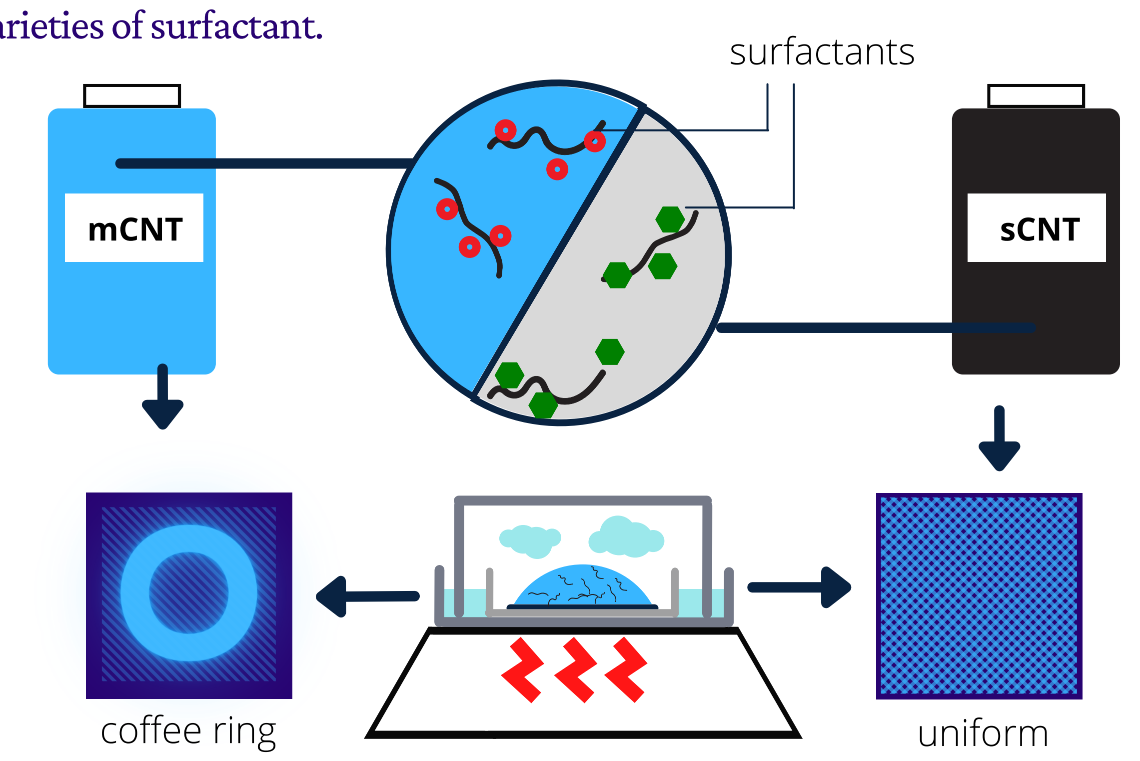
Exploring methods to deposit metallic carbon nanotubes

Intro

Carbon nanotubes (CNTs) are at the forefront of physics due to their electrical properties - showing either semiconducting (sCNT) or conducting/metallic (mCNT) behaviour. Creating continuous, transparent mCNT networks are advantageous in solar cells and other advanced electronics[1]. It was found that the standard deposition method for sCNT suspensions didn't work for mCNTs, so new deposition methods were needed. After finding a successful method, a conductive device made of acetate film was created — with the help of AFM (atomic force microscopy), electrical and optical measurements.

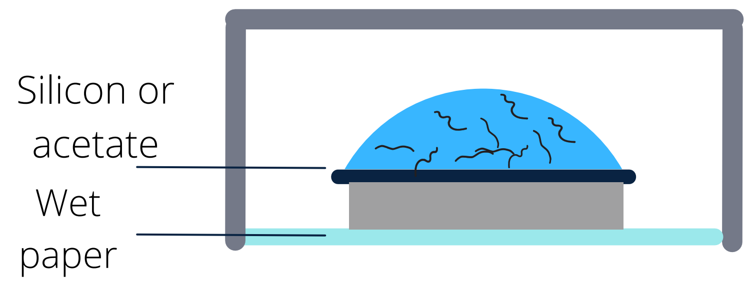
The Problem

The carbon nanotubes are suspended in water by chemicals called *surfactants* . Without them, the CNTs would bundle together, making a continuous deposition impossible. However, sCNT and mCNT suspensions use different varieties of surfactant.



