High-throughput, automatic and roboust identification of graphene and similar 2D thin-film materials in digital images. (Jessen, 2012)

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The experimental isolation of a single-layer of graphene by the Manchester group in 2004 has paved the way for an entire family of new truly two-dimensional (2D) materials including graphene, hexagonal boron nitride, and molybdenum disulphide. While they are truly fascinating materials each in its own right, a major bottleneck in using these materials for research purpose lies in the need for manual identification after mechanical exfoliation, where especially single-layer identification can be challenging due to low visibility. Furthermore, since the identification is manual different researchers often does not find the same flakes on the same wafers, thus lowering the effective yield.

To overcome this bottleneck there is thus a need for an automated, simple, reliable, and efficient way of identifying graphene and other thin-film materials in a digital image.

The contrast of 2D materials can be accurately modelled with the optical transfer matrix method (P. Blake, 2007). This yields the contrast as a function of wavelength and often serves as a guideline for researchers to choose an appropriate substrate. To describe the colours in a digital image, namely red, green and blue (RGB), it is necessary to couple this to the actual microscope used through the numerical aperture, light bulb spectra and charge coupled device (CCD) sensor spectral sensitivities (Guild, 1931). This provides an accurate framework for predicting the actual RGB values of the pixels corresponding to a given 2D material, as illustrated with single-layer graphene in figure 1.

Having obtained digital images of a wafer with e.g. graphene it is possible to accurately extract the pixels with graphene though dynamic background detection and careful application of image processing filters such as median smoothing, dilate, erode, and thesholding. This enables the identification of parts of an image containing e.g. single-layer graphene while removing false-positives such as graphite shadows, dirt, tape residues, etc, as shown in figure 2. Applying an edge-detection algorithm it is possible to extract quantitative information such as size, shape, along with defects and rips, allowing automatic selection of suitable flakes for further processing. Having accurate, digital representations of graphene flakes also allow for direct import into CAD programs significantly easing the design phase of device fabrication.

In summary it has been explained how the contrast of 2D thin film materials such as graphene, hexagonal boron nitride and molybdenum disulphide can be accurately mapped into the RGB colour-space as represented in digital images. By the application of dynamic background detection, various image processing filters and an edge-detection algorithm it is possible to automatically and with a high-throughput accurately detect individual layers of 2D thin film materials while gaining quantitative data about various properties such as size, shape, number of layers etc. This greatly speeds up basic research using novel 2D materials as the individual flakes moves from being scarce to being a commodity resource. Finally, the method only requires an optical microscope with a CCD camera and a programmable XY stage, relatively cheap equipment which are already found in most research labs.

Bibliography

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Guild, T. S. (1931). The C.I.E. colorimetric standards and their use. *Transactions of the Optical Society*, 73.

P. Blake, E. W. (2007). Making graphene visible. *Applied Physics Letters*, 063124.

Figures

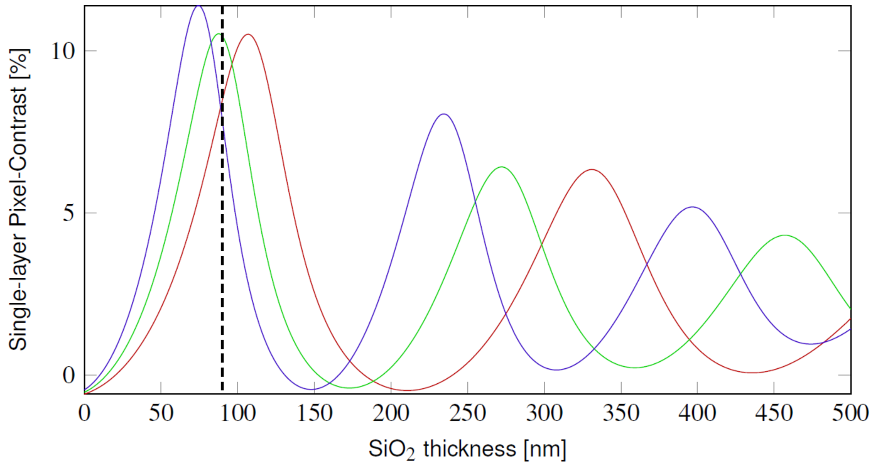

Figure 1 - Red, green and blue pixel-contrast of single-layer graphene on a SiO2/Si substrate as a function of varying thickness of SiO2. The dashed line is at 90 nm SiO2, a commonly used thickness for identifying graphene.

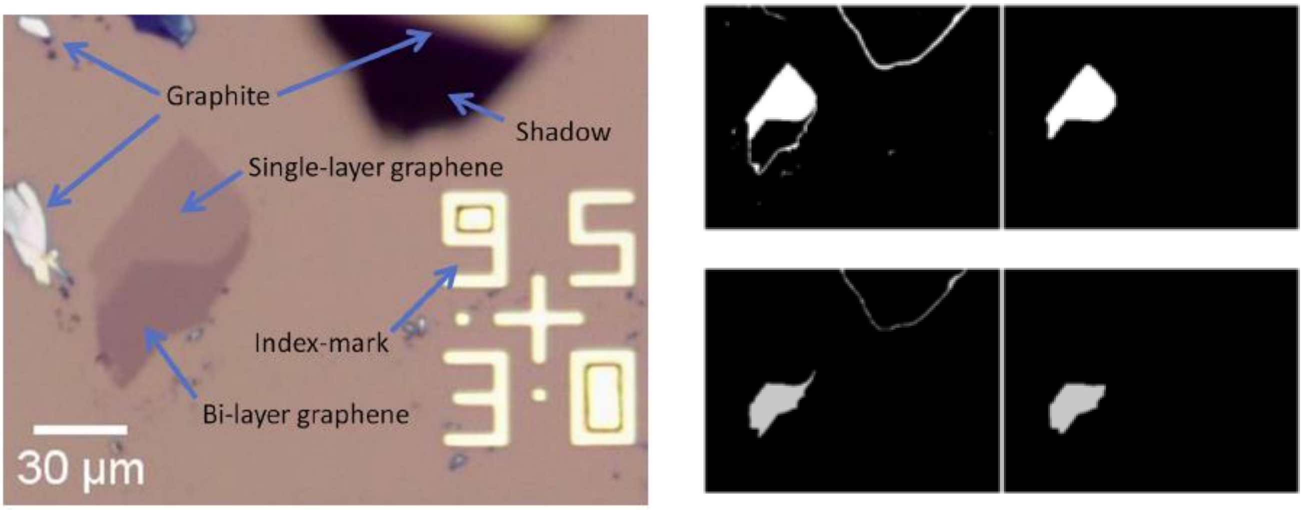

Figure 2 –(a) Image of single- and bi-layer graphene on a substrate of 90 nm SiO2 on Si. The image also contains graphite, shadows, index marks and residues, all typical to samples with mechanically exfoliated graphene. (b) digital representation of single- and bi-layer graphene after post processing of the digital image. False-negatives are removed, and the final shape is detected with an edge-detection algorithm.