Ordered Nanomaterials for Enhanced Electron Field Emission

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Introduction

Field emission from nanomaterials has received interest for applications including displays [1] microwave amplifiers [2], electron microscopy [3], parallel electron beam lithography [4] and X-ray sources [5].

Fowler Nordheim equation:

$$J = \left(\frac{A\beta^2E^2}{\varphi}\right)\exp\left[\frac{-B\varphi^{\frac{3}{2}}}{\beta E}\right]$$

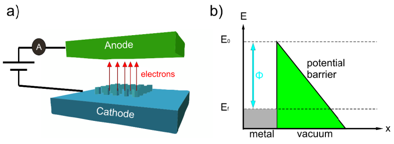

Figure 1. a) Field emission device operating in diode mode b) triangular vacuum potential barrier

Plasma Etching of Graphitic Nanocarbons

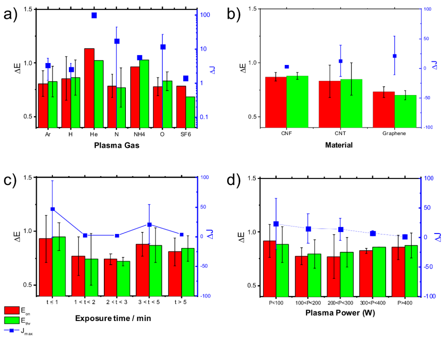

Figure 2. Effect of plasma etching on nanocarbons by a) etchant gas b) material c) exposure time d) operating power.

Field emitting capabilities can be judged according to the turn on field, E_{on}, threshold field, E_{thr}, and maximum current density, J_{max}. E_{on} is defined using a novel method, derived from J_{max}. Figure 2 shows this definition.

Current densities are normalised by plotting J/J_{max} then taking 10% (E_{on}) and 30% (E_{thr}).

Plasma etching improves field emission performance [6]. An overall decrease in E of 20% was seen, as well as an increase in J_{max} of 14 mA/cm^2.

Effect of Work Function on Field Emission

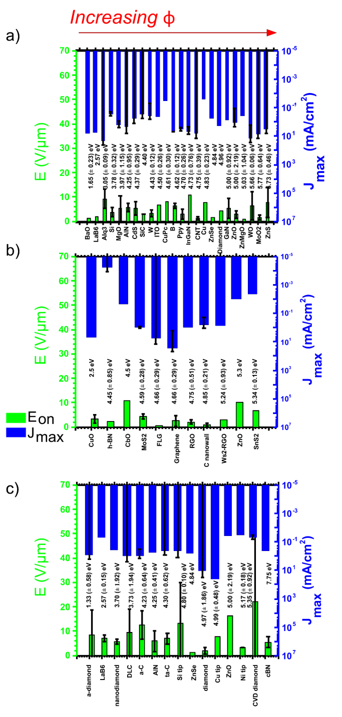

Figure 3. E_{on} and J_{max} for materials according to a) 1D b) 2D and c) 3D/bulk ordered by φ (written above material).

Materials are directly compared by work function, φ, in Figure 3 by setting E_{on} = 0.01 mA/cm for every emitter.

On average, 1D and 2D materials show similar performance, with $\langle E_{on}\rangle$ = 4.74 V/μm and 4.21 V/μm respectively. 3D/bulk materials show twice this value, with <E · = 8.09 V/μm. $\langle J_{max}\rangle$, however, was similar in each di nsionality: 1D = 3.61 mA/cm^2, 2D = 3.31mA/cm^2 and 3D ulk = 3.70 mA/cm^2.

No correlation can be seen between materials when ordered according to φ only. Materials can be judged on a material-to-material basis, with the nanocarbons performing consistently well.

In field emission applications, 1D and 2D nanomaterials perform twice as well as 3D/bulk materials, suggesting that the morphology of the emitter is important.

Field enhancement factor, β, is inconsistent, with a number of definitions across the field. The relationship between φ and β is shown in Figure 4a.

Aspect ratio, AR, is associated with β commonly, although their relationship is not clear.

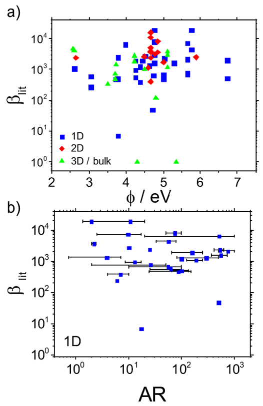

Figure 4. a) Work function, φ, vs local field enhancement (from the literature), β_{lit} b) Aspect ratio, AR, vs β_{lit}

The Importance of Morphology

In order to understand the influence of morphology, and β, CNT emitters have been fabricated with a wide range of different geometries.

The variables are: number of sides, width of polygon (x), wall width (w) emitter height (h), and growth area of CNTs.

5 1	5 2.5	5 5	5 10
10 2	10 5	10 10	10 20
50 10	50 25	50 50	50 100
100 20	100 50	100 100	100 200

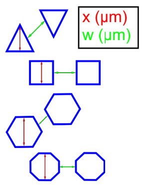

Figure 5. Dimensions of the width of the polygon, x, and wall, w, in the different zones of the chip and definitions.

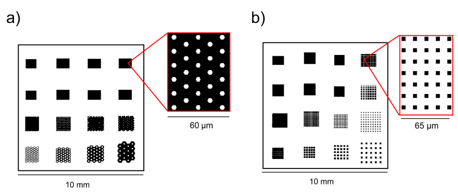

Figure 6. Examples of a) inverse hexagonal pillar array (black region where CNTs are grown) and b) square pillar array.

Factors that are commonly implicated in describing β are aspect ratio, surface roughness, degree of patterning, and vertical alignment.

These designs are fabricated to test the influence of aspect ratio by growing the emitters to over five different lengths. The electron screening effect is also tested by the different spacings seen in different zones.

Measurements of field emission will take place in a custom built Scanning Anode Field Emission Microscope (SAFEM).

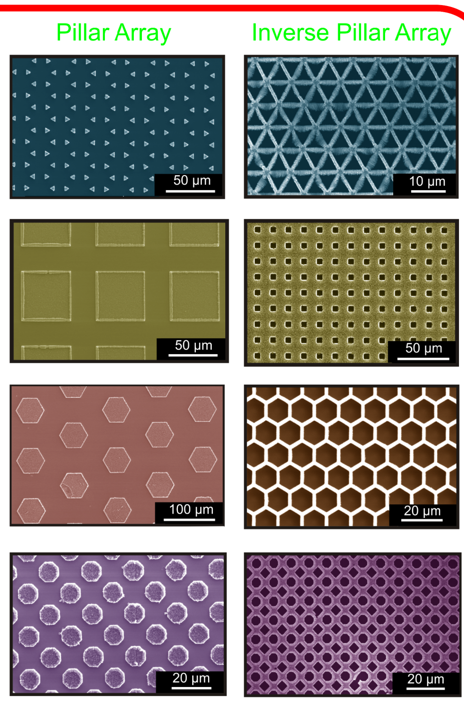

Figure 7. Examples of the different zones from triangle, square, hexagon and octagon pillar arrays and inverse pillar arrays.

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Acknowledgements

Thanks to EPSRC, UP DTC, Oppenheimer Trust, EPSRC IAA, Innovate UK/ Technology Strategy Board

EPSRC Engineering and Physical Sciences Research Council

Technology Strategy Board Driving Innovation

Cambridge XRAY SYSTEMS

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