Carbon nanotubes and their application in field emission devices

Edward Boughton[1,2], Wenhui Song[1], Benjamin Jones[2], Robert Bulpett[2], Sabina Orlowska[3], Geoff Sheehy[3], Michael Waite[3], Mike Miller[3]*

1. Wolfson Centre for Materials Processing, Brunel University, Uxbridge, Middlesex, UK
2. Experimental Techniques Centre, Brunel University, Uxbridge, Middlesex, UK
3. TMD Technologies Ltd., Hayes, Middlesex, UK

Introduction

Currently, electron beams are produced by heating a filament to the point where electrons have enough energy to overcome the work function, ϕ. In field emission, the potential barrier is lowered by the strength of the applied field only. Because this requires very high fields, current research focuses on exploiting the local increase in field strength which occurs around a sharp tip. The field enhancement factor, β, measures the degree to which this occurs and is related to the aspect ratio of the tip. In this study β is calculated using a simplified Fowler-Nordheim equation [1]:

$$I = \frac{nA \cdot 1.55 \cdot 10^8 \beta^2 \cdot E^2}{\varphi} \exp\left(\frac{-6.87 \times 10^3 \varphi^{1.5}}{\beta E}\right) \quad (1)$$

Where I is the emission current (µA), ϕ is the work function of the material, E is the applied field (Vμm^{-1}), n is the number of emitting sites, and A is the total emitting area.

Because no heat is required, a field emission electron source can be smaller, lighter, more efficient and have a faster response time than a thermionic filament source, which is advantageous to x-ray machine and high-powered microwave tube applications.

Materials

Multiwalled Carbon nanotubes (MWCNTs) are composed of sheets of hexagonally-arranged carbon atoms rolled-up into nanostructured tubes. Their small size, high aspect ratio and ballistic conductivity mean there is the potential to fabricate a field emission device with low turn-on field, a large number of individual emission sites and a high current density [2].

Type A:

Manufacturer: Rosseter Holdings Ltd.
Length: 200-300nm
Avg. diameter: 8.4nm
Purity: Low. Also includes nano-onions, graphitic carbon and amorphous carbon

Type B:

Manufacturer: Brunel University
Length: ~300µm
Avg. diameter: ~100nm
Purity: 90%

Type C:

Manufacturer: XinNano Materials Inc.
Length: >10µm
Avg. diameter: 7nm
Purity: 88%

