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 greater 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
High Frequency Electronics

still too slow, but getting better. A clear demand for dis-
posable electronics at minimal cost keeps investment
strong and research interest high. A key RF applica-
tion will be RFID, in response to high interest in
embedding a remotely-readable tag in everything from
pots to cereal boxes to individual sheets of paper in
important documents.

Optical Materials

The slowdown in the fiber optic market has damp-
ened activity somewhat in this area. And, some of the
most interesting work has been in using optical mate-
rials, 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 tech-
nologies beyond simple data transmission are driving
significant research. This is evidenced by a recent
announcement by Clemson University of a $10 million
dowed 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 con-
struction in Clemson Research Park.

A significant amount of development is also under-
way 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 semicon-
ductors, 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 per-
formance.

LTCC techniques have enabled integrated trans-
mision 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 capac-
itors 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 anten-
na 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 signifi-
cant 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 iso-
lateration 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 fin-
ished 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 function-
ality to electronic systems requires a lot of imagina-
tion, 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 sys-
tem, 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.