Compact, inexpensive, temperature-tunable thin-film filters that support a range of sensor applications can be developed by taking advantage of the thermal properties of amorphous semiconductors.

Tunable optical filters, if sufficiently compact and inexpensive, can be used to support low-cost sensor applications across many disciplines and wavelengths. By taking advantage of the thermal properties of certain thin-film materials, we have developed a series of low-cost tunable filters that support applications in telecom, trace gas detection, biomedicine, and the oil and civil engineering industries.

Development of new optical devices in recent years has been energized by the market pull of wavelength-division-multiplexed (WDM) fiber-optic networks, which require new capabilities in miniature tunable components. Until recently, the only commercially successful fiber-optic tunable filter had been the miniaturized micro electro-mechanical systems (MEMS) version of the classic Fabry-Perot design, with articulated micro-mirrors of micromachined silicon.

The principle of the Fabry-Perot design—two partially reflective mirrors with a variable space between—is more than a hundred years old. But Fabry-Perot filters are limited by the spectral bandpass profiles they can produce. When more carefully shaped bandpass filters are required, such as the flat-topped, steep-sided filters needed for WDM networks with closely-spaced channels, more sophisticated filter structures become essential. Thin-film interference filters were already more flexible in design than Fabry-Perot filters, but a tunable version was needed. Figure 1 shows the difference between the Fabry-Perot band shape and that possible with various tunable thin-film designs.

We designed tunable thin-film filters without moving parts by using amorphous semiconductors, such as hydrogenated amorphous silicon a-Si:H, a material well known in the solar cell and flat-panel-display industries, but as yet unfamiliar to those in in photonics. Semiconductor materials are strongly index tunable by temperature. In addition, although thin-film amorphous silicon has both excellent transparency in the near IR and a large refractive index, its temperature sensitivity has been a reason for excluding it from use in conventional WDM filters in the past. So, this was the area where we focused our research: we reversed this logic by trying to develop components with maximum temperature tunability.

For use in telecom applications in the 1500nm band, amorphous silicon, deposited by plasma-enhanced chemical-vapor deposition (PECVD), can be produced with an unusually large sensitivity of the refractive index to temperature (thermo-optic coefficient): between 20 and 100 times greater than typical dielectric films such as silicon dioxide. Figure 2 shows a scanning electron microscope (SEM) photo of a thin-film filter made of alternating layers of amorphous silicon and silicon nitride on a silicon wafer substrate. Measurements of the center wavelength versus temperature showed that up to 50nm of tuning was possible in the telecom ‘C’ band. The tuning range needed for this...
Figure 2. A thin-film filter can be made of alternating layers of amorphous silicon and silicon nitride (the line points to spacer).

Figure 3. The thin-film tunable filters are manufacturable and testable on a wafer scale (shown here on a 4-inch wafer).

Figure 4. This tunable optical detector includes a tunable filter and detector in a fiber-pigtailed co-axial transistor outline (TO-can).

Figure 5. Spectral emission of a narrowband IR source designed for carbon monoxide detection.

The first applications have been as sensors for fiber-optic networks, to measure and monitor the channel traffic in the fiber by tapping a small amount of light and scanning the filter continuously. Figure 4 shows our tunable optical detector, a tunable filter and detector in a fiber-pigtailed TO can, which could be the smallest optical spectrometer available.

Beyond simple wavelength tuning, our research has led to the development of thermo-optic filters that offer new types of dynamic functionality, such as switching between transmission and reflection at a fixed wavelength channel. At the Optical Fiber Conference (OFC) in 2003, data from a prototype five-cavity, 117 layer filter consisting of mixed cavities of thermo-optic and non-thermo-optic materials was shown. Instead of tuning over wavelength as the temperature is varied, this filter sits at a fixed wavelength channel and switches between transmissive and reflective states as it is thermally activated.

Continued on next page
We have also used the same concept of micro-tunable thin-film filters in applications in the mid-IR optical sensor market. By using germanium instead of silicon as the active material, the tunability is greater: about 5% (or 250nm) at 5μm, which is enough tuning to measure the CO₂ level in human breath.

For sensing trace gases in the mid-IR range, we have developed a narrowband integrated tunable emitter in which the tunable filter was packaged in close proximity to a modulated black-body in a small TO-5 can. Figure 5 shows the narrowband tunable emission of a unit made to detect carbon monoxide. In some applications, this miniature IR tunable emitter may be able to replace the function of a tunable laser for about 1% of the cost.

Author Information

Lawrence H. Domash
Chief Scientist
Aegis Semiconductor Inc.
Woburn, MA

Lawrence Domash is chief scientist at Aegis Semiconductor. Previously he was division manager, Photonics Division, of Foster-Miller Inc. He holds a Ph.D. in Physics from Princeton University and has worked in several areas of optical science, including optical-fiber design, laser physics, and diffractive optics.

References