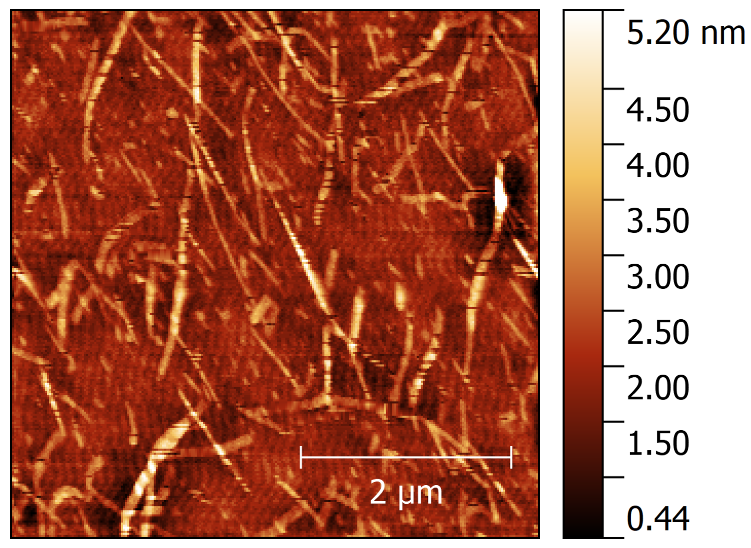
The CNT solution slowly evaporates in a "steam oven", but where the sCNT produces a uniform deposition, the mCNT produces a **coffee ring**[2] bundle due to the different surfactants, and this is not ideal for electrical devices. This is why three new methods to create a uniform mCNT deposition were tested.

Method 1: Meniscus Deposition



100 microlitres of mCNT solution is deposited on the substrate.

- It is covered with a beaker, where wet paper underneath keeps evaporation to a minimum.
- It is then left for a total of 24 hours.



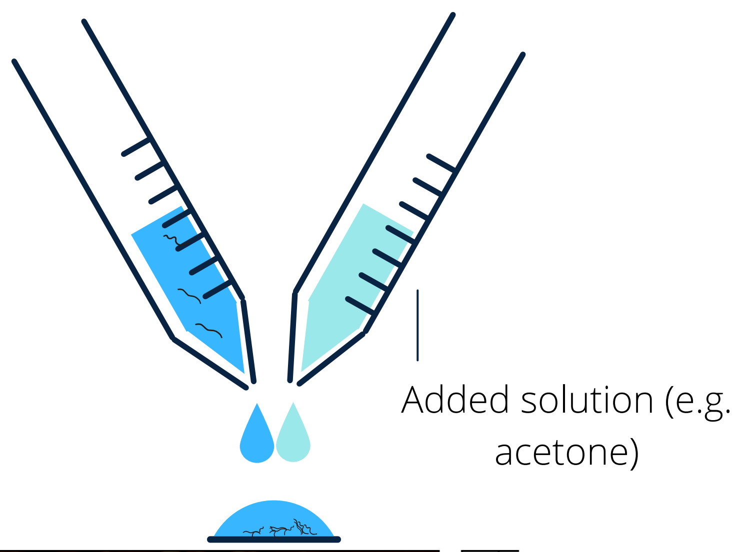
AFM image of mCNTs deposited on a silicon chip

The result: This mCNT network on silicon was not dense enough to create a uniformly conducting device. CNTs fail to stick to transparent acetate too.

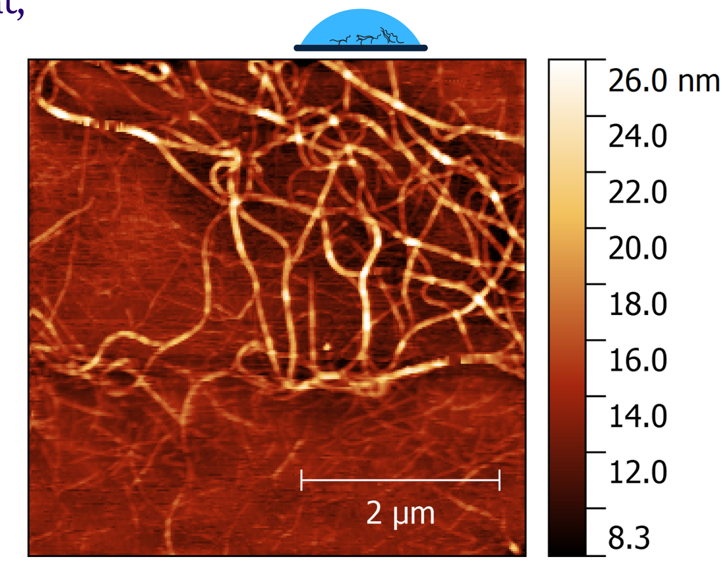
Method 2: Immediate Flocculation

A total 100 microlitres of solution is deposited on the substrate, made up of mCNT solution and another added liquid:

- Acetone and isopropyl alcohol remove surfactants, causing CNTs to "crash out of solution" (or flocculate).
- Water does not remove surfactant, but alters the ratio of CNT to surfactant, encouraging flocculation.

