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Ordered Nanomaterial Field Emission for X-Ray Sources

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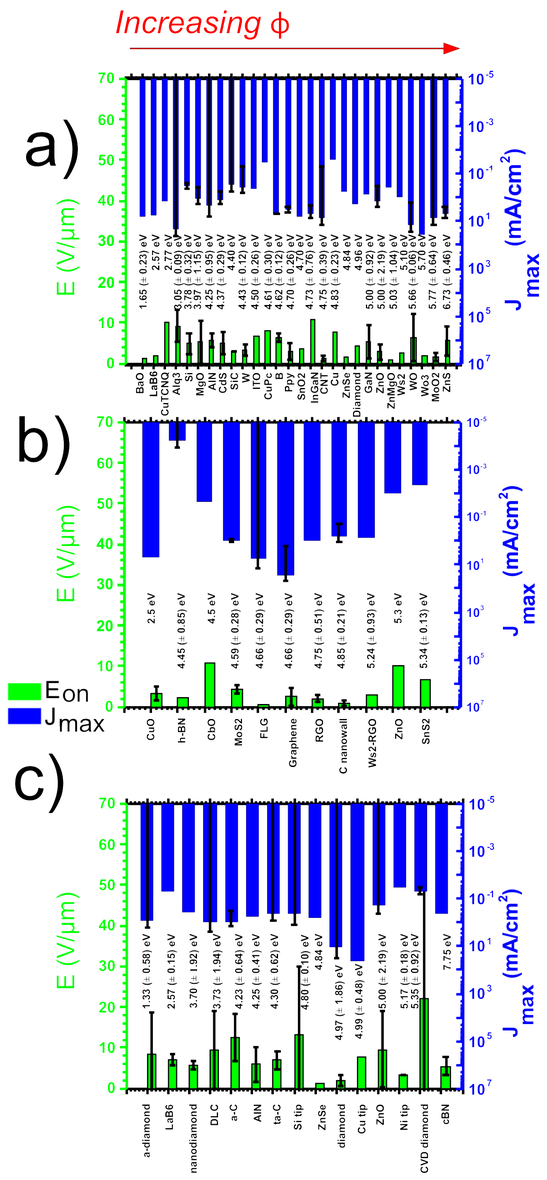
Ordered Nanomaterials



Materials are directly compared by work function, ϕ, in **Figure 1** by setting E_{on}= 0.01 mA/cm² for every emitter.

On average, 1D and 2D materials show similar performance, with < E_{on}> = 4.74 V/µm and 4.21 V/µm respectively. 3D/bulk materials show twice this value, with < E_{on}> = 8.09 V/µm. <J_{max}>, however, was similar in each dimensionality: 1D = 3.61 mA/cm², 2D = 3.31mA/cm² and 3D/bulk = 3.70 mA/cm².

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 2a**.

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

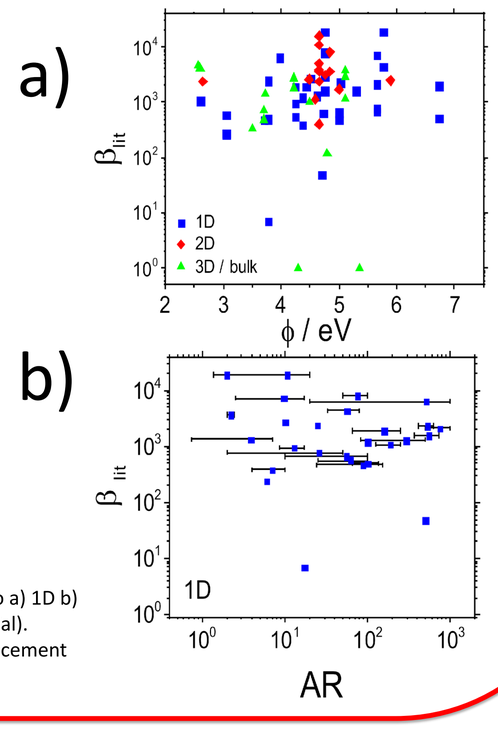


Figure 1 (above). E_{on} and J_{max} for materials according to a) 1D b) 2D and c) 3D/bulk ordered by ϕ (written above material).
Figure 2 (left). a) Work function, ϕ, vs local field enhancement (from the literature), β_{lit} b) Aspect ratio, AR, vs β_{lit}

Influence 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.

