TEMPERATURE DEPENDENCE OF PHOTOEMISSION FROM COPPER AND NIOBIUM*

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Abstract

Photocathodes remain the principal electron sources for many particle accelerators. With the increasing interest in the use of superconducting radiofrequency electron guns, it is important to understand how operation at cryogenic temperatures affects the performance of photocathodes. Here we report measurements of the quantum efficiency of copper and niobium under illumination with 266 nm light at temperatures between 85 K and 400 K. The quantum efficiency of copper was found to vary strongly over this range, while there was only a minimal change in the quantum efficiency of niobium.

INTRODUCTION

Superconducting radio-frequency (SRF) electron guns combine efficient CW operation with the excellent vacuum needed for high-quantum efficiency (QE) photocathodes and the high surface gradients needed to maintain the quality of high-charge bunches. However, they remain an immature technology, with a number of very different configurations currently being investigated [1]. One major concern has been how to best balance the tradeoffs associated with integrating photocathodes into these devices. As part of its research program on SRF guns [2,3,4,5], the Naval Postgraduate School has studied some of these issues, including the potential contamination from dispenser photocathodes [6,7] and cathode stalk cooling to mitigate thermal and RF losses [8]. Many SRF guns use a normal-conducting cathode which is mechanically isolated from the cavity to minimize heat leaks. But even without mechanical contact between the cavity and the cathode, the cathode will be radiatively cooled due to the surrounding 2 - 4 K environment. This raises the interesting question of how the cryogenic environment affects the performance of photocathodes. There have been many measurements of the QE of metal cathodes, including at cryogenic temperatures. However, comparing QE measurements from one experiment to the next is difficult because of differences in sample and testing conditions. Having a single experimental apparatus where the temperature of a cathode can be varied, while keeping other influences largely constant, aids in effectively isolating the dependence of QE on temperature. Accordingly, we modified the cathode stalk cooling experiment to serve as a temperature-controlled photoemission test stand, and used it to measure the QE of copper and niobium at temperatures from 85 K to 400 K with 266 nm light [9]. Our experimental apparatus and results are reported here.

EXPERIMENTAL APPARATUS

Figure 1 shows a schematic of the test stand. The cathode stalk (Fig. 2) was formed from a copper cylinder with a recess in the front surface to accept metal cathode samples, with the samples held in place by a copper retaining ring to provide good thermal and electrical contact between the samples and the stalk. Temperature control was provided by a liquid nitrogen line and a pair of resistive heaters in the back of the cylinder. The heaters were supplied from a variable autotransformer, while liquid nitrogen was supplied from a pressurized fill pot used for the experiments described in Ref. [8]. Temperature measurements were made with LakeShore DT-670-SD and DT-670-CU-HT diodes placed on the front and back faces of the cathode, respectively; these limited operation to temperatures at or below 400 K. The diodes were connected to a computer by a LakeShore 218 temperature monitor, and the data was recorded every 5 seconds by a LabView program.

The vacuum envelope was made from conventional UHV components, with an ion pump providing typical pressures of 3×10^{-8} - 4×10^{-7} Torr at room temperature during testing. In operation, the rate of cathode heating had to be limited to prevent vacuum pressure spikes. A ceramic break was placed around the cathode stalk, with the downstream end electrically isolated from the rest of the experiment to serve as the anode, and connected to a 10 kV Glassman high voltage supply. The floating end also contained a UV window and a small magnet to disperse the photoelectrons to prevent charging of the window. A Bergoz fast current transformer mounted outside the ceramic break provided a time-resolved measurement of the current flow on the stalk, and therefore served as a measure of emitted current.

