# Optical Technology: A Look into the (Near) Future

Optical technology has a strong influence on all electronics. Not only are microwave and high speed digital techniques used in optical communications, but optics are a big part of research, development, fabrication, and test & measurement. We all know some of the current optical applications, but rather than review current optical contributions to high frequency technology, this column will look ahead to a few interesting developments that will strengthen the bonds between optics and electronics.

These technology advances are already being used in the laboratory, and will find practical implementation in the near future.

## On-Chip Optical Signal Processing

A set of applications may need to be developed first in order to enable future developments is manipulation of lightwave transmission at the chip level. Routing, splitting and sampling lightwave signals through silicon layers—sometimes on a sapphire or similar optically transmissive substrate—has been demonstrated, along with MEMS technologies for switching those signals to various paths. Traditional optics with mirrors, prisms, etc., will be reduced to the chip level, where the precision and reproducibility of IC processes will support higher performance at (eventually) lower cost.

The simple reduction in size of an optical communications system will open up many new applications where an embedded optical interface is valuable. Nearly any wired interconnection could be replaced with an optical fiber, often replacing multiple wires with a single optical bus that can be switched among a number of information channels.

The automotive industry is very interested in this technology, since weight, bulk and increased data handling are all significant benefits. Communications enhancements like this are envisioned as an important co-development with new sensor technologies. While many sensors will be linked in wireless networks, many applications will benefit from a network the uses either individual optical links or an optical data bus.

As research and development proceeds in this particular area, a logical extension of basic optical functions is the basis for the next area of optical technology we'll discuss.

## On-Chip and Chip-to-Chip Optical Communications

Once the techniques are established for routing and switching optical signals at the IC level, it will enable an optical technology that has been discussed for some time. The concept is straightforward—the integrated circuit adds additional "short range" optical sources along with the necessary interface and driver circuitry. Literally, optical signals will replace wired or metal layer transmission of high frequency analog and high speed digital signals.

By containing RF, microwave and high speed digital circuitry within the small geometries of a fine-pitch IC process, many problems with signal integrity through packaging and substrate conductors would be eliminated. Of course, they would be replaced with some form of optical "wiring" to carry signals from chip-to-chip, along with in-chip optical pathways.

The ability to remove the troublesome behavior of device interconnections is an appealing idea, especially as wireless applications reach higher frequencies and digital systems attain higher clock speeds. Issues with reflected signals and radiation generally increase with frequency, since the physical dimensions of devices become much larger relative to the wavelength of the signal frequency.

This technology includes some significant challenges. The III-V semiconductors commonly used at the highest frequencies are optically sensitive, which can be used to advantage, but will also create the potential for internal interference (unwanted crosstalk, not the wave-related phenomena!). Instead of RF shielding, opaque layers will be needed. There are other problems to be solved, but this report is only presenting an overview of the possibilities.

## Supercontinuum or "White Light" Lasers

High profile science journals like *Nature* and *Scientific American* have run feature articles on this technology, highlighting its potential for future improvements in imaging, measurements and communications. While a source of this light can be purchased as a commercial product, most applications remain in the laboratory.

Supercontinuum (SC) light was first discovered/created in the late 1960s, using a high power pulsed laser to excite a transmission medium of crystal or glass into the nonlinear region (Kerr effect). The energy of the pulse alters the material so the refractive index is increased (slowed propagation). This alters the phase/frequency of the beam, but varies with time as the energy builds up—the pulse emerges from the medium with the leading edge at a higher frequency (shorter wavelength) than the trailing edge. If the process yields a range of wavelengths that includes the visible spectrum—about an octave—its appearance is white.

For many years, SC light was primarily used to explore the behavior of the materials that were excited. In the late 1990s, fiber optic technology had reached the point where a lower-power laser pulse could create SC light by exciting a specially-made fiber. This material has relatively low Kerr effect properties, but the light travels a long distance within the fiber. With this simpler technique, SC light is now readily available for experimentation and practical applications.

What can be done with SC light? First, it has two important properties: First, it is a comb of discrete frequencies, just like the harmonics and spurs generated by RF/microwave circuit nonlinearities. And the output frequencies exhibit something like coherence, that is, they have a defined phase relationship since they were all generated from a single source.

Frequency combs are useful for many types of distance, time and frequency measurements. An obvious application is as a source for multi-carrier optical communications with far greater data rates than current systems. The "partially coherent" property is especially useful for Optical Coherence Tomography (OCT), an interferometry-based imaging method with similarities to ultrasonic imaging. SC light improves OCT resolution by a factor of four or more, with demonstrated resolution as small as 0.5 micron.

Metrology is another "natural" application, where different phase-related frequencies enable greater precision compared to a single coherent laser. Interferometry among multiple signals is estimated to eventually improve time and frequency measurements by two to four orders of magnitude. This extreme precision is sufficient to detect variations in what are now considered "physical constants." A similarly extreme example of an application is the measurement of small variations in gravitational fields, which may have a significant impact close to home in the earth sciences, and at the relativistic distances of the universe.

## Summary Comments

Whether communications, measurements, imaging, or basic research, these advances in optical technology have already been proven to be valuable. And there are other areas of work that are equally fascinating, but perhaps less applicable to the electronics industry. Metamaterials have been demonstrated that bend light around objects to make them invisible, two-dimensional light waves have been created with unique properties, and other exotic techniques are being explored that may eventually have applications that affect our work. We will continue to follow those stories as well the ones noted above.

Like all technology, optical principles and applications are advancing rapidly. All the techniques reported here have benefitted from the continuing growth in our knowledge of the basic properties of time, space and matter. Now that the basics of technologies like chip-level optics and SC light have been demonstrated in the laboratory, it is up to the engineering community to develop the products that use these new technologies' special properties.

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