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

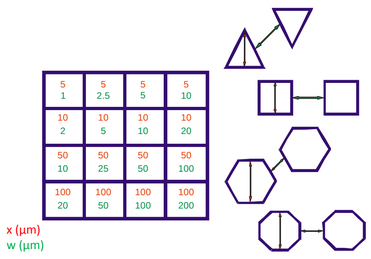
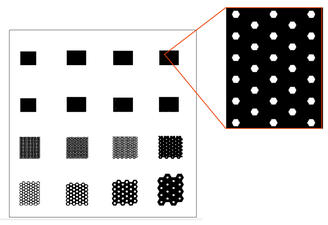


Figure 3: Geometry of chip morphology.

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 spacing seen in different zones.

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



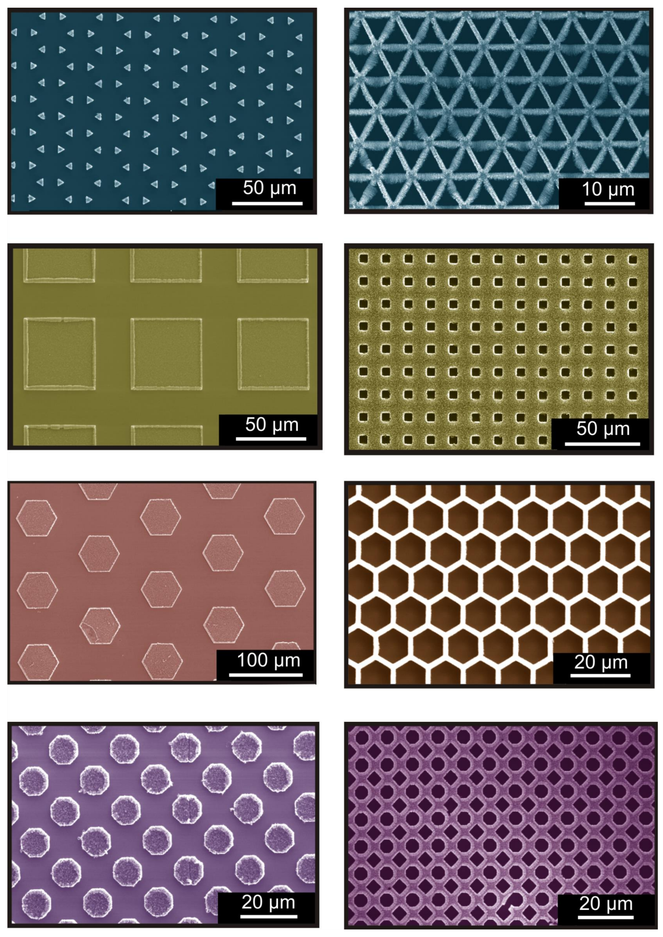


Figure 4 (left): Chip schematic showing different zones. **Figure 5** (right) SEM micrographs of examples from each type of morphology taken from intentionally different zones of a chip.

Scanning Anode Field Emission Microscope (SAFEM)

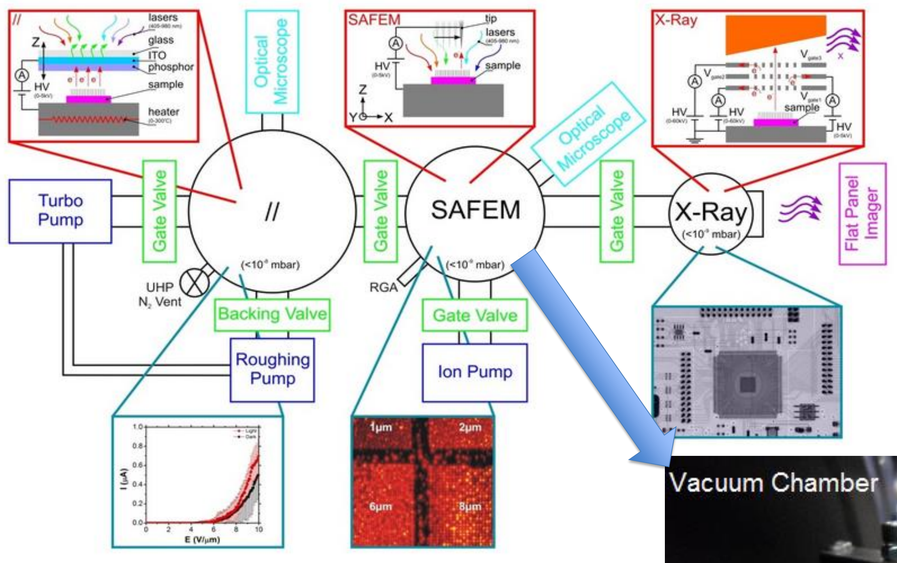


Figure 6 : Schematic of the parallel plate, SAFEM and X-Ray components of the machine.

