

# Standardisation of the measurement of graphene and related two-dimensional materials: Status and Learnings

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**Andrew J. Pollard**

National Physical Laboratory (NPL), Teddington, UK  
[andrew.pollard@npl.co.uk](mailto:andrew.pollard@npl.co.uk)

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Many different graphene related two-dimensional materials (GR2Ms) from different commercial suppliers are now in real-world products used around the world. However, without an understanding of the properties of the materials available in the supply chain, both these and new applications cannot be efficiently developed and improved. Thus, there is a need for reliable, accurate and precise measurements for material testing, which are standardised across the industry and therefore allow end-users to be able to compare commercially-available materials from around the world.

Over several years a set of international standards have been developed within ISO TC229 'Nanotechnologies', in a joint working group alongside IEC TC 113, to include the techniques and procedures for measuring the material properties of GR2Ms, such as chemical vapour deposition (CVD) produced graphene, graphene nanoplatelets (and different chemically-functionalised versions thereof), reduced graphene oxide and graphene oxide[1].

To ensure the accuracy of these measurement protocols so they can be undertaken with known uncertainties, fundamental metrology studies and international interlaboratory comparisons must be undertaken. These allow an improved understanding of the sources of uncertainty, how to reduce these uncertainties and ultimately the size of the uncertainties that can be expected in these measurements, when comparing products measured the same way, but in different laboratories around the world.

These studies have highlighted many improvements in the techniques included in international measurement standards, such as atomic force microscopy (AFM)[2], Raman spectroscopy [3], X-ray photoelectron spectroscopy (XPS)[4], gas physisorption (using the Brunauer-Emmett-Teller (BET) method)[5], thermogravimetric analysis (TGA)[6] and electron microscopy. Both the standardisation landscape and learnings from these studies will be discussed herein.

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## References

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