Optical Fiber Sensors: Just Around the Corner

By DIETRICK E. THOMSEN

What radar does for traffic police, light will soon be able to do for physicians. Just as the speeds of vehicles are measured by the frequency shift in radio waves that bounce off them, the rate of blood flow can now be measured by a new device that observes the frequency shift (Doppler shift) in light bounced off blood cells. This is just one of a number of new ways in which optical fibers are being applied to remote sensing techniques in science and industry—wherever physical or chemical characteristics need monitoring.

Research in the field of fiber-optic sensing began about a decade ago. By 1983 scientists felt the need to organize the First International Conference on Optical Fiber Sensors (OFS). This year they met in San Diego for the third in the series. "For the past 10 years," says the foreword to its program, "the development of optical fiber sensors has led to a new applications area for optical-guided wave technology. While most of the effort . . . remains in research and development, several commercial sensors have already been marketed. . . ."

The market is expected to grow. Says Takashi Nakayama of Mitsubishi Electric Corp., in Amagasaki, Japan, "The Japanese market for OFS and their instrumentation is expected to reach $100 million by 1990 from $10 million in 1982."

Fibers are thin and flexible, and they can guide light waves around corners. "We all know that light travels in straight lines," says David A. Jackson of the University of Kent in Canterbury, England. "But fibers get it into places that are difficult of access," such as veins, to measure blood flow. In some instances the fiber transmits information from a sensing element at its end. In other cases some physical property of the fiber is used as the sensor.

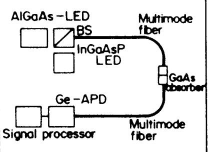
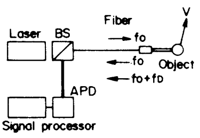
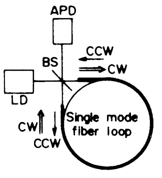
Interferometry often has a good deal to do with the sensing technique. A simple kind of interferometer takes a single beam of light, splits it and sends the two halves over different paths to mirrors that reflect them back to the point of division, where they recombine. If the two paths are equal or differ by an integral number of wavelengths of the light, the two halfbeams will reinforce each other on recombination. If the two paths differ by a fraction of a wavelength, the two halfbeams will interfere with each other on recombination, perceptibly lessening the brightness of the light. In the extreme case, when the two halfbeams differ by exactly half a wavelength, they will cancel each other, and the recombination yields no output; that is, darkness results.

This effect can be used to measure the length of one path relative to the other. If the two paths are optical fibers, anything that changes the length of one of them (temperature or pressure changes, for example) can make a sensor this way. An example cited by Jackson is to wrap one fiber around a piece of piezoelectric material. The piezoelectric material expands or contracts with changes of the electric field. The expansions and contractions either stretch or shorten the coiled fiber.

Anything that changes the phase or shifts the frequency of the light will contribute to such interference. This is the principle behind the velocimeter that measures blood flow, for example, discussed by Claus Dähne of Battelle's Geneva Research Center in Switzerland and other speakers. One such device can measure velocities between 5 millimeters per second and 5 centimeters per second (with a 15 percent margin of error).

In a birefringent fiber, components of the light that are polarized in different directions travel at different velocities. This too will produce an interference effect, and if something changes the birefringence — as a number of physical effects will — the interference will change. Gyroscopes can be made of loops of such fiber in which laser beams are circulating clockwise and counterclockwise. Rotation of the loop will change the relation between the two beams, and that will show up in the interference pattern. This is the Sagnac effect, a piece of physics so obscure that it does not even have an index entry in the 15-volume *McGraw-Hill Encyclopedia of Science and Technology.* Work on devices of this kind is proceeding in France, Germany, Great Britain, the United States, Japan and the Soviet Union.

Various materials susceptible to changes in different physical or chemical factors can be attached to the ends of fibers and then inserted into difficult places. Jackson and Nakayama described temperature sensors made of gallium arsenide. How much the gallium arsenide absorbs of light sent to it through the fiber depends on temperature. Nakayama says these sensors are good from −30°C to +300°C.

	Class 1 Sensor is in the fiber transmission line	Class 2 Sensor picks up the signal carrying light	Class 3 Fiber itself is the sensor element
Principle	· Elasto-optic effect · Electro-optic effect · Magneto-optic effect · Optical absorption, reflection · Optical shutter	· Laser Doppler effect · Black body radiation · Image fiber	· Interferometric effect Mach-Zehnder interferometer Michelson interferometer Sagnac interferometer · Microbending effect
Example	 Fiber-optic Thermometer	 Fiber-optic LDV	 Fiber-optic gyroscope
Sensor	Discrete optical element	Optical fiber probe	Optical fiber
Features	· Simple structure · High-reliability	· Noncontact sensing · High-sensitivity	· Ultra-high-sensitivity

Comparison of different kinds of optical fiber sensors.

Nakayama/Kyuma-OFS '85

Pressure-sensitive heads are also possible. A West German team described one that, when attached to the skin, measures blood pressure. It is used, for instance, to measure changes in blood pressure in a vein after exercise to help diagnose venous disorders.

According to Dähne, physicians can introduce into a patient's bloodstream a fluorescent tracer that attaches itself to tumor cells, and optical fiber sensors can then locate the tumor by recording the fluorescence. Heads sensitive to particular chemicals can make oximeters for measuring the lungs' oxygen intake in exercise or altitude studies. They can make glucose sensors for blood sugar measurements, as well as antigen sensors capable of detecting 10^{-15} mole per liter of a given substance for immunoassay studies.

The OFS conference took two days of several parallel morning and afternoon sessions to describe these and many other possible applications. Jackson, reviewing it all, concludes: "Before the end of this decade, optical fiber sensors will have been established as viable alternatives to conventional sensors. . . ." □