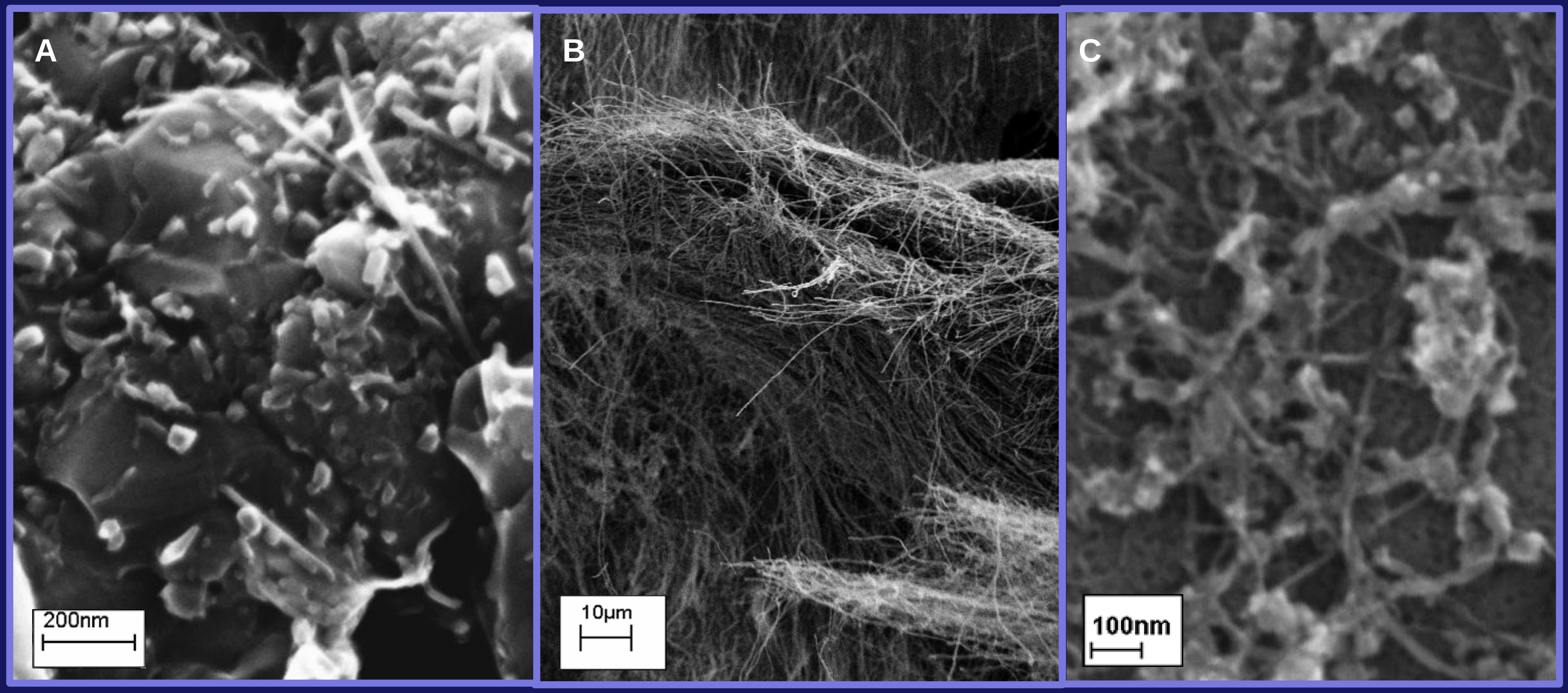

Fig 1: Scanning electron microscope (SEM) images of MWCNT types A, B & C

Fabrication

The MWCNTs are suspended in solvent by ultrasonication. The addition of further solvents and binders results in thick black ink. A screen printer is used to apply a thin layer of the ink to a gold-coated glass slide in the desired pattern. Baking at 450°C in air improves the adhesion of the MWCNTs to the substrate and drives off undesired ink components.

References

1. R. H. Fowler and L. Nordheim, Proc. R. Soc. London, Ser. A. 119, 173 (1928).
2. W.A. de Heer, A. Chatelain and D. Ugarte, Science 270, 1179(1995).

Testing

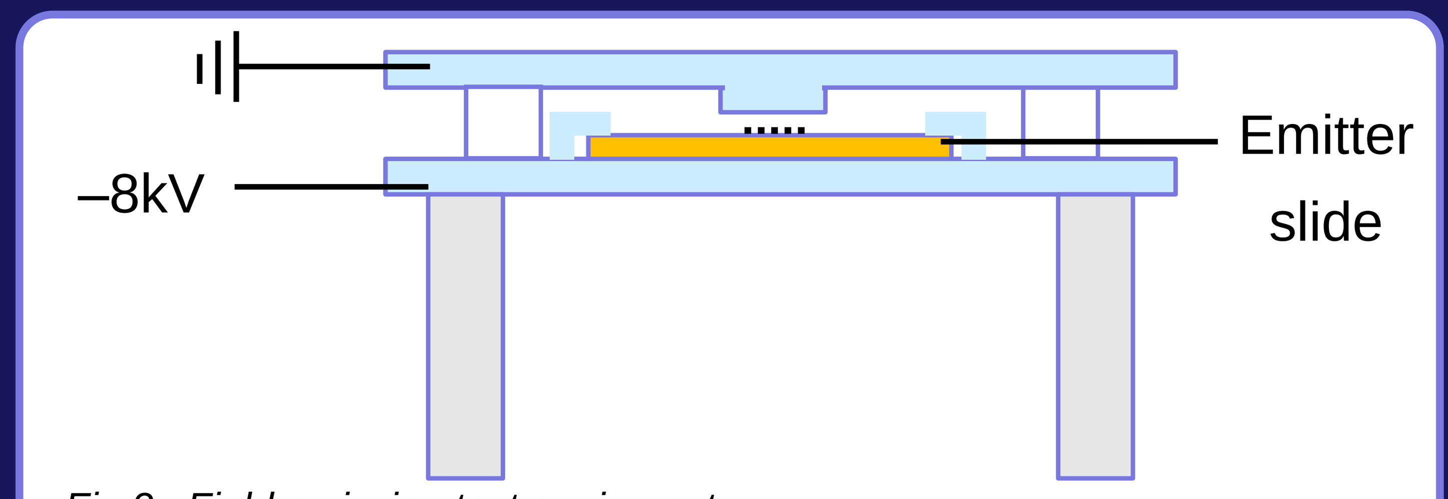

Fig 2: Field emission test equipment

Testing is performed by applying a negative bias to the emitter slide of up to 8kV, relative to an anode which is separated from the emitter by a gap of 200µm in vacuum of 10^{-6} mbar. Bias is increased gradually and the observed emission current recorded using an integrated microammeter.

