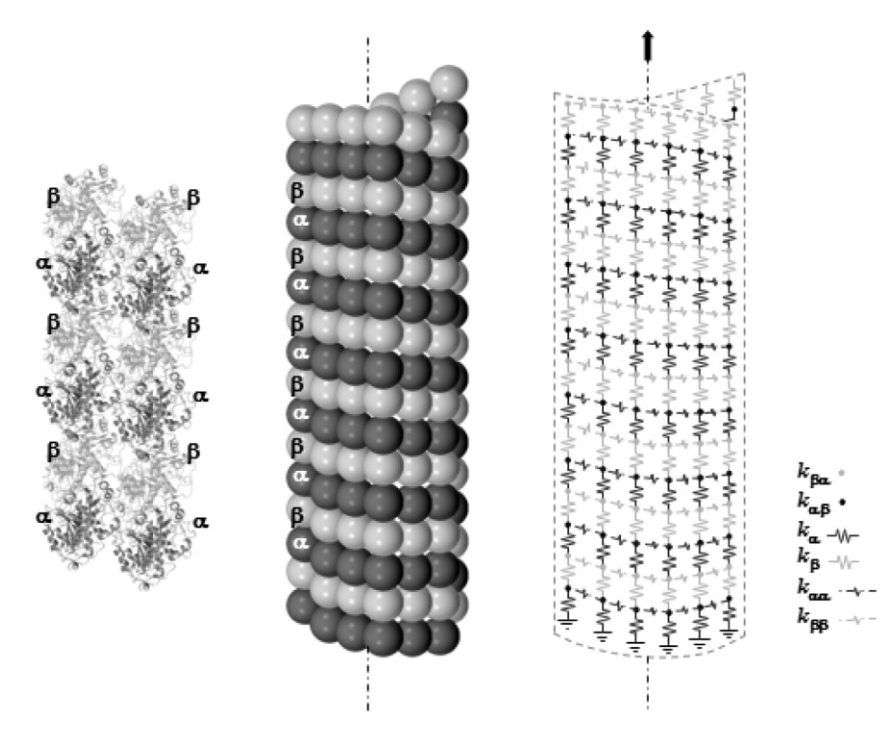
THE NANOMECHANICS IN ITALY

2007

Editor

NICOLA MARIA PUGNO



RESEARCH SIGNPOST

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Dedication

To my daughter Maria Consolata

Introduction:
Looking in the crystal buckyball

The Royal Swedish Academy of Sciences awarded the 1996 Nobel Prize in Chemistry jointly to R.F. Curl, H.W. Kroto and R.E. Smalley for their discovery in 1985 of fullerenes. Looking in the same year in the "crystal buckyball" one would expect to see the discovery of carbon nanotubes (CNTs). It is in fact common belief that it took place in 1991 thanks to Iijima, who reported in Nature (Nature, 354, 56, 1991) the observation of multi-walled (MW) CNTs. In 1993, in the same issue of Nature, two independent groups, again Iijima with Ichihashi (Nature, 363, 603, 1993) and Bethune et al. (Nature, 363, 605, 1993), reported the observation of single-walled (SW) CNTs. The impact of these papers on the scientific community has been tremendous, perhaps leading to the real birth of Nanomechanics (and in general Nanoscience). In spite of this, the first direct observation (by force subsequent to the production of the transmission electron microscope) was previously reported in 1952 in the Journal of Physical Chemistry of Russia by Radushkevich and Lukyanovich (Zurn. Fisic. Chim., 26, 88, 1952), whereas an image, even if controversial, of a single- or possibly double-walled CNT was reported in 1976 by Oberlin, Endo and Koyama in the Journal of Crystal Growth (Journal of Crystal Growth, 32, 335, 1976). Two editorials, appearing in Carbon in 1997 (Carbon, 35, 581, 1997) and 2006 (Carbon, 44, 1621, 2006), and a "Journey on the nanotube" (Pugno, Materials Today, 11, 44, 2008) support these pioneering observations. Thus, giving a last look in the crystal buckyball I hope to see a Nobel Prize for the discovery of CNTs awarded to all the scientists really involved in it.

Aside from the controversy surrounding their discovery, nanotubes have introduced humanity to the new nano-era. The tremendous mechanical properties of CNTs, such as strength (see the Chapter by Palla et al. on atomistic fracture, even if not specifically devoted to CNTs) and elasticity (see the Chapter on the characterization by inelastic scattering by Beghi and Bottani), combined with a low density, promise to revolutionize materials science. "More Moore" and even "more than Moore" can today be achieved by using nano electromechanical systems based on carbon nanotubes, expected to have an integration density of the order of 1000 billions per square centimeter and working frequency in the gigahertz band. Even if miniaturization is the tendency in electronics, a look in the crystal buckyball would surprisingly show in mechanics a prevailing opposite tendency. Obviously indentation (see the Chapter by Bignardi et al.), hard coatings (see the Chapter by Marchetti et al.) or scanning probe microscopy tips (see the Chapter by Buzio and Valbusa) are more effective and sensitive if smaller, and vectors for drug delivery must be nanosized by definition (sufficiently small to avoid the blockage of the blood flow in the capillaries but still large enough to avoid the body's defenses).

Nevertheless, using single CNTs as matrix fiber-reinforcements has been demonstrated not to be a panacea, and thus new insights are needed (see the Chapters by Pantano and Bellucci et al.). Perhaps, better prospects exist for “super-nanotubes” (hierarchical tubes composed by nanotubes) that could be used to produce hierarchical bio-inspired super-composites (see the Chapter by Pugno and Carpinteri); and multiscale, bottom-up or top-down, approaches have been demonstrated to be key tools not only in biomechanics (see the Chapter by Redaelli et al.).

In general, we are not much interested in a very strong nanofiber *per se*, because the proper size-scale of a man is the meter. Nanotubes are strong and stiff mainly because they are small and thus nearly defect-free, their best attribute. Thus, controlling and minimizing defects (e.g. at the thermodynamic limit) during a bottom-up scaling (see the commentary in Nature Materials, 4, 421, 2005 by Carpinteri and Pugno) would represent the real next breakthrough that can be seen in the crystal backyball. For example, a macroscopic cable with a strength of a single CNT would allow us to build fantastic structures such as the terrestrial space elevator (see the News at Nature 22 May 2006 and the Research Highlights in Nature 22 November 2007 related to my findings); or, if CNT-based tissues will be properly scaled-up, a Spiderman suit could in principle be realized (see New Scientist 28 April 2007 and my related Chapter). However, at larger size-scales not only the material but also the structure is expected to play a key role, thus flaw-tolerant designs --to counteract the weakest link concept-- are required. There is plenty of room also at the top, and especially in Nanomechanics.

In synthesis, this book is composed by a meditated collection of 10 Chapters, in order to present a comprehensive view including biological applications, from very active Italian research groups involved in Nanomechanics.

Torino **Nicola Maria Pugno**
8/12/2007

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