Quantifying crystallinity in carbon nanotubes and its influence on material properties.

Krister Svensson[1] and Mattias Flygare[1]

[1]*Department of engineering and physics, Karlstad University, SE-65188 Karlstad, Sweden*

Corresponding author: krister.svensson@kau.se

Carbon nanotubes have promising material properties, but these rely on a high crystallinity of the produced materials. Properties such as mechanical stiffness and overall behavior has been shown to vary substantially between different production methods [1] and there is a need for a better understanding and quantification of the crystallinity and its influence on material properties.

Here we show how transmission electron microscopy (TEM) can be used both to quantify the crystallinity of individual nanotubes as well as determine the influence of material properties, such as mechanical behavior and electrical conductance. By using electron diffraction, we can obtain effective crystallite sizes L_a in the graphene layers of multiwalled nanotubes [2]. We proceed by linking this to the mechanical and electrical behavior, and we see a profound influence on both.

We have found that the mechanical stiffness varies by an order of magnitude for values of L_a between 5 and 18nm, and we can provide a general scaling law [2]. The electrical conductance at room temperature shows an even greater variation, and we obtain linear resistivities in the range of 3-300kΩ/μm. These values in line with other studies both in terms of size and spread [3,4]. By linking the linear resistivity to the crystallinity, we can now investigate the origin of these large variations. In the high crystallinity material, the walls of the nanotube behave as graphene sheets, with a low sheet resistance, linked by grain boundaries. As the crystallites become smaller in the lower crystallinity samples, the sheet resistance increases together with an increased resistance from the boundaries. We infer this as being due to quantum confinement and edge effects that introduce energy gaps in the electron structure. The nanotubes are thus going from a semi-metal behavior at high crystallinities, into a semiconductor behavior at lower crystallinities. This explains the large variations in previous electrical conductivity measurements and can provide a future viable classification scheme for carbon nanotube materials.

[1] H. Jackman, P. Krakhmalev, and K. Svensson, J. Appl. Phys. **117**, 084318 (2015).
[2] M. Flygare and K. Svensson, Mater. Today Commun. **18**, 39 (2019).
[3] A. Bachtold, M. Henny, C. Terrier, C. Strunk, C. Schönenberger, J. P. Salvetat, J. M. Bonard, and L. Forró, Appl. Phys. Lett. **73**, 274 (1998).
[4] B. Bourlon, C. Miko, L. Forró, D. C. Glattli, and A. Bachtold, Phys. Rev. Lett. **93**, 176806 (2004).