ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS090

EXPERIMENTAL RESULTS OF DENSE ARRAY DIAMOND FIELD EMITTERS IN RF GUN*

K. E. Nichols†, H. L. Andrews, D. Kim, E. I. Simakov,
Los Alamos National Laboratory, Los Alamos, NM
M. Conde, D. S. Doran, G. Ha, W. Liu, J. F. Power, J. Shao, C. Whiteford, E. E. Wisniewski,
Argonne National Laboratory, Lemont, IL
S. P. Antipov, Euclid Beamlabs LLC, Bolingbrook, IL
G. Chen, IIT, Chicago, IL

Abstract

We present experimental emission results from arrays of diamond field emitter tips operating in an RF gun at the Argonne Cathode Test-stand. Results from various arrays will be presented with different spacing between array elements. Very high charge densities were produced at various field gradients. The maximum field gradient for a particular geometry was discovered and break-down effects will be presented. Cathode lifetime was preliminarily studied. Further experiments are being planned and work on the cathode design optimization to produce higher quality beams will be discussed.

INTRODUCTION

We present here initial results from two diamond field emitter array (DFEA) cathodes recently tested in a 1.3 GHz RF gun. Diamond field emitter arrays are micron-scale diamond pyramids spaced as close as three microns apart and fabricated as arrays in any arbitrary pattern or shape. These pyramids make excellent field emitters due to their sharp tips, which are on the order of 50 nm, see Fig. 1. Due to the mold process of fabrication, it is simple to arrange any number of DFEA pyramids in an arbitrary array shape or pattern. Inherently shaped beams are of interest primarily to produce inherently shaped electron beams for use in dielectric wakefield accelerators. In a beam driven collinear wakefield accelerator, a low charge "witness" bunch is accelerated by a wakefield excited by a higher charge drive bunch travelling in the same direction [1], [2], [3]. The most effective energy transfer from the drive bunch to the witness bunch is produced if the drive bunch has more electrons located at the tail of the bunch, in other words, if the drive bunch is effectively triangle shaped, [4], [5], [6]. This triangularly shaped drive bunch effectively increases the ratio of the maximum accelerating gradient seen by the witness bunch to the maximum decelerating gradient inside the drive bunch, this ratio is called the transformer ratio. One way in which a longitudinally triangular shaped beam can be produced is to use a transversely shaped beam and put it through an emittance exchanger (EEX) [7], [8], [9], [10]. Transversely shaped beams can be produced a number of ways, using a transverse mask, using a photocathode excited by a transversely shaped laser beam, or by using an inherently shaped cathode. Here we discuss results of recent test using transversely shaped cathodes, which have low beam jitter, low beam loss, low x-ray production and potentially more consistent beam shape than the other methods of producing transversely shaped beams. We explore different densities and different sizes of diamond pyramids in these tests.

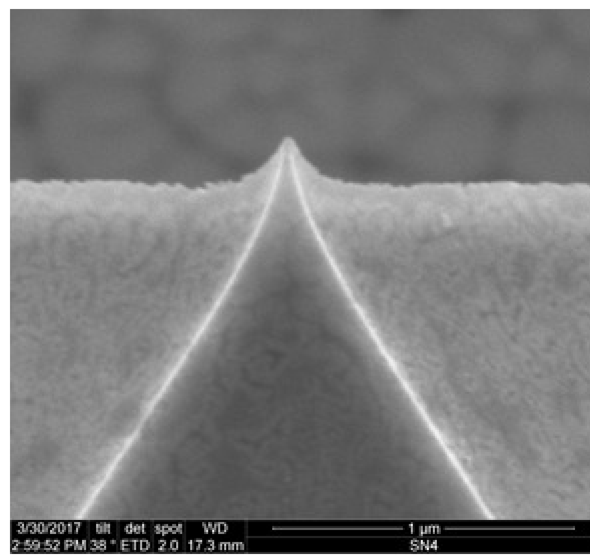

Figure 1: Sharp tip of a single diamond field emitter pyramid.

