Atomic scale characterization of carbon nanotubes combining transmission electron microscopy and deep learning image analysis

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In the recent years, major breakthroughs were accomplish in single wall carbon nanotubes (SWCNTs) based microelectronics, which has become one of the best candidates to produce beyond-silicon electronic systems [1]. This new technology requires a high level of control over the chirality of SWCNTs, which determines their semiconducting properties. Recently, advanced in-situ optical observations evidenced the complex relationship between the growth rate and chirality of SWCNTs grown by catalytic chemical vapour deposition (C−CVD) [2]. In-depth structural analysis of the SWCNTs identified by the in-situ analysis is now needed for further understanding of the chiral selectivity related to the growth kinetics. High-resolution transmission electron microscopy (HR-TEM) is the most powerful technique to assess local chirality of SWCNTs at the atomic scale. However, combining in-situ optical observations and ex-situ TEM characterization faces two main challenges: i) observation of a single SWCNT of interest by both techniques and ii) a fast determination of chirality from TEM images for high information throughput. Here, we present a unique and powerful characterization process for chirality assessment. This includes an original sample transfer protocol, which allows the localization of a targeted SWCNT inside the TEM. Then a deep learning algorithm [3] enables the fast chiral determination as well as their detailed atomic models directly from single TEM phase images. These observations are expected to help refine our current CNT growth models, by correlating CNTs' local structure with their growth kinetic.

References

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[3] Förster, G. D., et al. (2020). A deep learning approach for determining the chiral indices of carbon nanotubes from high-resolution transmission electron microscopy images. *Carbon*, *169*, 465-474.

Figures

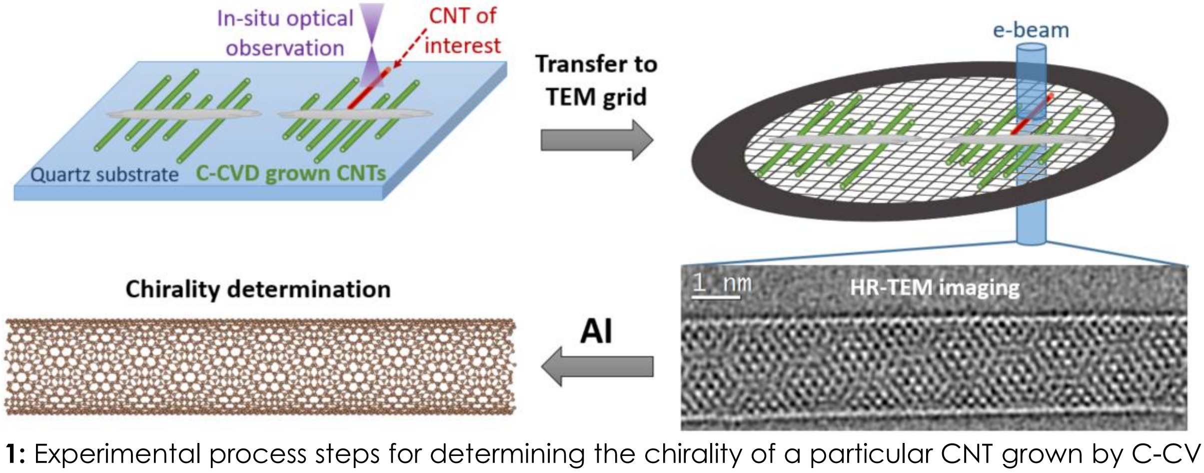

Figure 1: Experimental process steps for determining the chirality of a particular CNT grown by C-CVD on a quartz substrate.