ELECTRODYNAMICS OF NONOTUBES

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Rapid progress in the synthesis of a variety of different nanostructures with fascinating electronic and optical properties irreducible to properties of bulk media symbolizes a fundamental breakthrough in the physics and chemistry of condensed media, which significantly extends our knowledge of the nature of solids and our capabilities to control their properties. Despite different physical nature, nanoobjects share the common property of having extremely small dimensions in one or several directions, which are about 1 or 2 orders of magnitude bigger that of the characteristic interatomic distance. Thus, quantum nature of carrier motion exhibits itself to the full extent and traditional constitutive parameters in electrodynamics defined through macroscopic averaging cannot be applied; at least, they should be modified. Milestones in the development of electrodynamics have always been related to practical problems risen by new ideas in and means for the transmission and processing of electromagnetic signals. At present, electromagnetic simulation of nanostructures becomes one of the main directions of the modern electrodynamics development, where researchers face new problems, while the traditional electromagnetic methods receive new content being applied to new objects.

In our talk, a wide spectrum of electrodynamic effects in carbon nanotubes (CNs) - quasi-one-dimensional carbon macromolecules - is considered in the microwave, the infrared and the visible regimes. The talk stress the tight relation between traditional problems of classical macroscopic electrodynamics and electrodynamic problems of quasi-one-dimensional nanostructures. We demonstrate that such a relation allows extension to nanostructures of well-developed mathematical approaches and rich experience accumulated in the traditional electrodynamics. On the other hand, complicated conductivity low and pronounced nanoscale field inhomogeneity provide peculiar electromagnetic response of CNs irreducible to the response of macroscopic samples.

The talk covers linear electrodynamic response of nanotubes, nonlinear transport and optical effects in nanotubes, and foundation of quantum electrodynamics of nanotubes. The last issue is of interest in relation to recent idea to use nanoobjects in quantum networks that store and process quantum information being transmitted by entangled states of photons. Effective boundary conditions for the electromagnetic field in CNs are stated on the nanotube surface providing thereby the most appropriate tool for solving electrodynamic problems involving CNs and, more generally, any quasi-one-dimensional structures. The existence of surface TM--waves is pointed out and frequency ranges are shown to exist wherein these waves can propagate to distances essentially exceeding the CN length. That allows the concept of nanotubes as nanowaveguides. Scattering of electromagnetic waves at the nanotube edge is discussed. An exact solution of the diffraction problem is obtained by the Wiener-Hopf technique.

A theoretical model of the current-voltage characteristics of long carbon nanotubes in strong axial dc-fields at room temperatures has been presented and effect of negative differential conductivity has been predicted. The effect makes possible the design of wave-generating nanotube-based diodes for submillimeter and infrared ranges. The high-efficiency generation of high-order harmonics in nanotubes illuminated by an intense pumping field is theoretically demonstrated. Experimental results on third-harmonic generation in nanotube ensemble is compared with the theoretical predictions in a full quantum mechanical theory for harmonics generation from a single-wall CN. The results show an unusual non-perturbative behaviour of the third harmonic yield, for relatively low input laser fields, of ~ 10^{10} W/cm^2.

A theory has been developed of spontaneous decay process of an excited atom placed inside or outside (near the surface) a carbon nanotube. Numerical calculations of the atomic spontaneous decay enhancement factor have been performed for various achiral nanotubes. The effect of the nanotube surface has been demonstrated to dramatically increase the spontaneous decay rate - by 5 to 6 orders of magnitude compared with that of the same atom in vacuum. Such an increase is associated with the nonradiative decay via surface excitations in the nanotube.

A brief review of unsolved problems of electrodynamics of nanotubes, with the emphasis on potential applications, is presented. The talk relies on a series of works, which touch upon the problems mentioned above (see reviews [1,2] and references therein, as well as recent publications [3,4]).

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