

EFFECT OF ROUGHNESS ON EMITTANCE OF POTASSIUM CESIUM ANTIMONIDE PHOTOCATHODES*

T. Vecchione, J. Feng, W. Wan, and H. A. Padmore[#]

Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

I. Ben-Zvi, X. Liang, M. Ruiz-Oses,

Stony Brook University, Stony Brook, New York 11794, USA

T. Rao, and J. Smedley, Brookhaven National Laboratory, Upton, New York 11973, USA

D. Dowell, SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

Abstract

Here we present first measurements of the effect of roughness on the emittance of K_2CsSb photocathodes under high fields. We show that for very thin cathodes the effect is negligible at up to 3 MV/m but for thicker and more efficient cathodes the effect becomes significant. We discuss ways to modify the deposition to circumvent this problem.

INTRODUCTION

Alkali Antimonide photocathodes have been recently proven to have excellent characteristics as a low emittance, high quantum efficiency photocathode that offers reasonably robust operation in ultra-high vacuum photoguns, such as offered by DC or VHF designs [1-3]. One of several issues that still remain to be solved is that of micro-roughness and the consequent emittance growth with applied field. Metallic cathodes can be machined and polished to a very high degree of perfection, or better still evaporated onto an essentially defect free surface such as heavily doped electromechanically polished Si. In contrast the bi-alkali antimonides are made by reaction of the constituent elements and this creates a textured nanocrystalline surface. Here we present our first measurements of the effect of this structure on transverse emittance.

EXPERIMENTS ON THIN FILMS

We have previously measured the transverse momentum distribution from K_2CsSb photocathodes, using a new technique [3]. In this, we extract electrons photoemitted from a cathode through an anode grid. The electron beam then drifts for 257 mm and impinges on a high resolution phosphor screen and is imaged onto a CCD. The cathode anode gap is 5 mm and gradients of up to 3 MV/m can be used at present. The final radial location of an electron is directly related to its initial transverse velocity and hence we can measure directly transverse momentum and normalized emittance. The apparatus is shown in Fig. 1. The system is compact and allows cathodes to be transferred within a minute from the deposition chamber in UHV into this measurement

system. Transverse momentum measurements can be made in less than a second. This enables us to look at many different cathodes under a wide range of conditions (eg. field gradient, gas dosing etc.). The most significant error in the present arrangement is caused by defocusing by the electroformed anode grid. The action of the grid is to form a slightly divergent micro-lens array. Analytical and numerical evaluation of this error indicates that the effect allows accurate measurements even when the transverse energies are close to kT at room temperature. The system can be used with a range of diode laser sources covering 405, 473, 532, 543, 593, and 653 nm; each pre-aligned laser can be switched in via flip-mirrors and so we can rapidly change wavelength. The deposition system itself is equipped with a UV – Vis source and monochromator to allow wavelength resolved electron yield measurements. We also use a CW 266 nm laser for work on metals. Recently we have augmented the system by adding a stigmatic custom grating monochromator and visible – UV plasma source, to allow transverse momentum measurements with continuous wavelength coverage from 200 to 800 nm.

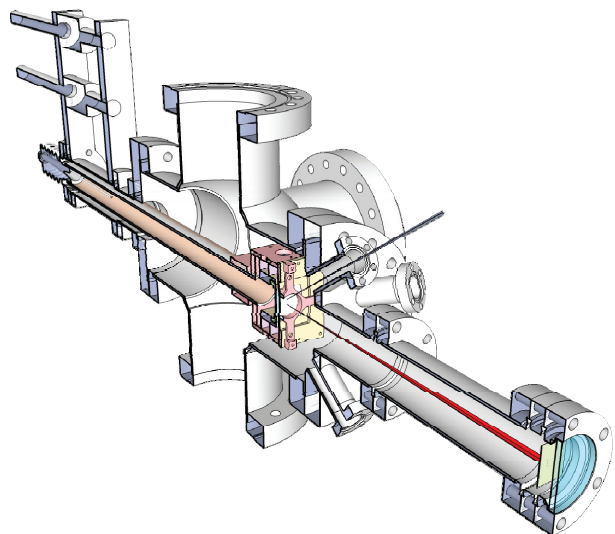


Figure 1: System for measuring cathode transverse momentum.