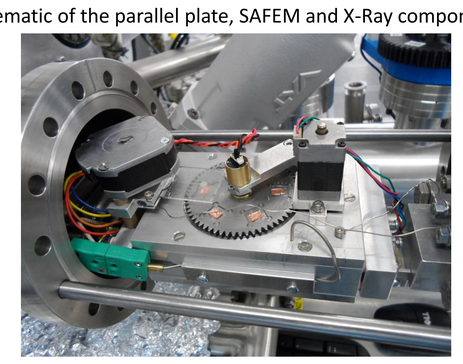


Figure 7: Six samples can be accommodated in the parallel plate set up seen above.

The difference between the parallel plate and SAFEM components of the machine is the area over which they measure. The parallel plates measure the macroscopic field emission from the entire chip, whilst the SAFEM measures field emission from individual locations, building up a map of the emission sites.

Measurements are made on chips that have a variety of morphologies. By building a map of the individual emission sites, information will be revealed about the influence of morphology on field emission capabilities and indeed where emission occurs.

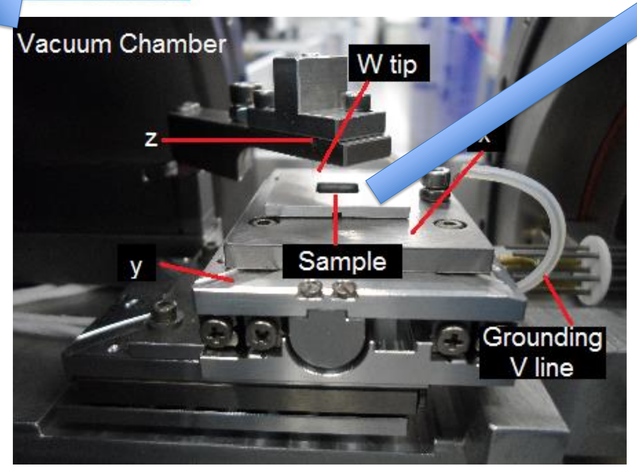


Figure 8: Photograph showing X,Y and Z stages in SAFEM chamber.

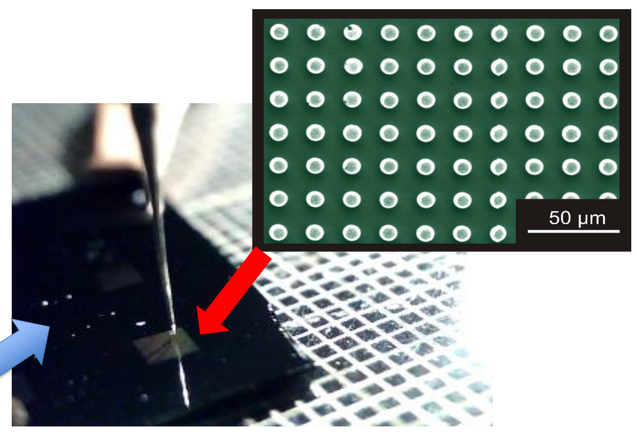


Figure 9: Photograph showing sample inside SAFEM with tungsten tip in place to measure field emission. Top right shows SEM of pillar array being measured.

A map of the electric field distribution is generated using a custom-built 3-axis stage (x, y, z), where x and y move the chip and z moves a tungsten tip. The x and y piezo actuated stage (Physik Instrumente LPS-45) has a step size (in x and y) of 40 nm with a maximum range of 13 mm. The z axis is made using a potassium hydroxide etched tungsten tip, which has a tip diameter of 100 nm, and a controllable step height of 1 µm. The tip scans using a further piezo stage (Physik Instrumente P-601.4S piezo motor equipped with strain gauge and controlled using an E-609 module) with a range of 400 µm and a resolution of 0.2 nm. Measurements are taken in a diode mode, with the tungsten tip positively biased between 0 V and 1100 V using a computer controlled high voltage supply (Keithley 237). Current is monitored using a source-measurement unit, SMU (Keithley 485). Measurements take place at ultra-high vacuum, of 10^{-7} to 10^{-8} mbar.

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