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DIAMOND FIELD EMITTER ARRAY CATHODE EXPERIMENTAL TESTS IN RF GUN *

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Abstract

Diamond Field Emitter Array (DFEA) cathodes are arbitrarily shaped arrays of sharp (50 nm tip size) nano-diamond pyramids with bases on the order of 3 to 25 microns and pitches 5 microns and greater. These cathodes have demonstrated very high bunch charge in tests at the L-band RF gun at the Argonne National Laboratory (ANL) Advanced Cathode Test Stand (ACT). Intrinsically shaped electron beams have a variety of applications, but primarily to achieve high transformer ratios for Dielectric Wakefield Accelerators (DWA) when used in conjunction with an Emittance Exchange (EEX) system. Here we present preliminary results from a number of recent cathode tests including bunch charge and YAG images. We have demonstrated shaped beam transport down the 2.54-meter beamline.

INTRODUCTION

Transversely shaped beams are currently produced in a number of ways, including using a photocathode excited by a transversely shaped laser beam [1], by use of a transverse mask to intercept a portion of the beam [2], [3], and [4]. The mask method has beam loss of up to 80%, the intercepted beam produces hazardous X-rays, and the beam shape is often inconsistent due to jitter. These disadvantages can be nullified by making an intrinsically shaped beam. Further, use of a field emission cathode significantly reduces the expense and cost of the beam source.

Diamond field emitter tips have been studied for a number of years, [5], [6] mostly in a small direct current test stands. Los Alamos National Laboratory has recently developed the capability to produce these cathodes completely in-house [7]. An SEM image of one of the sharp emitter tips can be seen in the inset in Fig. 1. We are able to produce the cathodes with a flat diamond base, and any number of ultra-sharp pyramidal emitters with base sizes ranging from 3 μm to 25 μm, with pitches of 5 μm and greater. This fabrication flexibility allows us to produce emitter arrays with nearly any macro shape we wish, in principle, arrays as large as two inches in diameter can be fabricated. Here we present results from both sparse and dense array cathodes that were tested in the rf gun at ACT. We demonstrated shaped beam production from the diamond field emission tips, and were able to transport the shaped beam down to the end of the beamline, approximately 2.54 meters from the cathode.

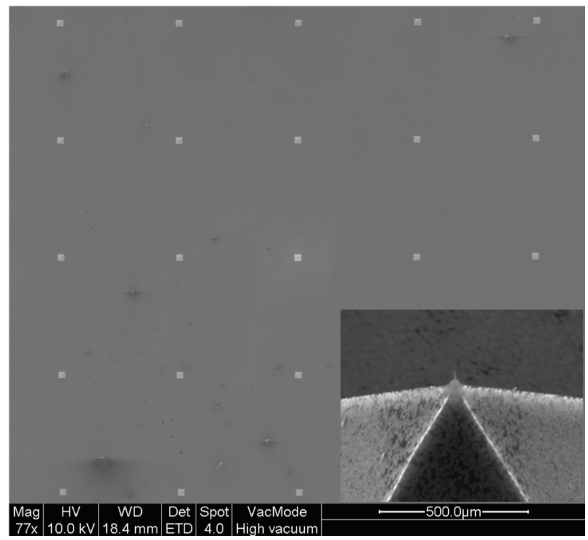

Figure 1: An SEM image of a 5x5 array and close up of a single diamond pyramid tip (insert).