Results from one of our initial measurements on thin film K_2CsSb is shown in Fig. 2. The full circularly symmetric distribute is azimuthally integrated and then analyzed to give a value of the rms normalized transverse

*Work supported by the Director, Office of Science, Office of Basic Energy Sciences of the U. S. Department of Energy, under Contract No. DE-AC02-05CH11231, KC0407-ALSJNT-I0013, and DE-SC0005713
#hapadmore@lbl.gov

momentum. For this case, the value found was 0.36 mm.mrad / mm (rms).

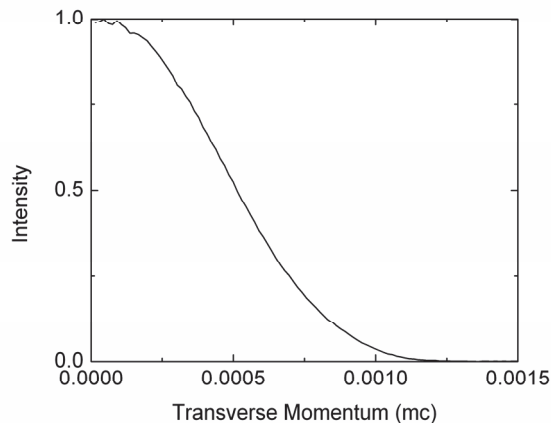


Figure 2: Transverse momentum distribution for K_2CsSb measured at 543 nm.

We have also investigated the normalized transverse momentum as a function of field gradient. The field gradient can be changed in the present system from 0.4 – 3 MV/m. Typical data is shown in Fig 3.

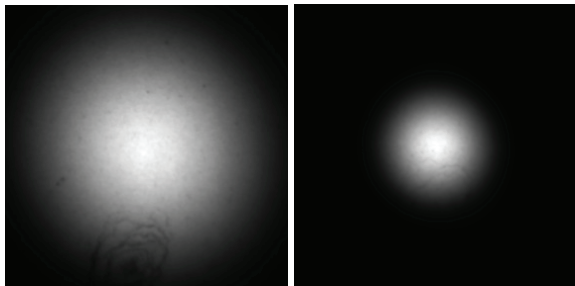


Figure 3: Transverse moment distributions as recorded by a CCD camera in real time for 473 nm wavelength and accelerating fields of 0.6 (left) and 3 MV/m (right).

From this data we can directly extract the normalized emittance as a function of extraction field gradient. The data for two types of cathodes are shown in Fig. 4 for an excitation wavelength of 532 nm. The dots correspond to a thin cathode, prepared from a nominal antimony thickness of 15 nm. We can see that in this case the measured emittance is virtually independent of extraction field up to 3 MV/m. The square dots correspond to a thicker cathode made up of several thin layers and from SEM measurements is significantly rougher than the thin cathode (see paper by Liang et al, this conference). There is now a quite remarkable field dependent emittance. A detailed analysis of this data will be published elsewhere, but we provide a brief initial analysis here.

Transverse energy generated by the cathode has 4 components, a) initial energy spread due to the difference of photon energy and the threshold energy for emission, b) a geometrical effect due to local tilting of the surface, c) a term due to bending of the field lines around curved

surfaces and d) a cross term that depends on b) and c). We can see that in this case the geometrical local tilting effect must be small, due to the fact that the extrapolation of the data back to zero field for smooth and rough films gives the same emittance. This means that term b) is small and therefore the cross term d) is small. We can therefore concentrate on the field dependent term c). The form of this term has been derived elsewhere and is given by [4-6],

$$\varepsilon_{rough} = \sigma_{x,y} \sqrt{\frac{\pi^2 a^2 E e}{2m_0 c^2 \lambda_{rough}}} \quad (1)$$

where a is the amplitude of roughness, E is the field gradient and λ_{rough} is the characteristic period of the roughness. In order to fit the data, we need to know either a or λ_{rough} . Here we assume that the roughness is of the order of the total film thickness, 80 nm in this case. Fitting the data with (1) gives us the solid line in Fig. 4, for a value of λ_{rough} of 710 nm.

