Fabrication of 2D Nanomaterial-Based Flexible Electronics

J. P. Millidge[1] & M. T. Cole[1*]

Introduction

Fabrication of wearable devices is transitioning from rigid materials towards lighter, flexible, and more space efficient devices[1].

This project explores the fabrication of electrically conductive thin-films using 2D materials, pushing towards a clearer realisation of flexible and stretchable, near-transparent electronic skin.

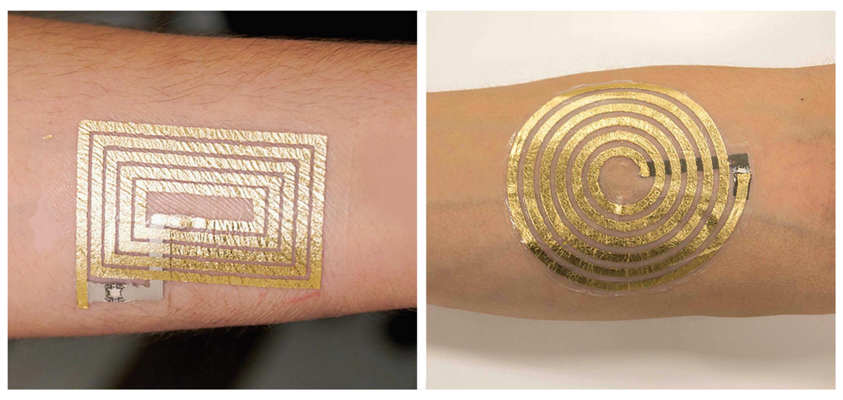

Figure 1. DuoSkin: skin friendly NFC circuit fabricated from gold leaf [2].

Graphene Ink Production

A high-yield, simple, and scalable graphene ink production was developed and conducted as part of the project; based on the liquid-phase exfoliation of graphite powder with surfactant assistance. In total, approximately 600 mL of graphene ink was produced.

The surfactant, sodium cholate was chosen via a decision matrix based on occurrence in literature, toxicity, cost per usage, and availability [3]

Figure 2 presents the pictorial stages of LPE of graphite powder to produce graphene dispersion (ink): a) ultrasonication of graphite power, b) sonicated graphene solution w/ aggregates, c) centrifugation to separate aggregates, d) bottled graphene ink.

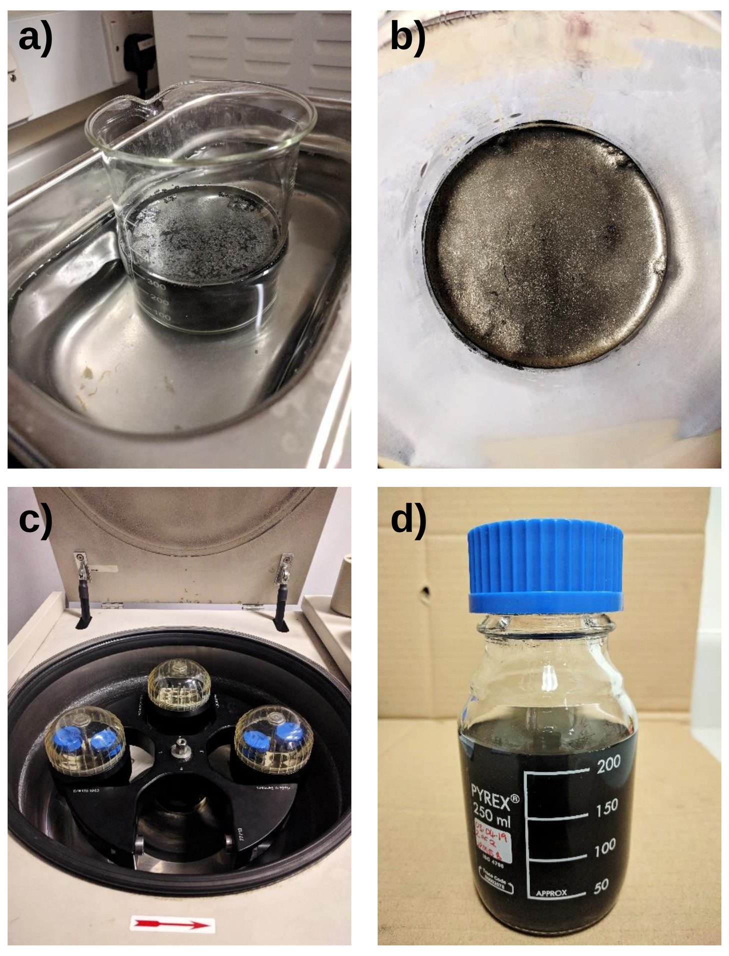

Figure 2. Pictorial stages of graphene ink production by liquid-phase exfoliation (LPE).

