Recent News in Semiconductor, Microwave and Optical Materials

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Materials are the foundation of the components and circuits that go into high frequency electronic products. There are enough different activities and developments in materials science, processing, measurement and manufacturing that it is impossible to provide a comprehensive report in two pages. Instead, we offer a variety of notes, news and overviews of a variety of interesting activities in the realm of semiconductor, microwave and optical materials, plus a look at the future.

Classic Silicon

One indicator of progress in semiconductor materials is the continued reduction in size—and resulting increase in transistor density—of CMOS, the silicon workhorse of the semiconductor world.

Intel is reported to be readying a new series of CPUs that use a 65-nm process. Current production at Intel is with 90-nm and 130-nm processes, so the next step will continue the life of Moore's Law with another ×1.4 increase in transistor density to a remarkable 10 million per square millimeter. By 2006, most production at the company is expected to use this process.

Development of 45-nm processes at several companies appears to be the next step in silicon miniaturization. Much university and proprietary industry research is underway to determine performance limitations of ever-smaller geometries. In general, small transistors operate at lower voltages and consume less current than their larger counterparts, but this presents a new set of problems.

The first problem of low voltage operation is noise. The low voltage swing reduces the difference between noise and desired signal voltages, creating an automatic decrease in signal-to-noise ratio. This is not linear, as the lower currents contribute to a reduction in the amount of internally-generated noise. Noise can result in data and timing errors if there is insufficient S/N ratio for reliable ON/OFF state transitions.

Another physical limitation is reliability in presence of external influences. At low transition voltages, transistors are more susceptible to the effects of magnetic and electric fields that are nearly imperceptible with larger voltage swings. The tiny size of the devices also means that they can be damaged by much weaker ionizing radiation sources that their larger brethren, from man-made and natural sources, including cosmic rays and the small environmental radioactivity that is present everywhere.

The latest developments in silicon do not approach these latter problems, but it will not be much further on the development path before "random" events are significant. Research into these problems not only addresses the degree of susceptibility, but also is pursuing options to work around them, including error detection, redundant and self-repairing systems.

RF and Microwave Semiconductors

Recent work appears to have focused on production rather than new science (although there is plenty of research underway). Silicon-germanium (SiGe) processes continue to be used by more companies and for more products as costs come down and grater experience operating the foundries increases yields. SiGe is finally delivering what it promised nearly 10 years ago: significantly better performance than silicon bipolar at a very small premium in cost.

At higher microwave frequencies where device and dollar volumes are lower, the variations on gallium arsenide (GaAs), indium-gallium-phosphide (InGaP) and indium phosphide (InP) and related materials continue to be developed. New materials and improved processes will undoubtedly emerge as large-scale applications move to production. Sensors (radars) will lead the way, particularly automotive speed, obstruction and traffic sensors.

Organic semiconductors are beginning to get some serious press attention, following several years of "gee whiz" news. The present state-of-the-art in polymer transistors is not yet suitable for RF circuits—they are still too slow, but getting better. A clear demand for disposable electronics at minimal cost keeps investment strong and research interest high. A key RF application will be RFID, in response to high interest in embedding a remotely-readable tag in *everything* from pets to cereal boxes to individual sheets of paper in important documents.

Optical Materials

The slowdown in the fiberoptic market has dampened activity somewhat in this area. And, some of the most interesting work has been in using optical materials, not making them. Tunable lasers, improved launchers and better detectors have had more impact that the steady stream of incremental improvements in the basic optical fiber.

However, the future requirements for optical technologies beyond simple data transmission are driving significant research. This is evidenced by a recent announcement by Clemson University of a $10 million endowed chair at the school's at the Center for Optical Materials Science and Engineering Technologies (COMSET). COMSET and the endowed chair faculty member will be in Clemson's new Advanced Materials Research Laboratory, a $21 million complex under construction in Clemson Research Park.

A significant amount of development is also underway for measurement of high performance optics, given that verification of performance is a necessity for the development of any new technology. Much of this work parallels similar efforts to accurately measure electronic behavior of ultra-small geometry semiconductors, using electron microscopy and other direct and indirect observations that operate at atomic and subatomic resolution.

Microwave Materials

The area of microwave materials with perhaps the greatest development effort in recent years is high dielectric constant ceramics, both "hard" ceramics and low temperature cofired ceramic technology (LTCC). High dielectric constant ceramics have made possible coaxial resonators with greatly reduced size, allowing dramatic miniaturization of oscillators and filters, while maintaining high Q for good noise and loss performance.

LTCC techniques have enabled integrated transmission line and passive component structures that are smaller, cheaper and higher performance than previous miniaturization methods. LTCC is also intended for mass production, further reducing the cost of these products.

A more recent development is the application of high dielectric constant ceramics to capacitors. Higher capacitance values in smaller footprints are the result. High voltage capacitors have also benefitted from this technology, allowing thicker dielectric layers in capacitors with the same capacitance values and footprint of their lower-voltage counterparts.

Dielectrics are another area of significant work. At mm-wave frequencies, it is practical to use optical techniques for tasks like focusing the beams of antenna arrays. Low cost, manufacturable materials for these types of applications are being developed by companies specializing in microwave materials.

Low loss radomes are another small, but significant area of attention. Again, the work is largely directed toward manufacturability, in anticipation of high-volume applications in the future, such as LMDS and other broadband access technologies.

Military applications are growing as the armed forces budgets have increased. Lightweight composite materials are being increasingly used for airframes, which permits a wide range of RF/microwave features to be included. Composites with integral absorber materials are used in stealthy applications. Embedded antennas are another area of development, including the new "frequency selective surfaces" technology that are required for both operation of antennas and isolation between antennas at different frequencies. These techniques are required in an environment that no longer has the inherent shielding of metal surfaces.

Farther into the Future

A few interesting areas of R&D that are underway for future applications include several methods for incorporating circuits, antennas and other operating and communication elements into the structure of finished products. We remember the first automotive antennas embedded between layers of glass, but these new techniques are much more advanced.

"Smart materials" are another area of research. These materials have adaptable characteristics, either at the time of manufacture, or available at all times. Familiar examples in the realm include automatic-darkening eyeglasses and polymers with "memory" of their physical shape after being rolled up for storage or transport. Extending this kind of built-in functionality to electronic systems requires a lot of imagination, but it is being done.

Nanotechnology is the final area of note, with enough work underway to fill an encyclopedia. MEMS switches and capacitors are just the first electronic applications to be developed. Sensors are another key focus are among the researchers exploring this tiny new frontier.

Materials are always part of any component or system, and it is fascinating to see what new ideas are being pursued in addition to the developments that are use in your daily design efforts.