In situ TEM for inorganic nanomaterial property analysis

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Diverse physical properties of inorganic nanotubes, nanowires, nanoparticles and nanosheets, *e.g.* their electrical, mechanical, optoelectronic, photovoltaic, thermal and/or cathodoluminescence performances, have been studied under delicate manipulations with various nanoscale objects in 200 kV and 300 kV JEOL high-resolution transmission electron microscopes (HRTEM) equipped with a variety of *in situ* TEM holders. The objects of interest include, but are not limited to, boron nitride and carbon nanotubes, pure and nitrogen-doped graphenes, boron nitride, boron carbo-nitride and molybdenum sulfide nanosheets, boron nitride nanoparticles, cadmium sulfide, zinc and copper oxide, and core-shell silicon-germanium nanowires, different nano-heterostructures, nanocomposites *etc.* Various mechanical, electrical, optoelectronic, photovoltaic and thermal characteristics, like Young's modulus, ultimate tensile strength, fracture toughness, conductivity, photocurrents, thermal gradients *etc*. have been determined as a function of nanostructure morphology, its atomic structure and existing or induced defects (as revealed by direct and in-tandem HRTEM imaging). For instance, optoelectronic and cathodoluminescence parameters of cadmium sulfide nanowires with and without elastic bents have been analyzed as a function of their bending ratios or existence of localized structural defects. Statistically unchanged values of on/off (photocurrent/dark current) ratios in bent nanowires have been documented in this case. Ultimate performances of different nanomaterials as electrodes in lithium- and sodium-ion batteries have also been investigated *via* construction of prototype ion-battery cells in HRTEM. All *in situ* TEM findings with respect to the measured nanomaterial properties have normally been theoretically supported by Density Functional Tight Binding (DFTB), Density Functional Theory (DFT) and/or Molecular Dynamics (MD) simulations. The regarded works have been performed through multiple and key contributions of the author's numerous colleagues participating in diverse *in situ* TEM projects at various stages of their accomplishments, namely, Drs. Chao Zhang, Dai-Ming Tang, Ming-Sheng Wang, Wenlong Wei, Ovidiu Cretu, Zhi Xu, Konstantin Firestein, Joseph Fernando, Katherine Elizabeth Moore, Pedro Costa, Xin Zhou, Naoyuki Kawamoto, Yohei Kakefuda, Isamu Yamada, Masanori Mitome, Yoshio Bando, Dmitry Kvashnin, Pavel Sorokin, Xi Wang, Qunhong Weng, Dai Penchung, Zhou Min, Yanming Xue, Maho Yamaguchi, Tianyou Zhai, Xuebin Wang, and Naoki Fukata. The author is particularly grateful to the Australian Research Council (ARC) for awarding a Laureate Fellowship (Project FL160100089) devoting to *in situ* TEM studies toward new structural and "green" energy nanomaterials.