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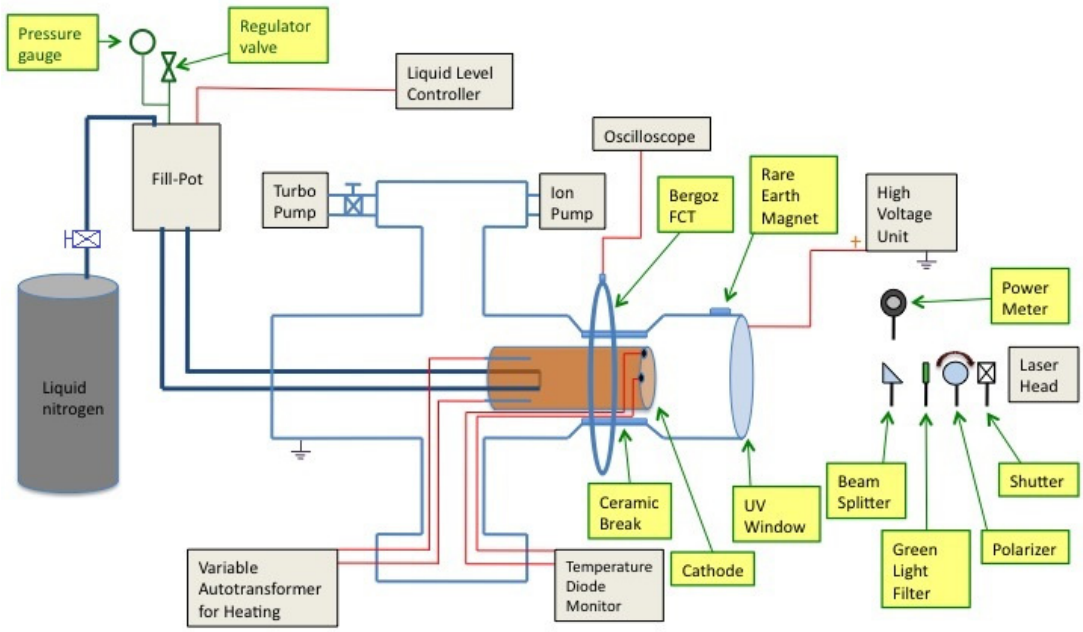

Figure 1: Schematic diagram of the temperature-controlled photoemission experiment [9].

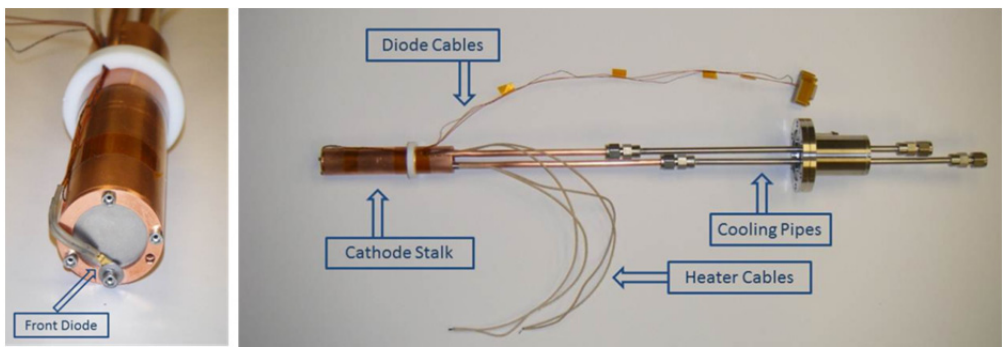

Figure 2: Photographs of the cathode stalk used in the temperature-controlled photoemission experiment, showing the niobium sample installed for testing [9].

Integrating under the transformer signal yielded the number of photoelectrons produced by each laser pulse.

This experiment used a frequency-quadrupled Continuum Minilite II Nd:YAG laser producing a 5 ns, 40 mW pulse of 266 nm light. A filter was used to block any light which was not fully converted to UV inside the laser, and a remote-controlled shutter and polarizer were used to control the laser power. Preliminary testing showed that at an anode voltage of 10 kV, the laser power on the cathode must be less than 4 mW to stay in an emission-limited, rather than space-charge-limited, regime. Conversely, our PM10 power meter required at least 5 mW to stay within its specified range and avoid a nonlinear response. To balance these requirements, 70% of the laser power was directed to the power meter using a beam splitter. The power meter measured the average power delivered to it by the laser; this was converted into the number of photons arriving at the cathode per shot using a conversion factor involving the measured UV window transmission coefficient, the nominal beam splitter power ratio, the laser repetition rate (10 Hz), and the energy per 266 nm photon.

RESULTS AND DISCUSSION

For this testing, a copper sample was machined from material already on hand, and a fine-grain niobium sample etched to 150 μm using buffered chemical polishing was provided by Cornell. Using the system described above, the sample temperatures were adjusted between 85 K and 400 K. At each temperature, the laser power was varied from the minimum power needed to avoid nonlinearity in the detector, to the maximum power that avoided the onset of space-charge-limited operation. The beam current data was integrated to determine the number of photoelectrons produced per laser pulse, and the power meter data was converted to find the number of photons arriving at the cathode per laser pulse. This data was plotted as shown in Fig. 3 and fit to a straight line, with the slope of that line giving the QE. Additional lines were used to conservatively bound the data, and the slopes of these lines set the upper and lower error estimates on the QE.