Ink Application

Spray deposition was chosen due to simplicity, scalability, and low equipment/setup costs.

Alternative Methods:
- Inkjet printing - were unreliable and inconsistent yet yielded the image in **Fig.6**)
- Langmuir-Blodgett (**Fig.5b**) - expensive and time inefficient

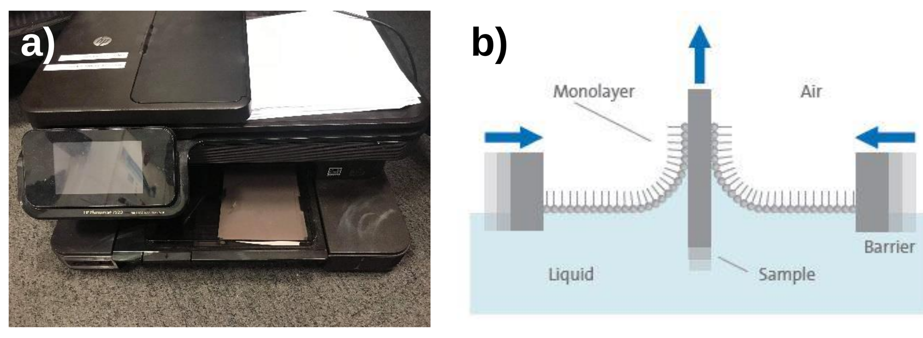

Figure 5. Alternative ink deposition methods: a) inkjet printing, b) Langmuir-Blodgett.

Figure 3. Air compressor driven spray gun used to vaporise graphene ink

Figure 6. Bath Uni logo printed with graphene ink using inkjet printer (**Fig.5a**).

Hydrophilic Treatment:
To increase adhesion between the graphene ink and the glass surface:
- UV radiation
- Piranha etch solution

Experiments Conducted:
- Time series
- Multilayer series (1 to 10 layers)

Outcome: Piranha solution was found to enable a more contiguous ink coating on the substrate.

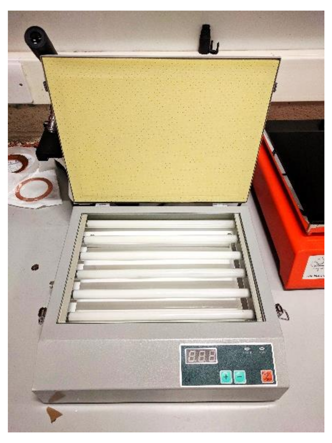

Figure 4. UV light box used to apply hydrophilic treatment to glass substrates.

Sample Capture:
Images were captured systematically (**Fig.7**) using microscope w/ integrated digital camera

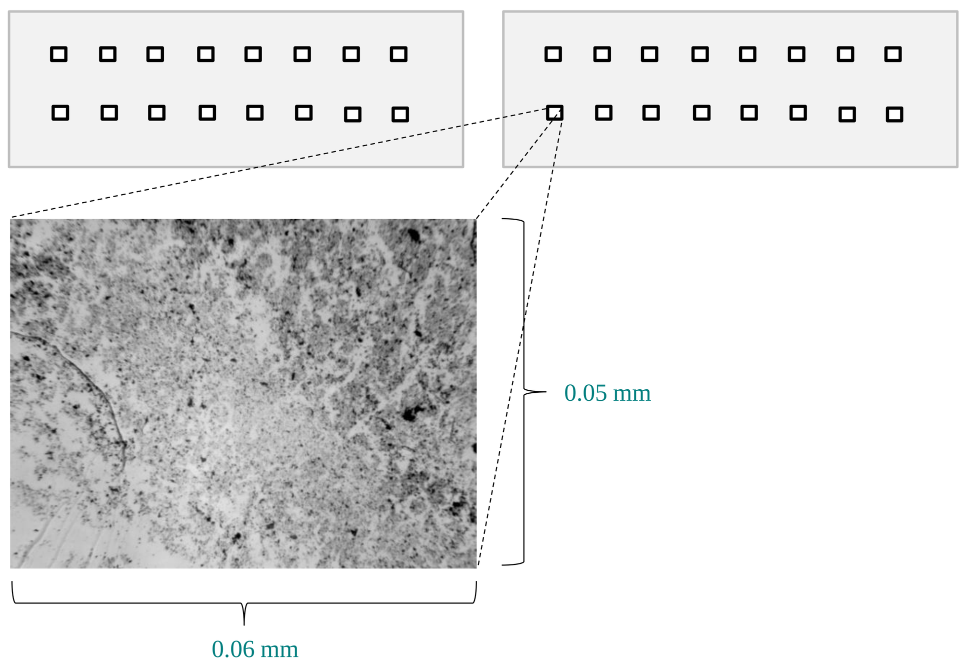

Figure 7. Schematic to demonstrate method of sample image capture from glass slides.

