# TRANSVERSE EMITTANCE OF DIAMOND FIELD-EMITTER ARRAYS

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## Abstract

We present progress in transverse-emittance measurements of ungated diamond field-emitter arrays. Fine-pitch arrays are conditioned to provide uniform emission prior to emittance testing. The testing is performed using a pepperpot technique with microlithographed silicon aperture arrays and a ZnO phosphor screen. Results are compared to simulations performed in POISSON/GPT.

## INTRODUCTION

Recent experiments have demonstrated the potential of diamond field-emitter arrays as cathodes for free-electron lasers [1, 2]. As such, it is important to characterize the fundamental emission properties of these cathodes. These include per-tip-current limits, temporal emission stability, beam energy spread, and transverse emittance. The transverse emittance is of critical importance for beam transport and beam-wave interaction in the lasing process. Specifically, the transverse emittance of the electron beam must be small compared to the laser wavelength to ensure acceptable volume overlap during the interaction. This can be written as

$$\frac{\varepsilon_N}{\beta\gamma} < \frac{\lambda}{4\pi}, \qquad (1)$$

where $\varepsilon_N$ is the normalized transverse emittance, $\beta c$ is the electron velocity, $\gamma$ is the Lorentz factor, and $\lambda$ is the laser wavelength.

To measure the transverse emittance from ungated diamond field-emitter arrays we utilize a pepperpot technique in a low-energy-DC test stand. In this report we review preliminary results of these measurements and compare them with simulations of the emitted beamlet from a single tip.

## EXPERIMENT

A schematic of the experimental configuration for these emittance measurements is shown in Figure 1.
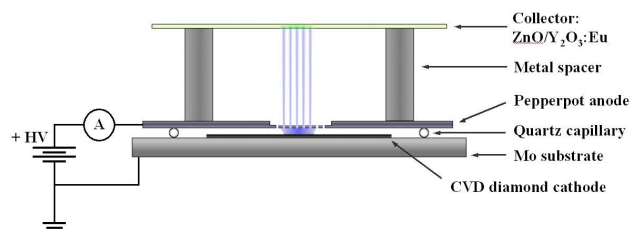


Figure 1. Emittance apparatus schematic.

An ungated, 3x24, 28 μm pitch, diamond field-emitter array (Figure 2) is placed in a close-diode configuration with a pepperpot as the primary anode.
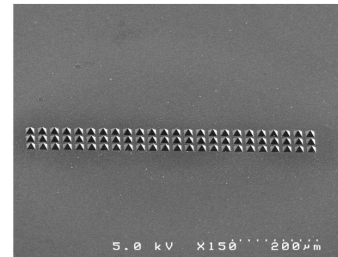


Figure 2. 3x24 diamond field-emitter array used in present experiments.

The anode-cathode gap is set using precision quartz capillaries, 330 μm in diameter. When the thickness of the diamond film is included, the gap is ~300 μm. In this arrangement, fields up to ~17 V/μm can be applied. The pepperpot is fabricated from a single SOI wafer and has 30 μm square holes with a 200 μm pitch (Figure 3).
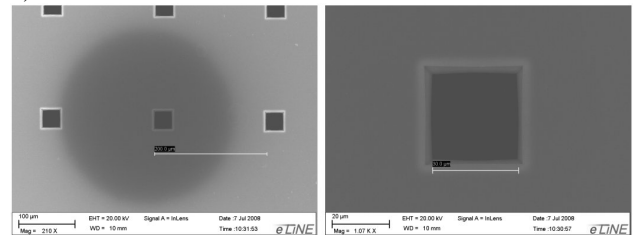


Figure 3. Detail of Si pepperpot used in present experiments.

A field-free-drift space of 5 mm is set with a cylindrical metal spacer and terminates at a high-sensitivity ZnO phophor screen. The apparatus has an integrated resistive heater, allowing annealing of the cathode up to ~350 °C. This annealing improves uniformity due to modification of adsorbed species on the emitter surface [2]. In the current experiment, the beamlet that emerges from the pepperpot comprises emission from fewer than a dozen tips. As a result, the beam has nonzero correlations that slightly preserve the aperture's square shape in the final image

Figure 2 shows one of the collected beamlets with the approximate location of a linescan that is used to estimate the cathode's rms angular divergence.
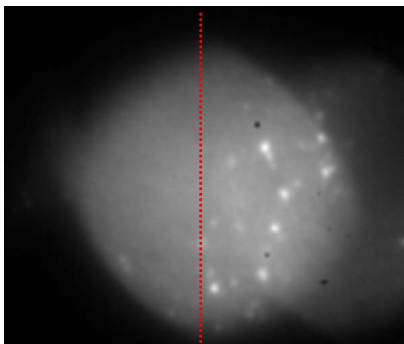
Figure 4. Collected beamlet from pepperpot after 5 mm drift length.