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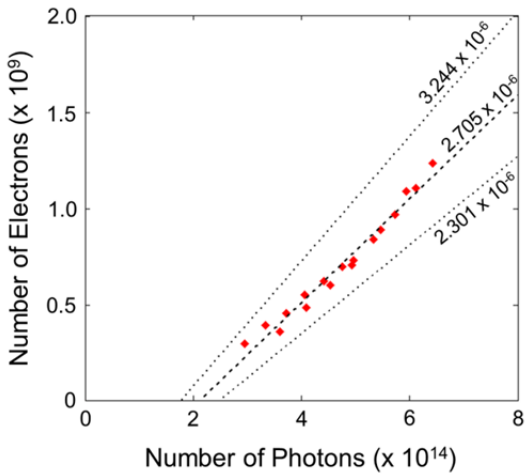

Figure 3: Data reduction for copper sample at 85 K, showing data, fitting line (dashed) and error bounding lines (dotted), with slopes (QE values) indicated.

Figure 4 summarizes the measured QE as a function of cathode temperature for the copper and niobium samples. Also shown are the measured vacuum pressures in the test stand at each temperature during the two sets of experiments. The measured QE of copper increased from 0.27 x 10^{-5} to 1.2 x 10^{-5} as the temperature increased from 85 K to 400 K. This represents a clear and statistically significant increase in QE by more than a factor of four. Over this range, the trend is well described by a quadratic fitting function (Fig. 5), except for the values at 200 K; the cause of this discrepancy is unknown. Vacuum pressure changed very little until the sample temperature exceeded about 350 K in these tests, suggesting that this does not explain the steady change in QE observed for copper.

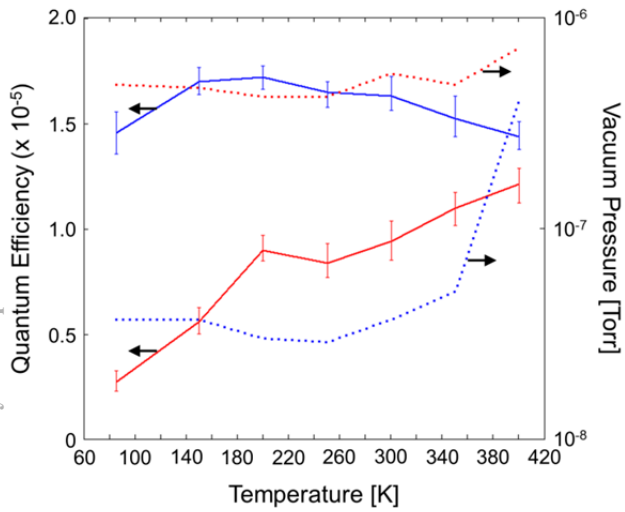

Figure 4: Measured QE (solid lines) and vacuum pressure (dotted lines) during experiments with copper (red) and niobium (blue) as a function of sample temperature.

By contrast, the observed dependence of QE on temperature for niobium is much weaker than for copper, with measured values varying from 1.4 to 1.7 x 10^{-5}.

This experiment found values of QE for copper and niobium that were generally in line with those reported in the literature [9], but the difference in the observed temperature dependence between copper and niobium is dramatic and unexplained. It is important to note that while the samples were handled and cleaned using standard vacuum procedures, the details of their surface conditions are unknown, and there was almost certainly some degree of oxidation present. However, this is representative of the likely surface conditions of these materials when used in actual accelerators.

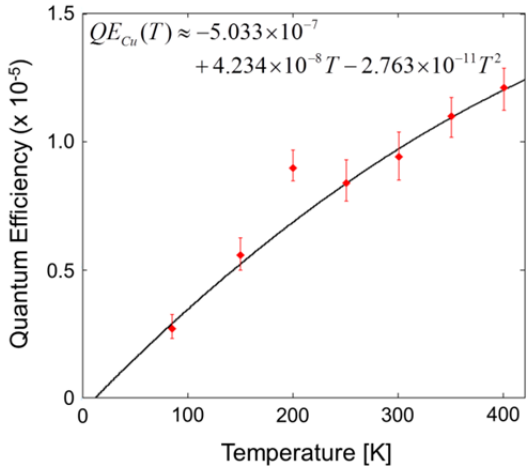

Figure 5: Measured QE of copper and fitting curve.

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