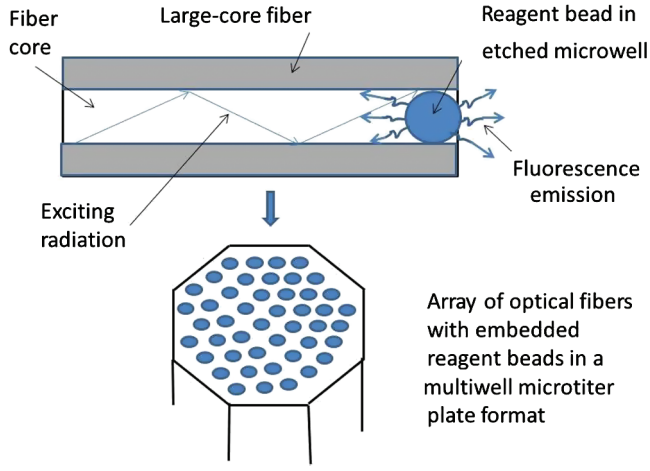

Figure 16.13 Fiber-optic-enabled arrays using fluorescence for high-speed screening.[1]

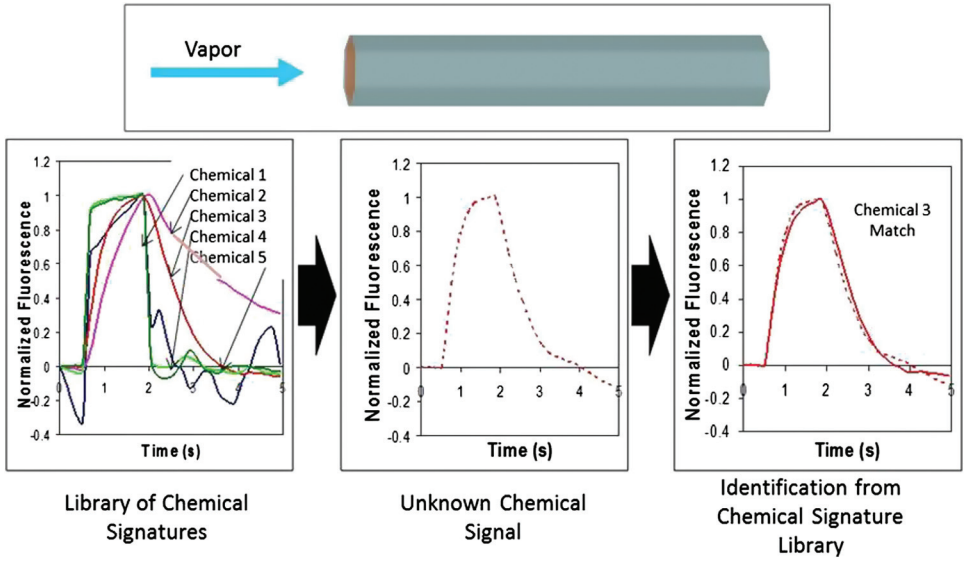

Figure 16.14 Fluorescent array microsphere sensors.[10]

to have low background fluorescence to maximize the fluorescent signal from each bead. The array has many beads modified with different chemistries. The multiplexed array has increased selectivity due to cross reactivity. The detection limit is improved as a result of signal averaging many sensors. An example of using the fluorescence-based microsphere array is vapor sensing. The fluorescent signature is known for gases and is stored. Therefore, the sample can be identified by comparison with the stored fluorescent signature library, as shown in Fig. 16.14.

16.2.4 Intrinsic biophotonic sensors: distributed sensor concepts

As discussed in Chapter 15, an intrinsic sensing concept in which a doped cladding turns a passive fiber into a chemical sensor is referred to as "Distributed Intrinsic Chemical Agent Sensing and Transmission" or DICAST®.[11] The entire fiber is the sensor.

The DICAST approach provides a sensing capability that is fully distributed, intrinsically sensitive, chemically active, cladding based, and provides seamless coverage. The multifiber/multichemistry approach provides a dramatic reduction in false alarms. The alarm signal is achieved with phase-locked-loop optoelectronic detection that is self-referenced and has high sensitivity. Visible wavelength OTDR provides the threat location.

Active DICAST fibers have been developed for chlorine, hydrogen sulfide, hydrogen cyanide, and sarin/soman. The fiber integrates total exposure over the short term and resets after 24 hours (HCN, H_2S). The system performance requirements are tabulated in Table 16.1. The sensor concept provides for specificity and low false-alarm rate. LCt_{50} is defined as the lethal concentration that will cause incapacitation within typically 1 minute. IDLH is an acronym for Immediately Dangerous to Life or Health, and is defined by the US National Institute for Occupational Safety and Health (NIOSH).