The sporadic bright spots in the image are the result of phosphor damage from unrelated experiments. The results of the linescan are presented in Figure 3.
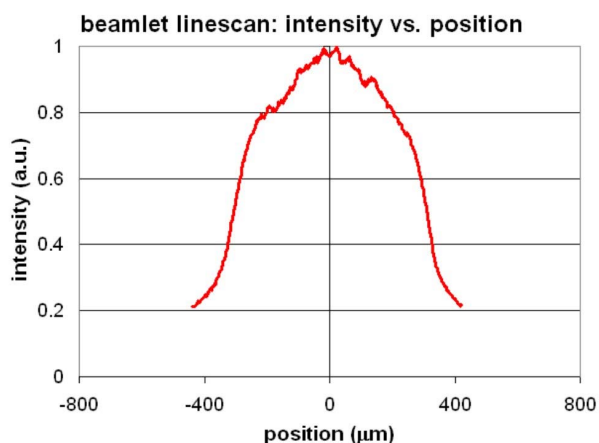


Figure 5. Linescan of observed beamlet in Fig 4.

The rms radius of the beamlet is estimated at approximately 250 μm, which corresponds to an rms angular divergence of ~50 mrad. The pepperpot aperture acts as a diverging lens and increases the measured divergence at the collector. The focal length is given by $f = 4L$, where L is the anode-cathode spacing. The focal length of 1.2 mm reduces the measured rms angular divergence to ~38 mrad. For a beam energy of 2 kV $(\beta\gamma \approx 0.09)$ and a cathode diameter of 1mm, the normalized x-emittance is

$$\varepsilon_{N_x} = \beta\gamma\sigma_x\sigma_{x'} \approx 1.4 \text{ mm-mrad} . \qquad (2)$$

In the next set of emittance measurements our results will be refined by using arrays with more than ten times the emitter density of the current array.

## SIMULATION

For comparison with our experimental results, we have performed simulations of the emitted beamlet from an individual microtip. Field solving for the emitter structure is carried out in POISSON while electron beam

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trajectories are computed in General Particle Tracer (GPT). These simulations are axially symmetric and cannot represent the pyramidal geometry of the actual emitters. A close up of the emitter's nanotip, emitted trajectories, and field solving mesh are seen in Figure 6.
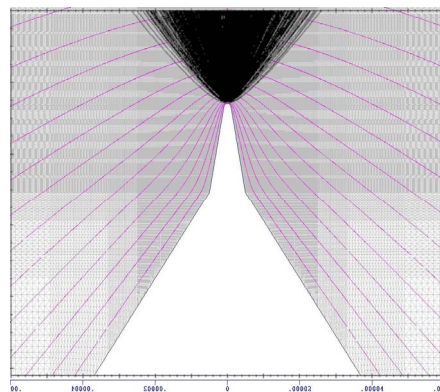


Figure 6. Detail of an individual emitter's nanotip structure with field solving mesh and trajectories. Entire length of x-axis is 1.2 μm.

Figure 7 demonstrates propagation of the beam to a distance of 300 μm, the pepperpot position, as well as detail of the trajectories near the tip.
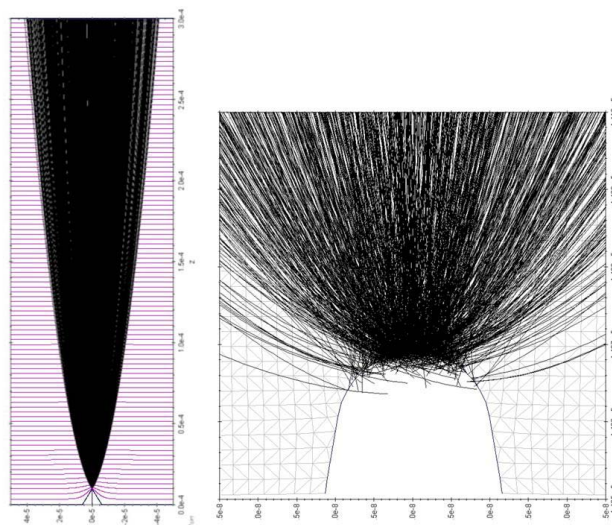


Figure 7. Propagation of beamlet to the pepperpot position (left), and trajectory detail near the cathode surface (right).

The calculated beam spot of ~50 μm is comparable to that measured in previous experiments [1]. The rms divergence at the pepperpot position is ~40 mrad, which agrees well with the measured value of 38 mrad.

## CONCLUSIONS

We have presented preliminary measurements of the transverse emittance of electron beams from ungated diamond field-emitter arrays. The measured x-emittance of ~1.4 mm-mrad is sufficient to ensure acceptable volume overlap of the electron beam and the laser mode

for a wide range of beam energies and laser wavelengths. The measurements presented here will soon be refined using higher density arrays. Additionally, gated diamond field emitter arrays with integrated focusing electrodes are being developed which will produce nearly collimated beams with very low emittance.

## ACKNOWLEDGEMENTS

## REFERENCES

[1] J. D. Jarvis et al, *Toward Energy Spread Measurements of Diamond Field-Emitter Arrays*, these proceedings

[2] J. D. Jarvis et al, *Uniformity Conditioning of Diamond Field-Emitter Arrays*, these proceedings