Analysis & Discussion

Image Analysis: Sample images were analysed in ImageJ to produce the following data:
- Diameter of "coffee-stain" ink depositions
- Percentage area coverage
- Transmission spectroscopy

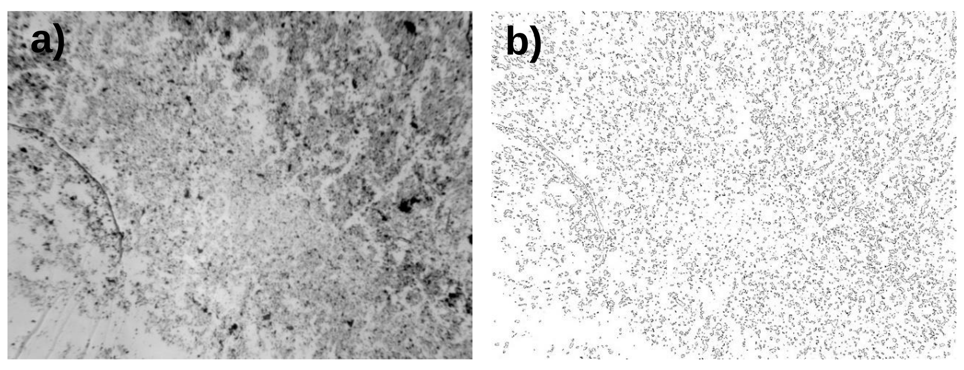

Figure 8. Percentage area coverage calculation using ImageJ **a)** Original Image **b)** Particle analysis image.

Outcomes:
- Strong positive correlation between duration of UV radiation exposure and diameter of deposition & area coverage
- Increasing durations of exposure to piranha solution led to a small increase of area coverage - i.e. the desired effect was rapidly achieved
- The multilayer investigation demonstrated a positive linear correlation with increasing layers. A contiguous layer of ink could be created over an area of ~0.1 mm² - However, yielded unreliable DC measurements

Transmission Spectroscopy: Using image analysis techniques the population of graphene monolayers was estimated for a 10-layer deposition:

- **Monolayer** = ~ 4 %
- **≤5** = 22 %
- **≤10** = 25%

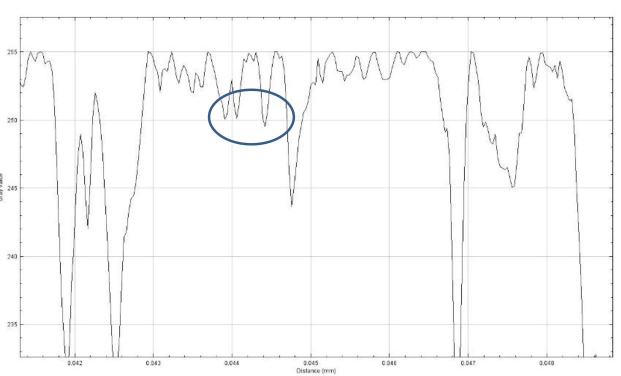

Figure 9. Plot of greyscale values (ImageJ) from sample image.