EXPERIMENTAL TEST SETUP

A schematic of the experimental set-up can be seen in Fig. 2. The ACT at ANL consists of a half-cell L-band RF gun, followed by several beamline diagnostics consisting of: gun solenoids, Gsol1 and Gsol2, a beam solenoid, Bsol, two Faraday cups, FC1 and FC2, and three YAG screens, YAG1, YAG2, and YAG3. The rf field in the gun cavity is measured by rf pickup, and the field at the cathode is extrapolated from simulations. In the experiments, the vacuum level was at or below $2x10{-}8$ Torr, the rf was 1.3 GHz, and the rf power level was slowly increased to observe cathode behavior. The I-V curves were measured with decreasing power levels, with the charge during a macro-pulse being collected and reported at FC2. Images were taken on all the YAG screens at various

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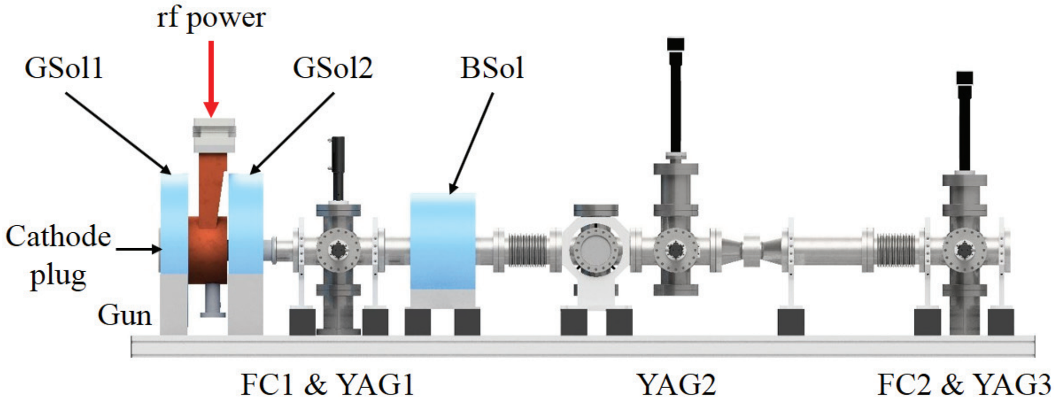

Figure 2: ACT beamline schematic, where FC1, and YAG1 are coincident, along with FC2, YAG3.

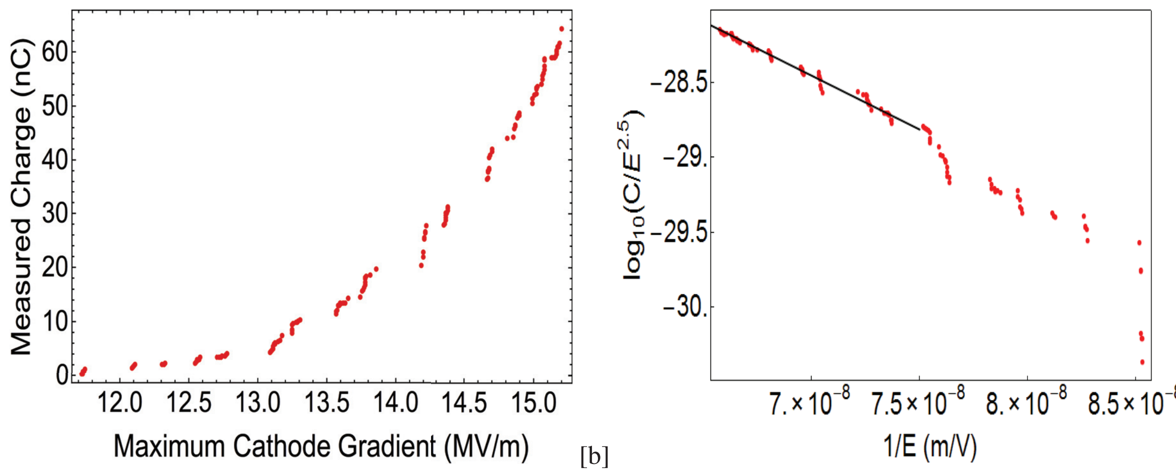

Figure 3: Bunch charge measured on FC2 at a range of cathode gradients [a]; the same data from [a] plotted in FN coordinates [b].

