Carbon nanotubes (CNTs) exhibit unique physicochemical properties that have led to their use in a variety of novel materials science applications. Despite rapid progress in the theoretical and experimental investigation of CNTs, techniques capable of studying the structural and electronic properties of individual tubes are limited. Here, the spectral signature of carbon is used to identify the electronic character of individual single-walled CNTs. In addition, a newly built laser-TEM system is used to study light-induced structural and electronic distortions in individual CNTs.

Using high-resolution EELS, we differentiate metallic and semiconducting SWCNTs based on the fine structure of the recorded carbon K edge [1]. While the overall features in the C-K edge are similar for metallic and semiconducting tubes, differences are observed in the fine structure of the π* peak between 284 and 286 eV (Fig. 1): semiconducting nanotubes have a shoulder to the left of the π* peak, metallic to the right. Results from scanning transmission X-ray microscopy performed on the same electronically pure SWCNTs are in good agreement with EELS and are of comparable spectral resolution. The quality of the EEL spectra of individual SWCNTs opens up the possibility to probe the electronic state of single-SWCNT devices.

The study of light driven electronic and structural changes in matter is fundamental to understanding materials properties and performance. While ultra-fast and time-resolved experiments provide unique information based on measurements from very short-time intervals, not much is known on the steady-state response of nanomaterials to an intense continuous beam of light [2]. To address this, a unique system has been built to deliver a focused and continuous laser spot coincident with the electron beam inside a TEM. The laser-TEM system allows the study of structural and electronic modifications in nanomaterials under intense light irradiation. Structural and electronic distortions in individual CNTs have been studied in-situ [3]. When illuminated, a multi-walled CNT expands radially with coupled changes in its σ* conduction band (Fig. 2), as well as in its π* plasmon spectral band. Such observations may aid our understanding of the unique photoconductivity and luminescence properties of CNTs.


Acknowledgement: D.R. acknowledges support from the University of Cambridge and the Royal Society in the form of a Newton International Fellowship.
Fig. 1: Differentiating between individual metallic (a) and semiconducting (b) SWCNTs by their EELS carbon K edge (c).

Fig. 2: (a) The boxed region of a multi-walled CNT extending over a hole in the support grid selected for analysis (b) contains 12 tubules and is free of any obvious defects. (c) Changes in the C-K edge of the tube during laser illumination are strongest in the vicinity of the $\sigma^*$ peak and are fully reversible.