Results

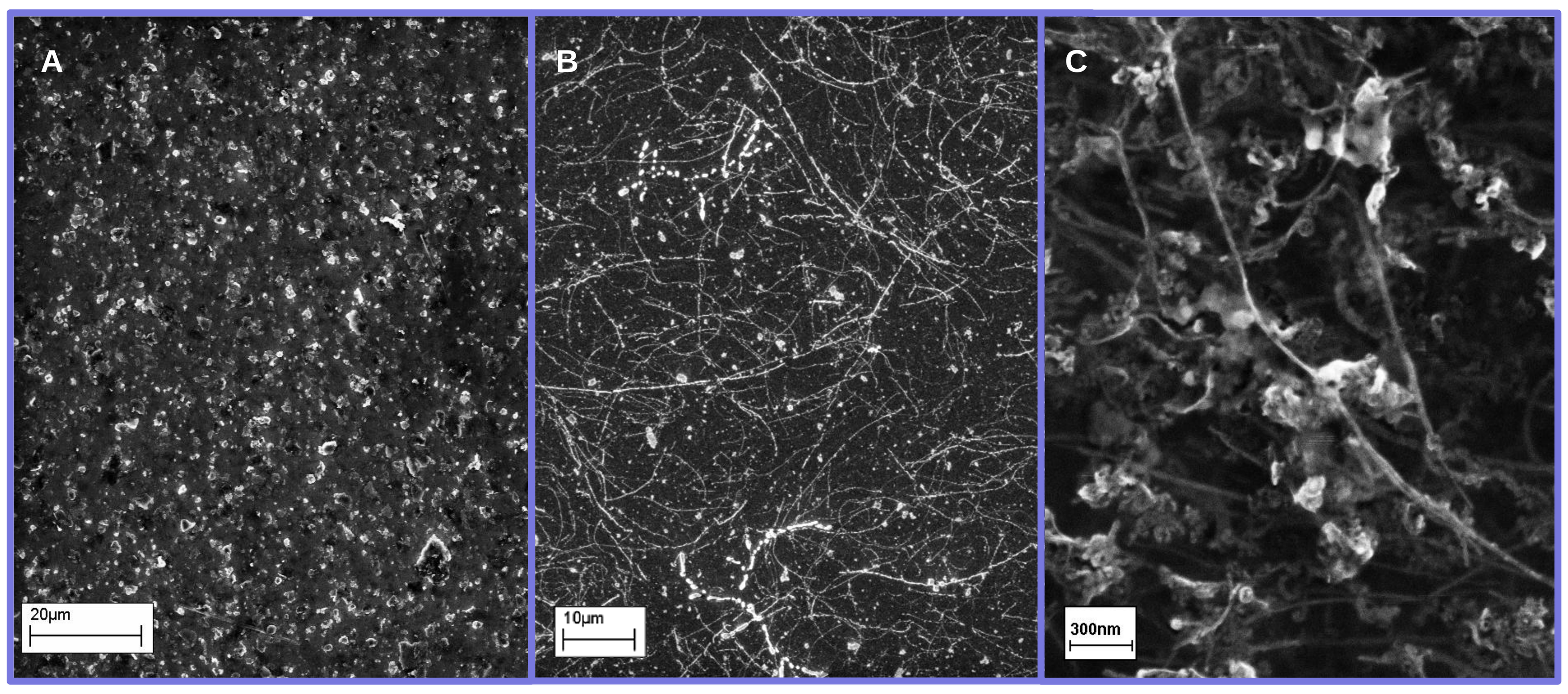

Fig 3: SEM images of field emitters fabricated using CNT types A, B & C

The below plot Fig. 4 shows that type C nanotubes produce the best emitter, with the highest maximum emission current density of 5mAcm^{-2} and a lower turn-on field among the emitters tested. Analysis using equation (1) gives a field enhancement factor for this emitter of 1920. Although type B MWCNTs have the potential to give high β, figure 3 shows that the nanotubes lie flat on the surface. Few sharp tips therefore protrude, and the field enhancement factor is lower than expected.

