Electromagnetics and Quantum Transport in Nanoelectronic Devices

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Abstract

Nanotechnology has potentials for epochal developments in various areas of science and technology. Specifically, RF Nanoelectronics represents an emerging branch of Nanotechnology with possibilities for unprecedented microwave, millimeter-wave, THz, optical devices and systems. While the advancement of research in this area heavily depends on the progress of manufacturing technology, still the global modeling of multi-physics phenomena from meso- to the nano-scale is crucial to its development. Modeling, in turn, provides the appropriate basis for design.

The main aim of this lecture is to investigate and model the combined electromagnetic and quantum transport phenomena in nanotechnology-enabled device/system. To this purpose, it is fundamental:
i) to introduce basic and/or new concepts for the understanding the physics of nanostructured materials, ii) to define the proper partial differential equations systems (PDES, e.g. Maxwell, Schrödinger, Dirac), governing the different physical domains as well as non-linear coupling effects, iii) iii) to build up advanced numerical techniques for their discretization and coupling, preserving consistency and conservation of energy.

In a more general perspective, this analysis is the core issue of a global multi-physics modeling paradigm of complex systems, including also thermal and mechanical aspects. The computational framework must be able to deal with the multi-scale nature of the coupled domains, from atomistic-, through the nano-, up to the meso-scale. The final goal is the realization of efficient numerical tools, for practical use.

We present full-wave techniques in the frequency - and time-domain for the analysis/modeling of the combined electromagnetic-transport phenomena in carbon-based devices/systems. In the ballistic regime, the quantum transport is described by the Schrödinger equation (CNT) and/or Dirac equation (graphene), for small energies. Maxwell and Schrödinger/Dirac equations are simultaneously solved. In the non-ballistic regime, the quantum effects are modeled in terms of dispersive surface conductivities, and incorporated into Maxwell equations. Equivalent dyadic Green's functions are derived.

Several examples and results are reported: CNT/graphene field effect transistors, graphene nanoribbon circuits, carbon interconnects, plasmonics propagation, carbon nano-antennas, photo-emission/generation, metal-carbon transition, non-linear effects.