SINGLE CRYSTAL COOPER PHOTO-CATHODE IN THE BNL/SLAC/UCLA 1.6 CELL RF GUN

D. T. PALMER

Stanford Linear Accelerator Center, 2575 Sand Hill Road, Menlo Park, CA 94025

S. ANDERSON AND J. B. ROSENZWEIG

Department of Physics and Astronomy, University of California Los Angeles, Los Angeles, CA 90095-1547

Previous experimental measurements in the two dimensional (2D) variation of the quantum efficiency, QE, of a polycrystalline copper photo-cathode have measured a 25% variation in this quantity. Two possible causes of this 2D QE variation are contamination of the photo-emitting surface and the work function variation of copper due to crystal facet orientation. We report on the progress to eliminate the 2D QE variation due to the non-uniform crystal facet orientation of copper photo-emitters. This is accomplished by replacing the polycrystalline photo-emitter region of the cathode plane in a modified version of the BNL/SLAC/UCLA 1.6 cell rf gun [1] with a thin disk a single crystal copper Cu_{100}. In this paper we present a theoretical discussion on the effect that the crystal structure orientation of a photo-emitter has on the 2D QE. The manufacturing process used in the construction of the single crystal Cu_{100} photo-cathode used in these photo-emission experiments are discussed. Preliminary experimental results are presented along with a discussion of our future experimental plans.

1 Introduction

Previous experimental results have shown a 25% variation in the two dimensional quantum efficiency of polycrystalline copper photo-cathodes[1]. Simulations of the emittance compensation process using PARMELA indicate that the electron beams normalized rms emittance, $\varepsilon_{n,rms}$, is minimized with a uniform transverse charge distribution. Therefor the 2D QE variation of the photo-emitter will degrade the electron beams emittance. The transverse space charge distribution is equal to the convolution of the 2D QE of the photo-cathode the laser beam energy distribution, see equation 1. Where ρ is the electron beam traverses charge density, Ω is the laser pulses transverse energy density and δ is the 2D QE of the photo-cathode.

$$\rho = \Omega \otimes \delta \qquad (1)$$

2 Theory

The use of polycrystalline copper as a photo-emitter has the major benefit that it is a robust material. But it has the drawback that there is no control over the crystal orientation exposed by the laser light, since the laser pulse is required to illuminate the geometric center of the cathode plate to eliminate any rf induced emittance growth due to asymmetrical rf fields. The size of the copper crystal depends strongly on the amount of work hardening and the amount and level of thermal cycling that the copper has undergone. The facet size of OFHC grade II copper is between 200 - 400 μm [2]. Therefore there are a possible 25 - 100 different crystal facets illuminated by the 2 mm diameter laser pulse. Clearly this is a undesirable situations. To eliminate this situation we just replace the polycrystalline central portion of the cathode plate with a single crystal copper slug made out of CU_{100}. Any other crystal facet could have been chosen as long as it zero field work function is below the laser photon energy.

The work function of a metal cathode is reduced with an applied field. Assuming that the QE of a metal cathode scales linear as in Equation 2. Where QE_o is the zero field work function of the photo-emitter, $\Delta\Phi$ is the reduction of the photo-emitter work function due to the applied field, k is Boltzmann's constant, and T is effective temperature of the cathode.

$$QE = QE_o\, e^{\Delta\Phi/kT} \approx QE_o\,(1 + \Delta\Phi/kT) \qquad (2)$$

$$\Delta\Phi = \sqrt{\beta_\gamma \quad E_o \quad \sin(\theta_o)} \qquad (3)$$

In equation 3, β_γ is the field enhancement factor of the photo-emitting surface, E_o is the peak accelerating field at the cathode, and ϕ_o laser injection phase. From equation 2 and 3, the quantum efficiency of a polycrystalline photo-emitter varies as the square root of the applied field and scales linearly with the zero field work function. If we assume that a polycrystalline photo-emitter has a uniform statically distribution of crystal facets, then from Table 1 [3] we see that a 10% variation in the zero field work function with manifest itself into a 10% variation in the 2D QE of a copper polycrystalline photo-emitter.

Taking the polycrystalline work function variation into account indicates that the remaining 15% variation observed experimental is due to surface contamination Which can be minimized with proper material cleaning and handing.

CU_{ijk}	Φ_o (eV)
100	4.59
110	4.48
111	4.94
112	4.53
<ijk>	4.65

Table 1. Various copper crystal orientation and their respective zero field work functions.

3 Manufacturing Process

The cathode plate was constructed out of Oxygen Free High Conductive (OFHC) Copper, grade II material. A thin disk of single crystal Copper, $Cu_{100,}$ was brazed into the cathode plate, using 35-65 gold-copper alloy, The cathode plate was then machined flat with a diamond tool bit. This step induced machining rings that could not be totally eliminated by lapping the cathode plate with 6, 3, 1, and 0.25 μm diamond grit. As a final processing step a small ring of Ti Nitride was deposited on the outer diameter to insure that the cathode plate can be removed from the half cell, after thermal cycling, for future cathode replacements.

X-ray diffraction studies were conducted on a test sample from the same boule of Cu_{100} to insure that the bulk crystal structure of the photo-emitter was not adversely effected due to the H_2 brazing cycle. In principle, the photo-cathode should have had X-ray diffraction studies conducted on it to insure that the single crystal natural of the material was not adversely effected in the H_2 brazing cycle. Due to the sample size limit of the X-ray diffractometer this was not possible. There was no change seen in the Laue pattern of the test sample due to the brazing thermal of 1025^{o}C for 1 hour, figure 1. After H_2 brazing the photo-cathode was machined flat and then lapped with different sizes of diamond grit to minimized the machining rings.