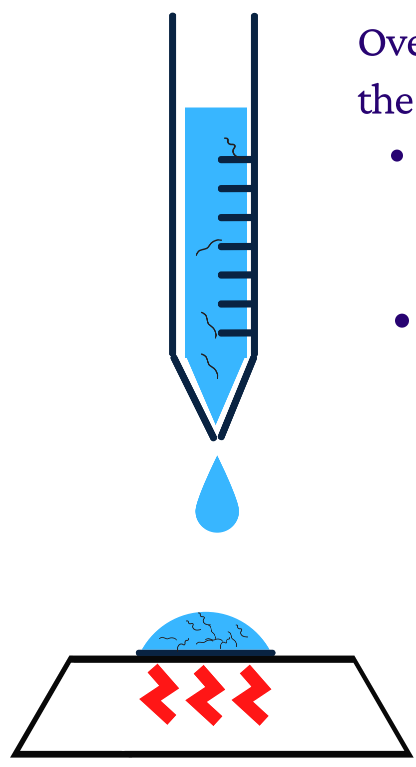


The result: The CNT network on silicon is bundled up in some places but absent from others, failing to form a uniform conductive chip. On acetate, CNTs did not stick to the surface.



AFM of an mCNT solution and isopropyl alcohol application (50 microlitres each) on a silicon chip corner

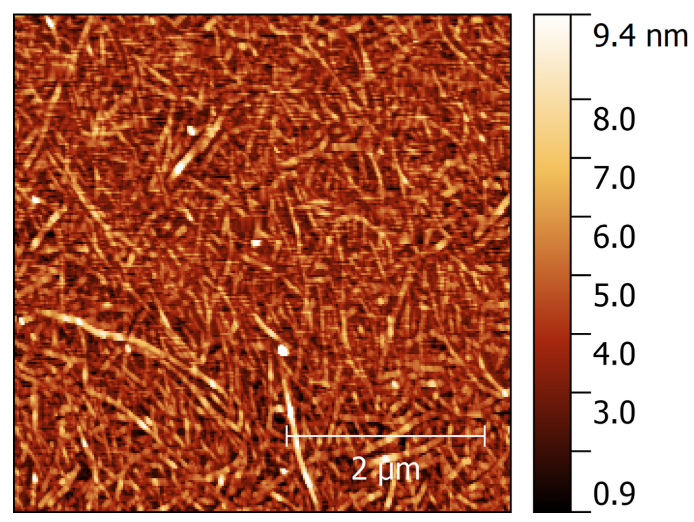
Method 3: Running Evap-Reapplication



Over a 1½-hour period, mCNT solution is applied on the substrate while being heated at 40-50 °C.

- Constant reapplication of solution when the meniscus is flat ensures that it never dries up completely, avoiding the coffee ring effect.
- CNTs concentrate and deposit as water is driven off.

The result: As shown in the AFM, the CNT networks are dense and uniform, leading to an electrically conductive silicon device (average resistance ~ 10 kΩ)