Dense Array Tests

Two dense array cathodes were tested, both of which were 1 mm side-length triangles. The first cathode (CAT1) tested has pyramids of 7 micron base with 10 micron pitch, the second cathode tested (CAT2) has 10u base, 25u pitch. SEM photos of the two cathodes can be seen side by side in Fig. 2.

EXPERIMENTAL SET-UP

These experiments were conducted at the Advanced Cathode Test Stand (ACTS) at Argonne National Laboratory [11]. The test stand has a single-cell 1.3 GHz RF gun, which can produce cathode gradients from 10 MV/m to 70 MV/m. The gun has a removable cathode plug which can be positioned flush to the cavity wall, or recessed a few millimeters. The beamline is shown in Fig. 3, it has three YAG screens shown in the schematic as YAG1 at 0.43 meters from the cathode,

* Work supported by LANL/LDRD
† knichols@lanl.gov

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS090

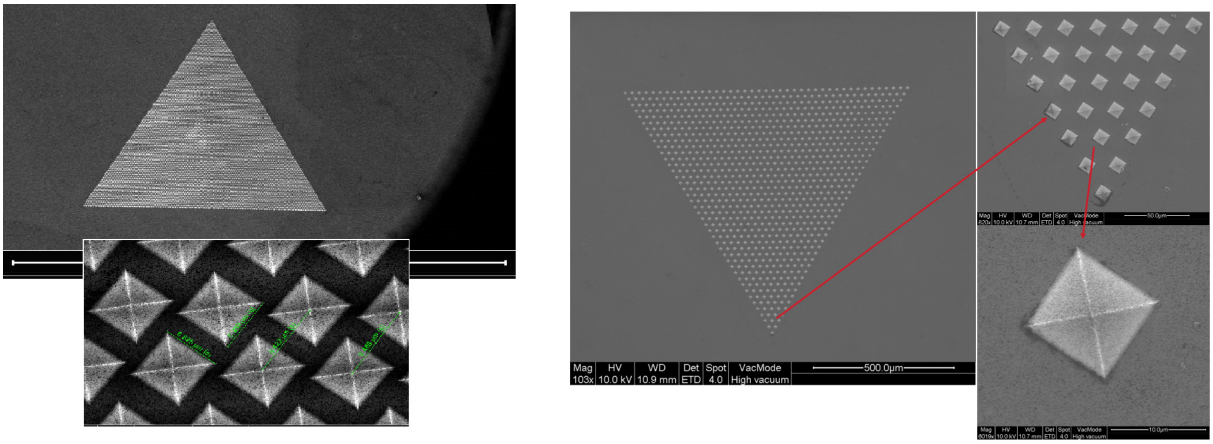

Figure 2: Cathode 1, left, called "CAT1", 7u base, 10u pitch. Cathode 2, called "CAT2" on the right, 10u base, 25u pitch. Both cathodes have the emitters arranged in a 1mm-sided equilateral triangle configuration.

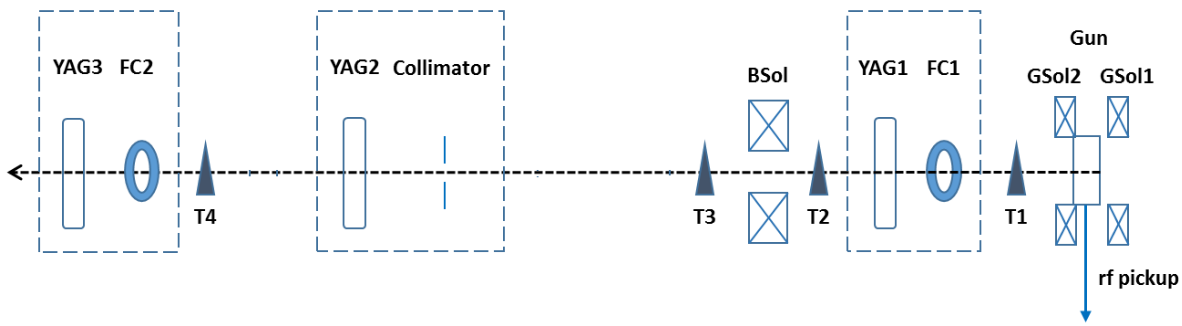

Figure 3: ACT beamline schematic, where FC1, and YAG1 are coincident, along with FC2, YAG3, T1-4 represent trim magnets.

