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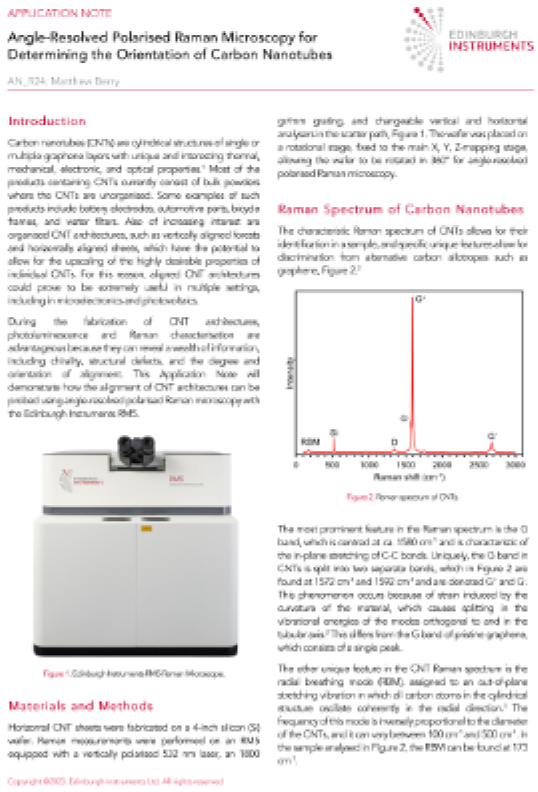
APPLICATION NOTE

Angle-Resolved Polarised Raman Microscopy for Determining the Orientation of Carbon Nanotubes

EDINBURGH INSTRUMENTS

AN_R24; Matthew Berry

Introduction

Carbon nanotubes (CNTs) are cylindrical structures of single or multiple graphene layers with unique and interesting thermal, mechanical, electronic, and optical properties.[1] Most of the products containing CNTs currently consist of bulk powders where the CNTs are unorganised. Some examples of such products include battery electrodes, automotive parts, bicycle frames, and water filters. Also of increasing interest are organised CNT architectures, such as vertically aligned forests and horizontally aligned sheets, which have the potential to allow for the upscaling of the highly desirable properties of individual CNTs. For this reason, aligned CNT architectures could prove to be extremely useful in multiple settings, including in microelectronics and photovoltaics.

During the fabrication of CNT architectures, photoluminescence and Raman characterisation are advantageous because they can reveal a wealth of information, including chirality, structural defects, and the degree and orientation of alignment. This Application Note will demonstrate how the alignment of CNT architectures can be probed using angle-resolved polarised Raman microscopy with the Edinburgh Instruments RM5.

Figure 1. Edinburgh Instruments RM5 Raman Microscope.

Materials and Methods

Horizontal CNT sheets were fabricated on a 4-inch silicon (Si) wafer. Raman measurements were performed on an RM5 equipped with a vertically polarised 532 nm laser, an 1800 gr/mm grating, and changeable vertical and horizontal analysers in the scatter path, Figure 1. The wafer was placed on a rotational stage, fixed to the main X, Y, Z-mapping stage, allowing the wafer to be rotated in 360° for angle-resolved polarised Raman microscopy.

Raman Spectrum of Carbon Nanotubes

The characteristic Raman spectrum of CNTs allows for their identification in a sample, and specific unique features allow for discrimination from alternative carbon allotropes such as graphene, Figure 2.[2]

Figure 2. Raman spectrum of CNTs.

The most prominent feature in the Raman spectrum is the G band, which is centred at ca. 1580 cm^{-1} and is characteristic of the in-plane stretching of C-C bonds. Uniquely, the G band in CNTs is split into two separate bands, which in Figure 2 are found at 1572 cm^{-1} and 1592 cm^{-1} and are denoted G^- and G^+. This phenomenon occurs because of strain induced by the curvature of the material, which causes splitting in the vibrational energies of the modes orthogonal to and in the tubular axis.[2] This differs from the G band of pristine graphene, which consists of a single peak.

The other unique feature in the CNT Raman spectrum is the radial breathing mode (RBM), assigned to an out-of-plane stretching vibration in which all carbon atoms in the cylindrical structure oscillate coherently in the radial direction.[3] The frequency of this mode is inversely proportional to the diameter of the CNTs, and it can vary between 100 cm^{-1} and 500 cm^{-1}. In the sample analysed in Figure 2, the RBM can be found at 173 cm^{-1}.

Angle-Resolved Polarized Raman Microscopy for Determining the Orientation of Carbon Nanotubes

Determining the orientation of carbon nanotubes can expose crucial structural information about the material, which can help explain its properties and potential applications. A technique used to investigate this is angle-resolved polarized Raman microscopy. Carbon nanotube architectures are valuable in several technologies because of their attractive properties. Raman spectroscopy can analyze many properties of carbon nanotubes, including strain, diameter, and defects. Angle-resolved polarized Raman microscopy can determine carbon nanotube architectures' orientational axis and relative alignment.

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