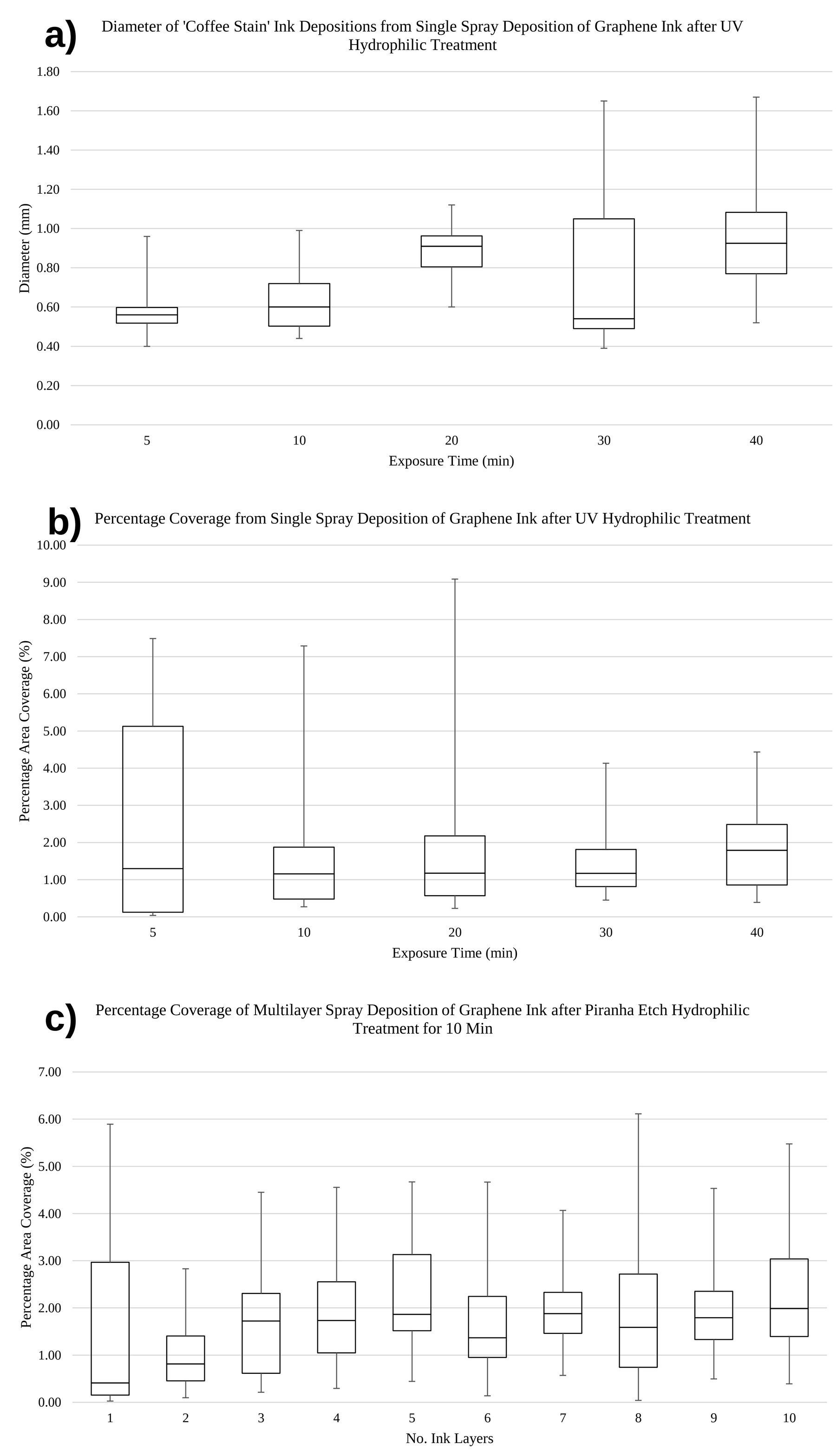

Figure 10. Presented results: a) b) UV hydrophilic treatment, c) Multilayer Piranha.

References

[1] S. J. Kim, K. Choi, B. Lee, Y. Kim and B. H. Hong, "Materials for Flexible, Stretchable Electronics: Graphene and 2D Materials," Annual Reviews, Seoul, 2015.

[2] H.-L. Kao, C. Holz, A. Roseway, A. Calvo and C. Schmandt, "DuoSkin: Rapidly Prototyping On-Skin User Interfaces Using Skin Friendly Materials," ACM, Heidelburg, 2016.

[3] P. J. K. M. L. A. O. E. M. D. Y. H. G. S. D. J. N. C. Sukanta De, "Flexible, Transparent, Conducting Films of Randomly Stacked Graphene from Surfactant-Stabilized, Oxide-Free Graphene Dispersions," small (nano, micro), vol. 6, no. 3, pp. 458-464, 2010.

[4] Biolin Scientific, "The Deposition and Characterization of Single Sheet Graphene Films," AZO Materials, 06 10 2014. [Online]. Available: https://www.azom.com/article.aspx?ArticleID=11433. [Accessed 02 05 2019].

Acknowledgements

Dr Matthew Cole, Sivapathasundaram Sivaraya and the Nanomaterial research group for their mentorship, support and supervision.

Department of Electronic & Electrical Engineering

UNIVERSITY OF BATH

[1] Department of Electronic & Electrical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom

* mtc47@bath.ac.uk