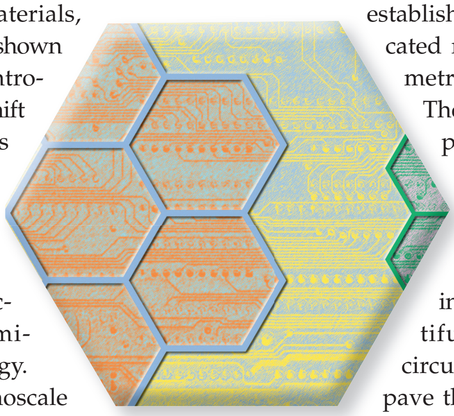
From the Guest Editors' Desk

Nanoelectronics: The Paradigm Shift

■ **Luca Pierantoni, Fabio Coccetti, and Peter Russer**

Fostered by the continuous qualitative and quantitative progress that nanotechnology enables and prompted by recent breakthroughs in the area of nanomaterials, nanoelectronics has shown the potential to introduce a paradigm shift in electronic devices and system design. This paradigm shift is similar, to some extent, to the transition from vacuum tubes to semiconductor technology.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Since many nanoscale devices and materials exhibit their most interesting properties at radio frequencies, nanoelectronics represents an enormous and yet widely undiscovered challenge for the microwave engineering community. In fact, dealing with new concepts in nanoelectronics requires a growing volume of theoretical and modeling foundations, which need to be supported by established and sophisticated manufacturing and metrology capabilities. The issue at stake is paramount: to close the gap between the nanoscience and a new generation of highly integrated and multifunctional devices, circuits, and systems to pave the way for a broad range of applications and operating frequencies covering the radio-frequency (RF) spectrum, through the microwave region, and up to the optical region.

The IEEE Microwave Theory and Techniques Society (MTT-S) has recently approved a new Technical Committee, named MTT-25 "RF Nanotechnology" [1]. The main goal of MTT-25 is to provide an appropriate venue to review perspectives and foster innovations that are of the most interest to the microwave engineering community on the topic of nanotechnology and nanoelectronics.

Recently, a set of three overview articles addressing this hot topic were simultaneously submitted to *IEEE Microwave Magazine*, and the Editorial Board considered it of interest to print them together as the present focused issue on "RF Nanoelectronics."

The first of these articles, "Nanoelectronics-Based Integrated Antennas," by Peter Russer et al. introduces silicon and silicon-germanium-based monolithic integrated millimeter-wave circuits for the realization of communication and sensing systems operating at frequencies up to the millimeter-wave range. Monolithic integration of antennas should contribute significantly to the compactness of front ends and avoids lossy and expensive cable connections between circuitry and antennas.

An overview over the state of the art in integration of antennas into semiconductor-based monolithic integrated circuits is presented. Then, the emerging possibility to integrate antennas within future nanoelectronic device platforms based, for example, on polymer materials, carbon nanotubes, graphene, superconductors, or plasmonic devices, is investigated. Finally, technical applications in communications, sensors, and photonic energy harvesting are discussed.

The second article, "Nanoscale Devices for Large-Scale Applications,"

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by N. Rouhi et al., deals with carbon nanotubes- and semiconducting nanowire-based devices and systems, which show an outstanding potential on a wide range of applications including field effect transistors and high-frequency electronics, chemical sensors, nano-electromechanical systems, thin film transistors, and display electronics. In fact, their small size, high mobility (near-ballistic electron transport), high intrinsic cut-off frequency, mechanical and thermal stability, high current carrying density, and the capability of having both semiconducting and metallic tubes, makes these carbon-based devices a promising candidate to replace the silicon-based devices in some applications. In this article, different carbon nanotube synthesis methods are discussed along with a RF circuit model for field effect transistors. Moreover, recent achievements in the area of RF nanotube systems including radios, amplifiers, and a new inkjet printing concept for RFID tags are also presented.

The third article, written by M. Dragoman et al., presents an overview of "Graphene for Microwaves."

Currently, electronics is striving toward faster, smaller, more efficient, yet cost-effective, solutions. In doing so, the limits of what materials are currently available within the technologies are frequently reached. Because of this, the search for new materials that are endowed with disruptive, enhanced properties, and a high degree of compatibility with standard process, has become paramount. In this difficult quest, graphene has shown proven results as an emblematic protagonist, seeming to answer many needs. Characterized by superior electric and mechanical performance, it is also quite compatible with conventional manufacturing techniques. Hence, graphene may become a key enabling material, breaking ground for a new generation of high-speed nanoscale electronics with consequences and breakthroughs similar to that of silicon's in the last few decades. This article describes and predicts the evolution of this fascinating material, beginning with early observations and moving into the practical microwave applications envisioned for its bright future.

We hope that issue is the first of a long and fruitful series. Enjoy!

Acknowledgment

Many people worked very hard on this issue. Our sincere thanks to all of you.

Reference

[1] L. Pierantoni, "RF Nanotechnology - Concept, Birth, Mission and Perspectives," *IEEE Microwave Mag.*, vol. 11. no. 4, pp. 130–137, June 2010.