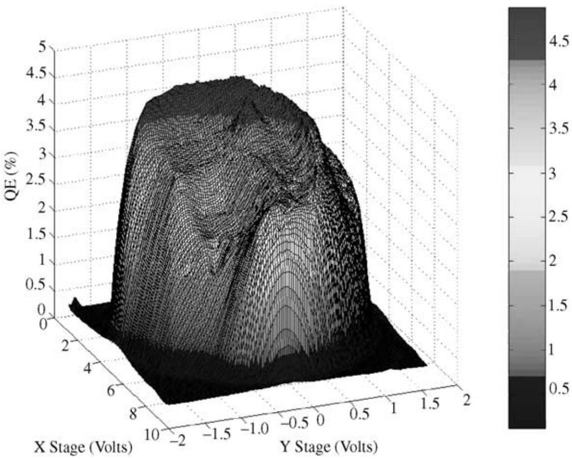

Fig. 8. 3-D photocathode plot.

4. Conclusion

4.1. Summary

The need to quickly determine photocathode operational availability has been met in all respects by the quantum efficiency scanner. Using the raster board to both control the scanning mirrors and to provide a coordinate position of the laser spot on the cathode surface has proven to be a reliable way to scan the wafer. With 240 horizontal and 271 vertical lines of resolution, a scan of more than 65,000 points can be obtained in 36 s. The logarithmic amplifier used to measure the resultant current flow from the biased photocathode is sensitive to changes of a few nanoamps. An EPICS interface to the digitizer card provides a colorful 2-D or 3-D representation of the wafer's quantum efficiency.

Acknowledgements

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