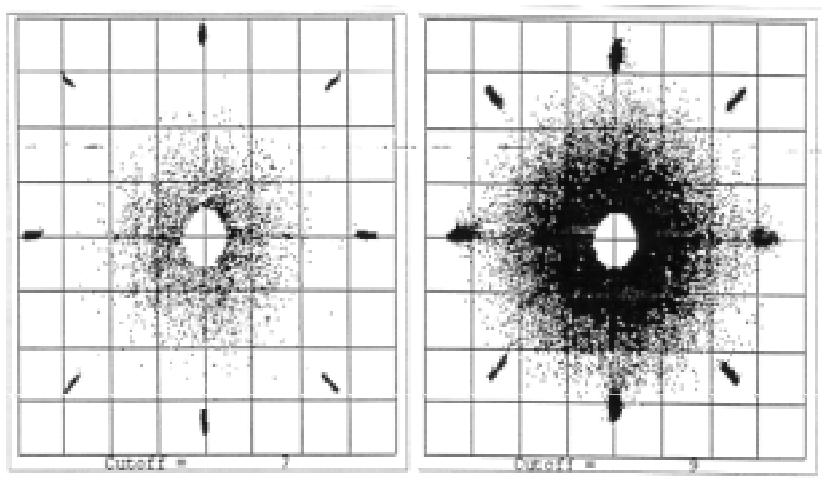

Figure 1. Laue patterns produced by X-ray diffraction studies of Cu_{100} before and after a 1025°C thermal cycle that models the Hydrogen brazing cycle.

4 Experiment Results

A copper single crystal photo-cathode, Cu_{100}, has been installed in a copy of the BNL/SLAC/UCLA 1.6 cell S-Band rf gun located at the UCLA Neptune Laboratory [4]. For a laser injection phase of $\phi_o = 45^o$, which is optimum for the emittance compensation process [5], the measured QE was found to be $4.6x10^{-5}$. Utilizing the full Schottky enhancement with a laser injection phase of $\phi_o = 90^o$, the measured QE was found to be $6.2x10^{-5}$, see figure 2. These two results agree, to within experimental error, with equations 2 and 3. The maximum field gradient on the cathode for these QE measurements was E_Z = 90 MV/m. Preliminary results indicate that the single crystal copper cathode is quite a bit more uniform than polycrystalline copper.

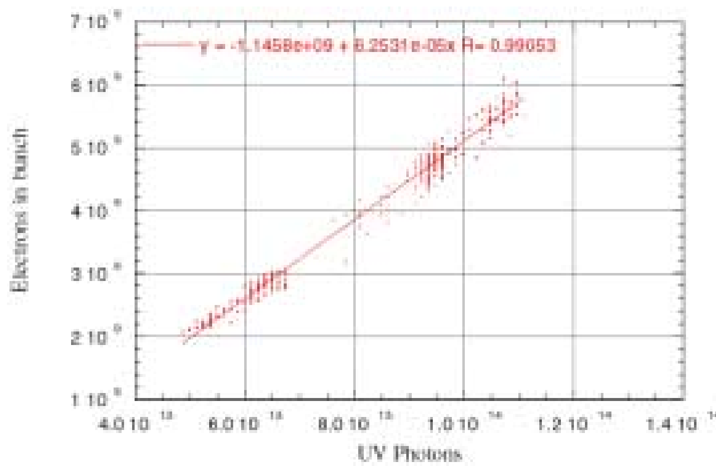

Figure 2. The slope of this plot is the QE of the single crystal photo-cathode for a laser injection phase of $\phi_o = 90^o$ and a cathode field gradient of $E_Z = 90$ MV/m.

5 Future Work

Detailed 2D QE scans of the single crystal CU_{100} photo-cathode are planned to verify the uniformity of the photo-emission process. Future work is required to eliminated the 2D QE variation due to surface contamination. This will be accomplished by electron beam cleaning process [6] that will be installed on the Neptune photo-injector. The manufacturing process will be modified to insure the single crystal nature of the photo-cathodes are maintained throughout the manufacture process.

6 Conclusions

We have manufactured and experimentally studied the photo-emission properties of a single crystal copper photo-cathode in an rf gun. We have verified that the single crystal nature of the photo-cathode is undisturbed by an elevated temperature of 1025^oC for 1 hour, which was used to model the hydrogen brazing cycle. Initial QE measurements for a laser injection phase of $\phi_o = 90^o$ and field gradient of $E_Z = 90$ MV/m were found to be $QE = 6.2x10^{-5}$. Preliminary photo-emission uniformity studies indicate that single crystal copper is quite a bit more uniform than polycrystalline copper.

7 Acknowledgements

We would like to thank the Physical Electronic Group at the Stanford Linear Accelerator Center for conducting the X-ray diffraction studies and lapping of the single crystal CU_{100} photo-cathode. The authors would like to thank Jym Clendenin, John Schmerge, and Gregory Mulhollan for interesting and valuable discussions.

References

1 D. T. Palmer, The Next Generation Photoinjector, Ph.D. Thesis, Stanford University
2 J. Francis, Personal Communications
3 Robert C. West, Editor-in-Chief, CRC Press, Handbook of Chemistry and Physics, 66th edition, Page: E-86
4 J. Rosenzweig et al., The Neptune Photoinjector, ICFA Second Generation Plasma Acceleration Workshop, Kyoto, 1997
5 L. Serafini and J. B. Rosenzweig, *Phys. Rev. E*, 55(6):7565-7590, 1997
6 M. Thompson et al., Proceedings of the Workshop on Physics of High Brightness Beams, UCLA Faculty Center, November 9-12, 1999