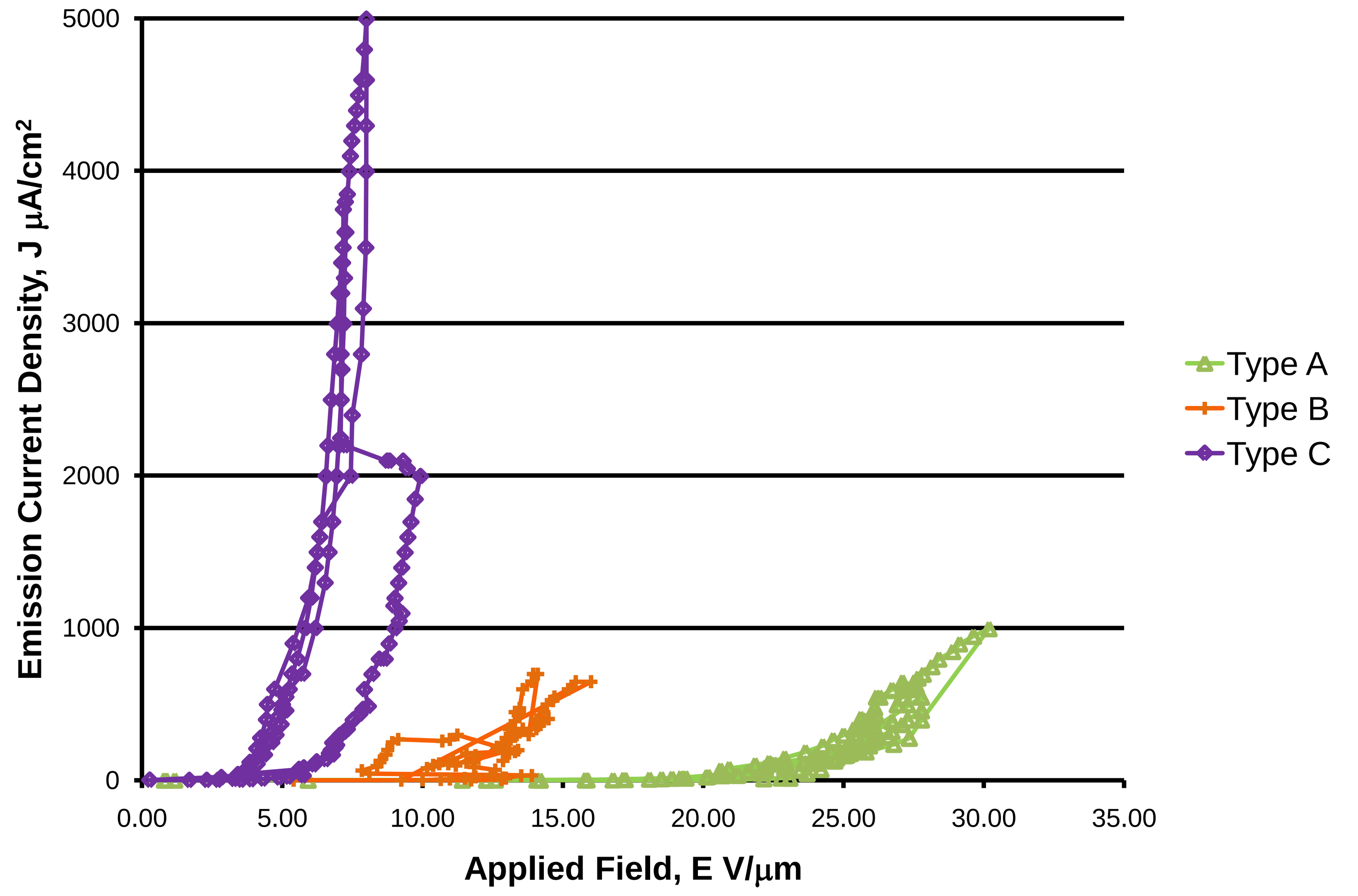

Fig 4: Plot of field emission performance of printed emitters

Conclusion

The superiority of the type C material over type B is attributed to their small size, which allows them to protrude from the surface. The performance of the type A material suffers as a result of the low MWCNT purity. A phosphor screen must be used to evaluate the emitter's uniformity and pulsed-mode testing must be performed to assess the suitability of the material for real-world applications.

Further information: edward.boughton@brunel.ac.uk