16.2.5 Intrinsic biophotonic sensors: surface plasmon resonance

Blood group detection errors can lead to serious medical problems. To address this issue, an errorless blood group detection probe has been designed.[12] The probe provides rapid results with a smaller blood sample than required with other approaches.

Table 16.1 DICAST system performance specificiations.[11]

System Parameter	Requirement
Sensitivity	Will alarm at 10% of LCt_{50} integrated dosage; zero false negatives
Specificity	Will not alarm to interferants anticipated to be found in indoor, outdoor, and military environments
Accuracy/Linearity/Resolution	Alarm system: • Triggers when 3 ft exposed anywhere • 50-ft distance resolution OTDR system: Linear concentration-versus-length plot • 10% concentration accuracy • 3-ft distance resolution
Response Time	• 10 sec 100% LCt_{50}/IDLH • 20 sec 50% LCt_{50}/IDLH • 45 sec 25% LCt_{50}/IDLH
Cable Length	200 ft (chemically sensitive) Can be interspersed with >1,000 ft of conventional fiber cable
Cable Lifetime	1 year
Calibration	Electronic compensation
False Alarm	Less than 1% (not to exceed 1 per year)

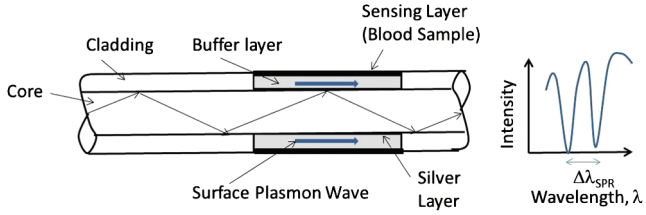

Figure 16.15 A proposed fiber optic SPR sensor probe for detecting human blood groups.[12]

The probe design consists of coating a small segment of optical fiber (typically 10 to 15 mm) with a surface plasmon resonance (SPR) active metal such as silver. The coating thickness is a few nanometers. The thin metal layer is then coated with a buffer that prevents any contaminants from being deposited on top of the metal, as shown in Fig. 16.15. For measurements, the blood sample is brought into contact with the probe, and light is launched into the input end of the optical fiber. The resulting light emitted at the other end of the probe provides information such as resonant wavelength, from which the blood group can be deduced. Specifically, in the presence of a blood sample, the output signal exhibits a sharp dip at a resonance wavelength because of strong optical absorption by the surface plasmon wave (occurrence of SPR). The shift in resonance wavelength $\Delta\lambda_{SPR}$ is shown in Fig. 16.15.

Optimum results were obtained using an optical fiber with a large core diameter and small sensing regions with silver layer thicknesses typically around 50 nm. Another important feature is that with an appropriate buffer solution, the probe was reusable. This basic concept can be used in a distributed configuration.

Tilted Bragg gratings can be used efficiently with surface plasmons in a metal-coated fiber similar to the configuration shown in Fig. 16.15, where the fiber has a thin silver coating. The tilted Bragg enhances the evanescent wave interaction. Minute changes at the surface of the fiber facilitate biochemical reactions. As an example, micromolar concentrations of proteins have been detected by attaching synthetic DNA sequences on a gold-coated fiber using a tilted Bragg grating incorporated in an SPR sensor.[16]

16.3 Extrinsic Biophotonic Sensors

Conventional photonic sensing techniques can also be used for monitoring biological processes extrinsically. In general, extrinsic biophotonic sensors provide indirect chemical process measurement such as changes in pressure, temperature, or polarization state. White-light interferometry (WLI) technology can be used for biomedical pressure monitoring.[14] The concept is shown in Fig. 16.16.