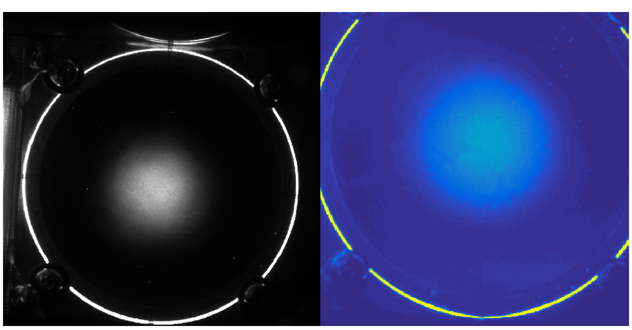

Figure 4: Cathode 1, left, imaged on YAG1, Cathode 2, right, imaged on YAG1.

YAG2 at 1.57 m from the cathode, and YAG3 at 2.54 m from the cathode, two faraday cups at FC1, which is coincident with YAG1, and FC2, which is coincident with YAG3, with various solenoids and trim magnets used for beam steering. RF input power controls the field on the cathode which is deduced with three-dimensional simulations. A pickup in the cavity measures forward and reflected power, giving us an approximate flat top of five microseconds. The cavity has a rep rate of 2 Hz. The beamline features two gun solenoids GSol1 and GSol2, and one beam solenoid BSol, used to transport beams down to the end of the beamline.

Both dense array cathodes were tested with the same method. The vacuum pressure was approximately 5e-9 or better, RF power was coupled into the gun via a coupling loop and power in the gun was measured on another probe. Power in the gun determined the field on the cathode via simulations. We began the experiment with a low electric field gradient on the cathode and increased the gradient (RF input power) until emission was observed on the first YAG screen. Images were captured on the YAG screen, YAG1, and then the screen was removed and charge data was collected on the Faraday cup, FC1, coincident with YAG1.

RESULTS

Images from YAG1 can be seen for both CAT1 and CAT2 in Fig. 4. These images were taken at approximately 15 MV/m for each cathode. Nonetheless, the images stayed pretty similar for all cathode gradients tested. We believe the triangle shape of the emitter was not preserved on the YAG screen due to more space charge than expected. We were unable to get clean transport with these cathodes downstream at YAG2 and YAG3 due to the difficulty of centering the