AFM of a silicon chip using this method with mCNT solution

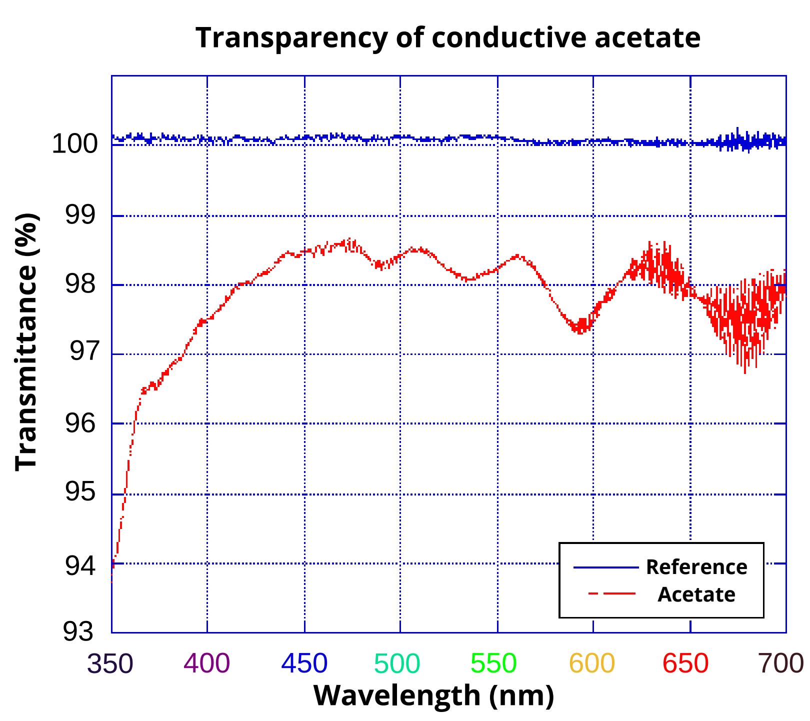
Conclusion

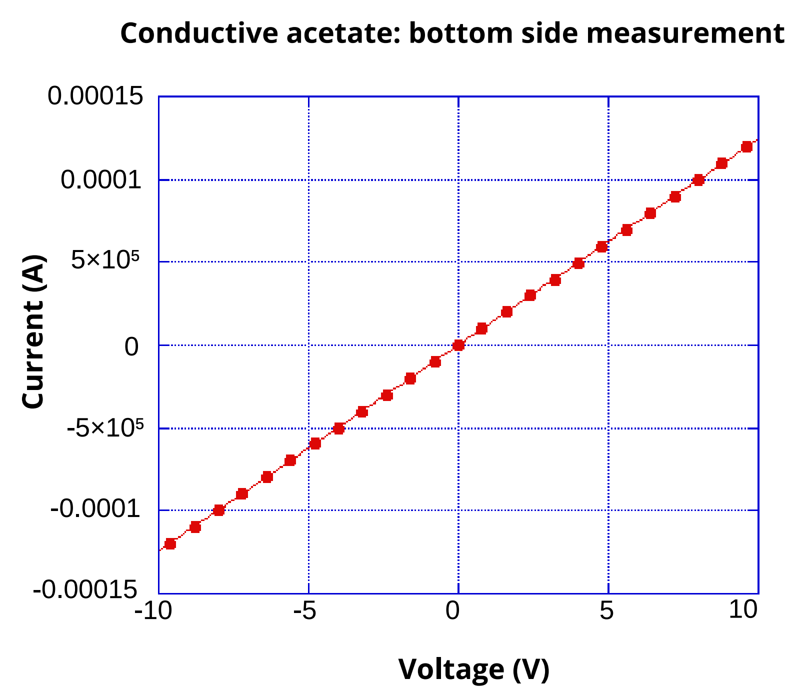
While the first two methods did deposit some mCNTs on silicon, they did not create a conductive mCNT network on transparent materials like acetate. Running evap-reapplication worked the best for silicon, and it was shown to be the only method to work on acetate. This is because mCNTs become concentrated and are forced to deposit as the water evaporates. Further optimisation of this process is required to create devices with higher conductivity.

Liam Anderson, Dr. Natalie Plank (supervisor), Erica Happe (supervisor) - Victoria University of Wellington School of Chemical and Physical Sciences

Conductive acetate using Running Evap-Reapplication

Electrical measurements used the "two point probe" method, measuring the resistance of each side of the acetate slide, showing high transparency (98.4% at 500 nm) with an average side resistance of ~ 200 kΩ.





VICTORIA UNIVERSITY OF WELLINGTON TE HERENGA WAKA

References

[1] Du, J., Pei, S., Ma, L., & Cheng, H.-M. (2014). 25th anniversary article: Carbon nanotube- and graphene-based transparent conductive films for optoelectronic devices. Advanced Materials, 26(13), 1958–1991. https://doi.org/10.1002/adma.201304135

[2] Bishop, M. D., Hills, G., Srimani, T., Lau, C., Murphy, D., Fuller, S., Humes, J., Ratkovich, A., Nelson, M., & Shulaker, M. M. (2020). Fabrication of carbon nanotube field-effect transistors in commercial silicon manufacturing facilities. Nature Electronics, 3(8), 492–501. https://doi.org/10.1038/s41928-020-0419-7