An Update on Nano-Scale Technologies for RF and Microwave Applications

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Many years ago, the advent of the integrated circuit revolutionized electronics, allowing much greater complexity, speed and performance in a small size—and at the same time, dramatically lowering costs. Today, new steps in miniaturization promise another leap in capabilities at smaller size. Nanomaterials, micro-machining, and other microscopic methods are beginning to reach the market in many fields, including medicine, computing, and of course, electronics.

In the area of wireless communications, these technologies are being pursued to achieve greater capabilities in handheld platforms. The only way to put more features into a limited-size package is to make the circuitry smaller. In the digital realm, Moore's Law has helped with the processing and memory portion of wireless devices. Nanoscale technologies are being readied to help with the basic radio performance that enables portability.

According to Larry Morrell, Executive VP of Sales & Marketing at Cavendish Kinetics, microelectromechanical systems (MEMS) switched-capacitor devices for antenna tuning are scheduled for release in 2011. Morrell notes that demand for this capability—which is also being addressed by tunable technologies and other switching devices—is due to a re-discovery of the important of core radio performance. The high data rates of 3G, 4G and beyond require maximum signal-to-noise ratio communication. Solutions include improved base station performance (e.g., MIMO, smart antennas) and microcell/picocell deployments. These infrastructure improvements are costly, so new attention is being given to the handset radio.

The key performance limitation in handheld devices is the antenna. Early cell phones had extendable monopoles that had relatively high efficiency, but in the quest for smaller size, embedded antennas became standard. These antennas are not only less efficient, they are susceptible to detuning by the proximity of the user's hands (famously demonstrated by the first generation iPhone). Antenna tunability allows optimization of impedance matching to combat such degradation. Tunability also has the potential to enhance antenna sharing by the multiple services now supported in a handset—multi-band wireless, GPS, Bluetooth, WiFi, broadcast DTV and others.

Morrell, who is also Chairman of the Tunable Components & Architectures group of the industry organization IWPC (www.iwpc.org), offered some insight into the challenges of fabricating MEMS devices at costs low enough for consumer products. The primary issue is the required hermetic seal to protect the active structures from contamination. Most developmental work involved gluing two die face-to-face, then sealing the assembly in plastic. This method has been supplanted by either a silicon etching process developed at Bosch, or a process of built-up metallization, passivated to achieve the hermetic seal. Both methods are compatible with traditional silicon wafer fabrication, which should be able to achieve cost goals.

Another promising area of nanoscale technology involves carbon structures—nanotubes and graphene sheets. Carbon nanotubes have extremely high thermal conductivity, and laboratory devices have been created that use this characteristic to enhance heat removal from transistors and integrated circuits. Arrays of nanotubes expand the heat transfer capacity without degradation, since there is minimal coupling between adjacent nanotubes.

Graphene is the sheet version of single-atom-thickness carbon. This material also has the nanotubes' characteristic of being able to adopt either conductor or semiconductor properties. Extremely small transistors operating in the THz range are possible with graphene, and quantum dot logic switches have been demonstrated, as well. Demand for communications bandwidth is driving research at ever-higher frequencies, and graphene a a promising technology for practical devices.

A final area to note in the nanoscale realm is on-chip optics, which may be the enabling technology for replacement of data buses with a higher-speed alternative. The dimensions of today's smallest-featured fabrication technologies could rightly be considered part of nanotechnology, but the search for an optimal physical structure for on-chip laser diodes is clearly fits the definition. To allow optical communication with the smallest die area and lowest power consumption, research in this area involves materials at the atomic level.

Summary

Smaller, faster, more capable, and cheaper are the goals for almost all useful electronic devices. To achieve those goals, nanoscale technologies represent the future. Whether internal to devices, connected by wire or optical fiber to other devices, or as part of a wireless product's circuitry, nanotechnology will play an essential part in the development of new communications options.

Nanotechnology News Items

Nanoscale Energy Harvesting

In the laboratory of Zhong Lin Wang at the **Georgia Institute of Technology** (www.gatech.edu), the blinking number on a small LCD signals the success of a five-year effort to power conventional electronic devices with nanoscale generators that harvest mechanical energy from the environment using an array of tiny nanowires. In this case, the mechanical energy comes from compressing a nanogenerator between two fingers, but it could also come from a heartbeat, the pounding of a hiker's shoe on a trail, the rustling of a shirt, or the vibration of a heavy machine. While these nanogenerators will never produce large amounts of electricity for conventional purposes, they could be used to power nanoscale and microscale devices—and even to recharge pacemakers or consumer electronic devices.

Wang's nanogenerators rely on the piezoelectric effect seen in crystalline materials such as zinc oxide, in which an electric charge potential is created when structures made from the material are flexed or compressed. By capturing and combining the charges from millions of these nanoscale zinc oxide wires, Wang and his research team can produce as much as three volts—and up to 300 nanoamps.

The earliest zinc oxide nanogenerators used arrays of nanowires grown on a rigid substrate and topped with a metal electrode. Later versions embedded both ends of the nanowires in polymer and produced power by simple flexing. Regardless of the configuration, the devices required careful growth of the nanowire arrays and painstaking assembly. In the latest paper, Wang and his group reported on much simpler fabrication techniques. First, they grew arrays of a new type of nanowire that has a conical shape. These wires were cut from their growth substrate and placed into an alcohol solution. The solution containing the nanowires was then dripped onto a thin metal electrode and a sheet of flexible polymer film. As the alcohol dries, another layer is created. Multiple nanowire/polymer layers were built up into a kind of composite, using a process that Wang believes could be scaled up to industrial production.

Nanoindentation Instrumentation

Agilent Technologies Inc. (www.agilent.com) has announced an innovative nanoindentation technique available exclusively on the Agilent Nano Indenter G200 instrumentation platform. The new technique gives researchers the ability to make substrate-independent measurements on thin film materials quickly, easily and confidently by means of nanoindentation. It is ideal for evaluating the elastic modulus of hard samples on soft substrates, or of soft samples on hard substrates. Substrate influence is a common problem when using nanoindentation to evaluate the elastic modulus of thin film materials. The technique is able to extract the film modulus from the measured substrate-affected modulus, assuming that the film thickness and substrate modulus are known.

Carbon Nanotube THz Polarizer

In a 2009 paper, "Carbon Nanotube Terahertz Polarizer," researchers from **Rice University** (www. rice.edu) and **Osaka University** reported on studies that show strong anisotropic behavior of carbon nanotubes on a film substrate. With lengths that resonate in the THz frequency range, the highly aligned structure was verified by measuring the transmission of THz energy through the film. When the signal polarization was aligned with the nanotube structure, absorbance was very high. Near-zero absorbance was observed when the signal and materials were oriented at right angles. The research verified the strong alignment of carbon nanotubes, which has many applications in addition to the polarizer described in the paper.

Graphene-based Supercapacitor

Researchers at Nanotek Instruments (www.nanotekinstruments.com) have developed a new graphene-based supercapacitor that can store as much energy as NiMH batteries, but charge and discharge in minutes or even seconds. The new device has a specific energy density of 85.6 Wh/kg at room temperature and 136 Wh/kg at 80 °C. The problem with single-layer Graphene sheets, according to the team, is that they tend to re-stack together. They are trying to overcome this problem by developing a strategy that prevents the graphene sheets from sticking to each other face-to-face. This can be achieved if curved graphene sheets are used instead of flat ones.