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS090

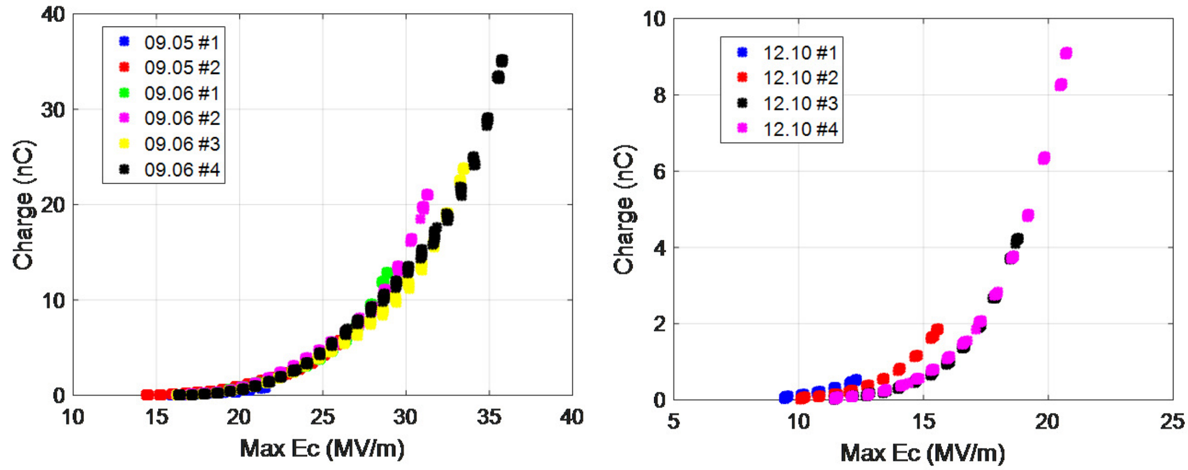

Figure 5: Charge measured on YAG1 for increasing cathode gradients for CAT1, left, and CAT2, right. # represents different instances of measurements during conditioning.

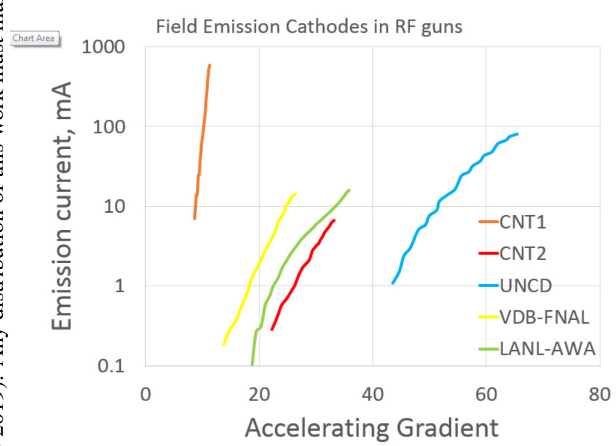

Figure 6: Emission current measured for CAT1 is compared to other recent field emitter cathodes tested, CAT1 is green, labeled LANL-AWA.

emitters on the cathode, which made using the solenoids ineffectual.

Charge for both cathodes can be seen in Fig. 5. Despite there being more emitters on CAT1, 5̃000 compared to 8̃00 emitters on CAT2, CAT2 emitted more charge. We believe this is due to tip to tip shielding effects, and potentially to the height difference in the emitters as well, their height being proportional to their bases. CAT2 had a lower breakdown threshold that CAT1, and hence we could not go to as high cathode fields without significantly damaging the cathode.

CONCLUSION

In Fig. 6, current from our emitters is compared to other recent experiments on diamond field emitters with different geometry. Current is extrapolated from the charge measurements using the likely emission time in the RF gun, and assuming an average current over that time.

Overall, the charge/current measurements demonstrate a high charge cathode, but more experiments are needed with various densities to optimize the emission current with minimal space-charge such that the shaped beam can be transported maintaining it's shape.

ACKNOWLEDGEMENTS

Authors wish to thank Argonne National Laboratory for use of their ACTS cathode test stand, as well as Los Alamos National Laboratory for LDRD funding.

REFERENCES

[1] W. Gai, *et al.*, *Phys. Rev. Lett.* 61, 2756 (1988).

[2] M. Rosing and W. Gai, *Phys. Rev. D* 42, 1829 (1990).

[3] P. Chen, *et al.*, *Phys. Rev. Lett.* 54, 693 (1985).

[4] C. Jing *et al. Phys. Rev. Lett.* 98, 144801 (2007).

[5] A. Zholents *et al.*, *Nuclear Instruments and Methods in Physics Research A* 829, 190 (2016).

[6] F. Lemery and P. Piot, *Phys. Rev. STAB* 18, 181301 (2015).

[7] D. Y. Shchegolkov and E. I. Simakov, *Phys. Rev. Accel. Beams* 17, 041301 (2014).

[8] G. Ha *et al.*, *Phys. Rev. Lett.* 118(10), 104801 (2017).

[9] G. Ha *et al.*, *Phys. Rev. AB* 19(12), 121301 (2016).

[10] Q Gao *et al.*, *Phys. Rev. Lett.* 120 (11), 114801 (2018).

[11] J. Shao *et al.*, *Phys. Rev. Lett.* 115, 264802 (2015).