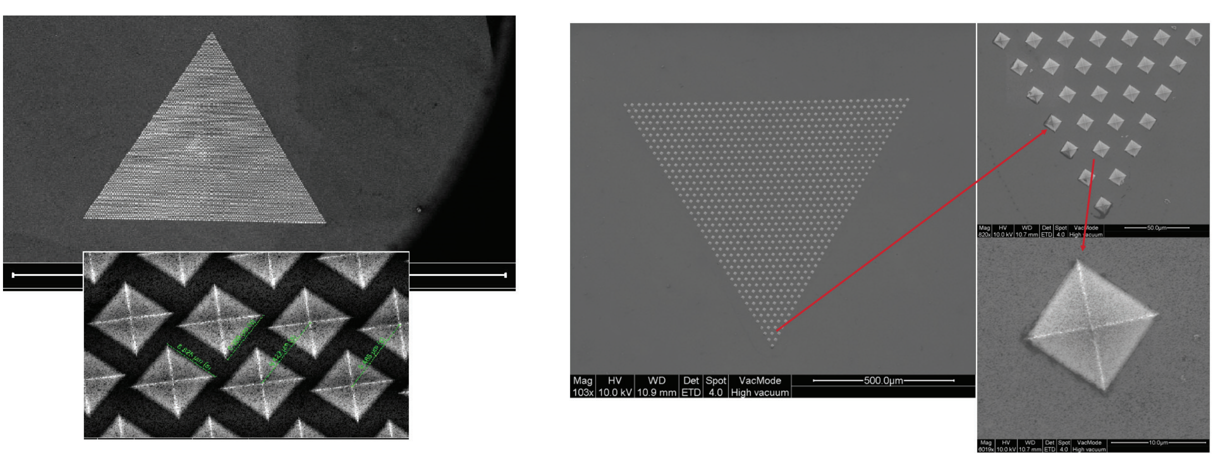

Figure 4: Cathode 1, left, called "CAT1", 7u base, 10u pitch. Cathode 2, called "CAT2" on the right, 10u base, 25u pitch. Both cathodes have the emitters arranged in a 1mm-sided equilateral triangle configuration.

times during the run to observe emitting tips, beam shape, and charge distribution.

EXPERIMENTAL RESULTS

Sparse Array

The sparse array tests were performed using a cathode with a 5x5 pattern of 25 μm base pyramids with a pitch of

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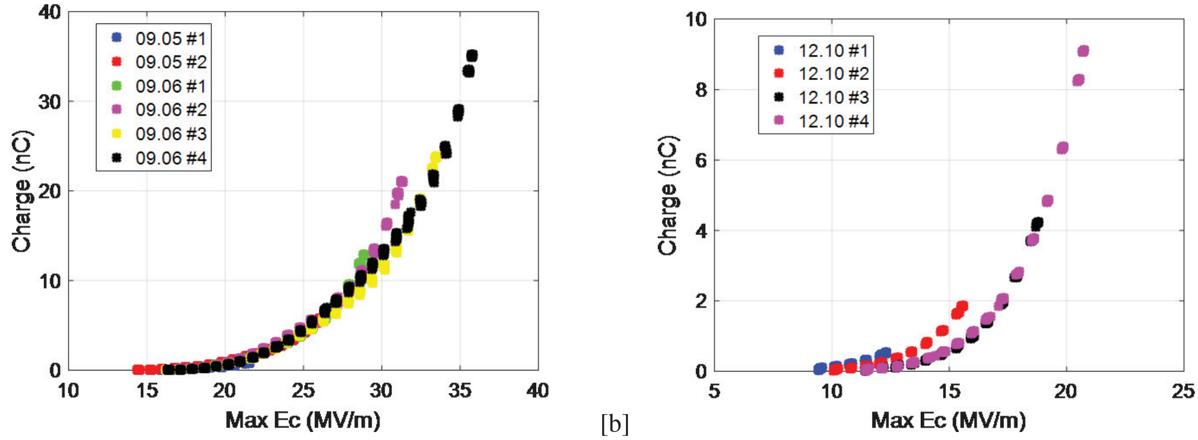

