Interactions of ultra soft X-rays with carbon nanotube arrays

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Carbon nanotubes (CNTs) are among the most promising elements of future nanotechnologies. A vast amount of information on the structure and properties of CNTs obtained in the past 15 years point to considerable potential for application of these unique structures in nanoelectronics, energetics, medicine, and other high-technology industries. One of the most important problems is to produce ordered CNT arrays with desired texture and properties. Arrays of CNTs aligned perpendicular to the substrate surface have strong anisotropy of mechanical and electrical properties and are used for fabricating planar field emitters, electrochemical electrodes, sensors, etc. Several methods are available for characterizing the texture of aligned CNT arrays. Information on the distribution of nanotube directions in an array can be obtained from Fourier transformation of the lateral cleavage image. Anisotropy of the optical response of fundamental vibrational modes was observed in the Raman spectra of CNT arrays and in the optical absorption and fluorescence spectra of aligned CNTs. Unfortunately, because of a large optical wavelength, these methods are insensitive to ordering in domains smaller that 100 nm. Orientation of graphite layers in multi-walled CNTs can be determined by X-ray diffraction. However, this method is applicable only for well-graphitized nanotubes. Angle-resolved X-ray spectroscopy is free of most of the above limitations. Measuring the angular dependences of X-ray emission and absorption spectra of graphite allows the determination of its texture. Similar to graphite, CNTs are also characterized by chemical bond anisotropy; however, the angular dependence of the spectra of aligned CNTs is less pronounced than for graphite because of high structural disorder in CNT samples. Carbon K-edge X-ray absorption spectra of the aligned MWNT films were measured. The angular dependent changes observed for the spectral profiles were interpreted in terms of variation of π- and σ-contributions depending on the take-off or incidence angle of X-ray radiation. Measurements of angle dependence of X-ray fluorescent and X-ray absorption spectra from a film of aligned single wall carbon nanotubes allowed estimation of their ordering in the arrays. The theoretical model considering the deflection of orientation of cylindrical tubes from the normal to the substrate have been developed and used for calculation of theoretical angular dependences. The π^*/σ^* intensity ratio was used for determination of the SWNT film texture from the comparison between the calculated and experimental data.