There are several benefits of white light interferometric sensors. They can be made extremely small. They are resistant to harsh chemical and thermal environments. Absolute or relative measurements are possible. Several types

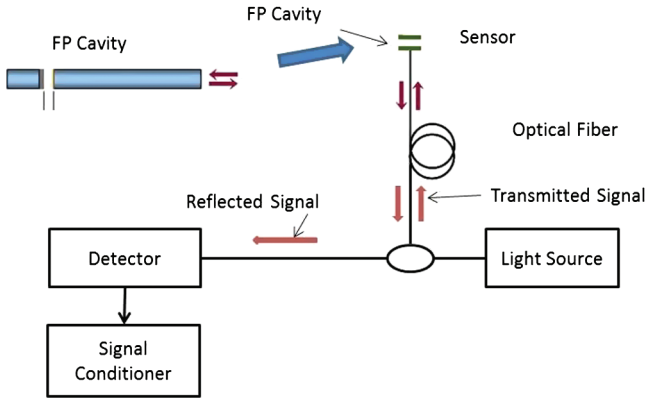

Figure 16.16 White light interferometry for medical applications.[14]

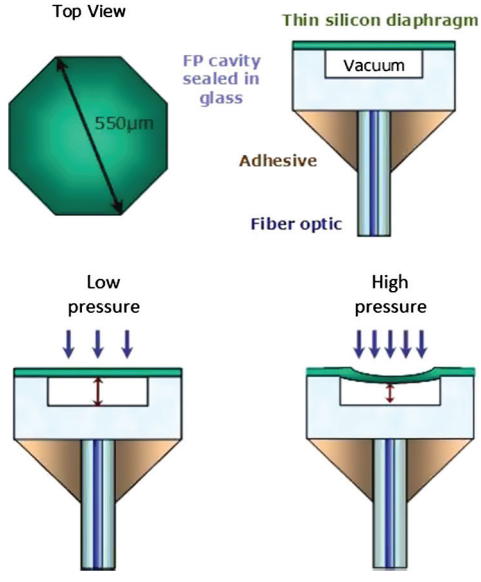

Figure 16.17 Pressure sensor design.[14]

of sensors can be used with the same signal analyzer (pressure, temperature, strain, force/load, displacement, refractive index, etc.). They have a high tolerance to fiber losses such as fiber bending, fiber attenuation, and source fluctuations. The technology promotes cost-effective sensors. The pressure sensor design is shown in Fig 16.17.

The pressure sensor performance is defined below:[14]

- Absolute pressure measure (0.25 mm Hg)
- Physiologic pressure range (±300 mm Hg)
- Robustness: Proof pressure (> 6 atm)
- Linear pressure response (NL < 1%)

- Good sensitivity (~2 nm/mm Hg)
- Stability (low drift <1 mm Hg)
- Predictable low thermal shift (<0.4 mm Hg/°C)
- Fully biocompatible materials
- Sterilization [ethylene oxide (EtO), electron-beam, etc.]

As discussed in the chapters on temperature and pressure, several fiber optic technologies can provide measurements suitable for biomedical applications. As an example, a Bragg-grating-based sensor can be integrated with an endoscope to provide pressure or temperature data in conjunction with imaging.[15] Bragg grating temperature sensors have been used to enhance the effectiveness of laser-induced thermotherapy. A problem with thermotherapy is detecting the temperature distribution of the treated tissue in real time. Bragg grating sensors were able to provide the temperature distribution with a spatial resolution of 0.25 mm within 10 sec. The temperature distribution information allowed more precise control of the laser parameters and a better therapeutic result.[16]

Medical applications for pressure sensors include: intracranial pressure monitoring, intrauterine diagnostics, pediatric surgery, bleed control during surgery, intraocular pressure control, and urodynamics. An example of using a fiber optic pressure sensor in counter-pulsation [intra-aortic balloon (IAB)] therapy is shown in Fig. 16.18.

The biophotonic concepts can function over a broad spectral range including UV, visible, near IR, and mid-IR. The advanced stage of component availability in the C band due to telecommunications investment has generated biophotonic sensing schemes that utilize this established technology. Those applications that can function in the UV, visible, and near IR also benefit greatly from optical fiber technology and are for the most part compatible with optical fiber integration. However, biophotonic sensors that have unique chemical sensing properties in the mid-IR are no longer compatible with silica-based optical fibers, which are limited to wavelengths less than 2 μm. However, fibers are available that function into the mid-IR range.

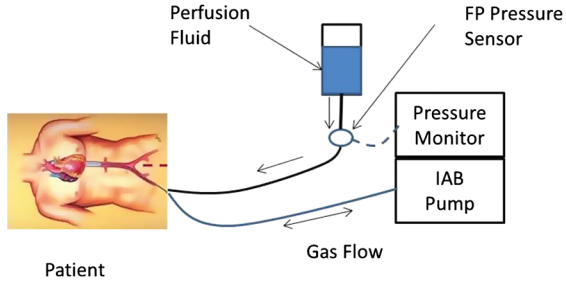

Figure 16.18 Fluid pressure transduction.[14]