Figure 5: Charge vs. electric field gradient at the cathode for CAT1 and CAT2

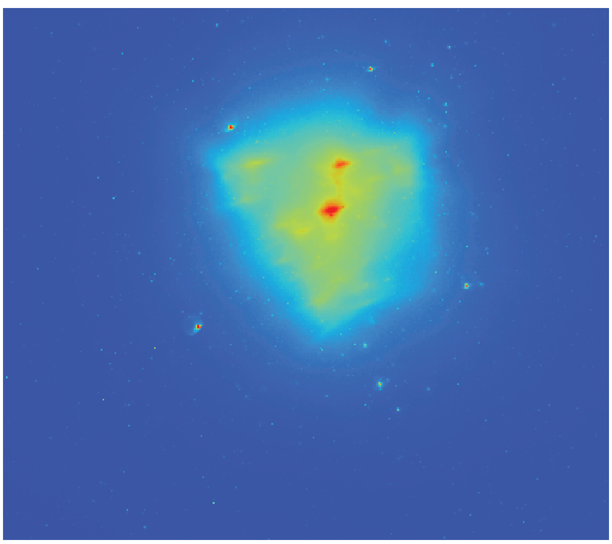

Figure 6: Beam Image at YAG3 from recent cathode emitter array tested at 34 Mv/m cathode gradient.

400 μm. Charge collected on the second Faraday cup for various cathode gradients is given in Fig. 3. Fitted parameters are field enhancement factor, $\beta = 450$, and effective emission area $A_e = 5490\ nm^2$ [8]. The average per-tip current can be estimated using our bunch charge measurements of 60 pC at 15.1 MV/m cathode field and the 8 tips we observed on a corresponding YAG image. We find the average per-tip charge per macro-pulse to be 7.5 pC. Dividing this charge by the flat-top macro-pulse duration of 6 μs, we can determine the average current emitted per macro-pulse to be approximately 1.25 μA per tip. This is a very low estimate because the tips only emit and current only transports out of the gun for a small fraction of the rf macro-pulse. This cathode experienced multiple breakdowns at gradients above 10 Mv/m, which likely limited its robustness, and the charge dropped significantly above 18 Mv/m. Current tests use a new cathode plug with a rounded edge whereas all previous cathodes had a sharp-edged cathode plug.

Dense Array

Two dense triangular arrays, shown in Fig. 4, have recently been tested. These experiments were performed in the same way as the sparse array described above. Charge measured on FC2 is shown in Fig. 5. Considering the fitted emission area, these charge measurements are very high. Notably, the charge for the larger spacing and slightly larger pyramids, CAT2, is higher than for the denser smaller pyramids, CAT1, for the same field, even though there were significantly more field emission tips in CAT1. There were a number of challenges in these tests including difficulty centering the arrays on the cathode plug in addition to the sharp edges of the cathode plugs. The first challenge likely contributed to a difficulty in imaging the beam especially as it was transported down the beamline, the second likely contributed to the maximum cathode field gradients that we were able to achieve.

CURRENT TESTS

In the most recent test, we were able to use a rounded cathode plug and a very well centered array with good brazing and we experiences many fewer breakdowns in the gun. This most recent cathode had 25 μm pyramid bases with 50 μm pitch, in the same 1 mm triangle array configuration as the two previous triangular cathodes tested. With this cathode we were able to measure a charge of approximately 925 pC at a cathode field gradient of 34 Mv/m. In addition, we were able to clearly see the preserved triangle shape of the beam transported to the end of the beamline (2.54 m to YAG3), as shown in Fig. 6.

CONCLUSION

Initial DFEA cathode tests in an rf gun show great promise; we are able to achieve high charge per bunch and preserve the beam shape. More results are in preparation for publication.

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