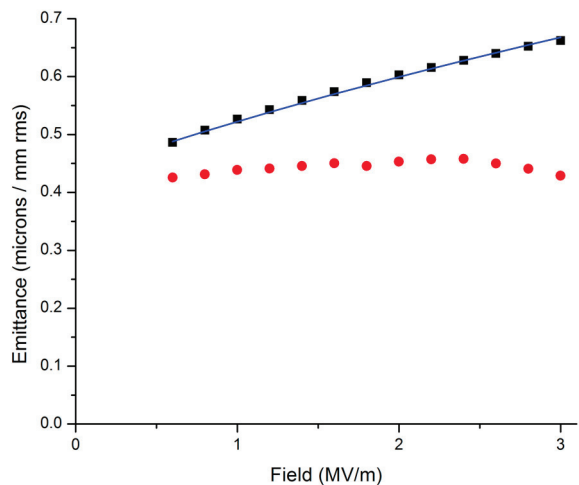


Figure 4: Normalized emittance of a K_2CsSb photocathode as a function of field gradient for two types of cathode. The red dots show data for a thin and smooth cathode and the black squares show data for a thicker cathode consisting of several layers. The blue line shows a fit to a model of field dependent emittance growth.

From the fit in Fig. 4, we can see excellent agreement between the rough data and the fit to a simple model of the effect of roughness.

CURRENT STATUS AND FUTURE PLANS

We have taken data from 405 nm to 593 nm using 4 laser sources and are in the process of analyzing this to provide a more complete overall picture. In order to continuously cover the relevant wavelength range we have recently added a high brightness UV-Vis source to our transverse momentum measurement system covering 200 – 800 nm, with typically $1e13$ ph/sec into a 0.1 mm spot size at the sample. We would like to directly measure surface roughness in order to model its effects, but unfortunately this is quite difficult and ideally is done in-situ due to the reactivity of the cathodes. AFM is the ideal tool, and we plan to attempt these measurements in the near future. In order to further understand the effects of roughness, we are working on the preparation of standards based on the nucleation of metals on silicon. Although the metals will oxidize on extraction from the deposition and measurement system, the morphology will remain constant and will allow ex-situ accurate AFM measurements of roughness. This will allow us to fully explore analytical and numerical simulations of the effects of roughness on emittance. Finally it should be noted that the effects we have shown here for thick cathodes would result in completely unacceptable emittance growth in high gradient photoguns. We are therefore using the tools of synchrotron materials science, mostly x-ray wide and small angle scattering and x-ray reflectivity to understand the growth of alkali antimonides in order to be able to optimize the overall performance of the system in terms of QE, threshold and roughness induced emittance growth.

REFERENCES

- [1] Bazarov, I., L. Cultrera, A. Bartnik, B. Dunham, S. Karkare, Y. Li, X. Liu, J. Maxson, and W. Roussel, Thermal emittance measurements of a cesium potassium antimonide photocathode. *Applied Physics Letters*, 2011. **98**(22): p. 224101-3.
- [2] Dowell, D.H., S.Z. Bethel, and K.D. Friddell, Results from the average power laser experiment photocathode injector test. *Nucl. Inst. Meth.*, 1995. **356**(2-3): p. 167-176.
- [3] Vecchione, T., I. Ben-Zvi, D.H. Dowell, J. Feng, T. Rao, J. Smedley, W. Wan, and H.A. Padmore, A low emittance and high efficiency visible light photocathode for high brightness accelerator-based X-ray light sources. *Applied Physics Letters*, 2011. **99**: p. 034103.
- [4] Bradley, D.J., M.B. Allenson, and B.R. Holeman, The transverse energy of electrons emitted from a photocathode. *Journal of Physics D: Applied Physics*, 1977. **10**(1): p. 111.
- [5] Xiang, D., W.-H. Huang, Y.-C. Du, L.-X. Yan, R.-K. Li, C.-X. Tang, Y.-Z. Lin, S.-J. Park, and J. Park, First principle measurements of thermal emittance for copper and magnesium. PAC07, Albuquerque, New Mexico, 2007. **TUPMN055**.
- [6] Qian, H.J., C. Li, Y.C. Du, L.X. Yan, J.F. Hua, W.H. Huang, and C.X. Tang, Experimental investigation of thermal emittance components of copper photocathode. *Physical Review Special Topics - Accelerators and Beams*, 2012. **15**(4): p. 040102.