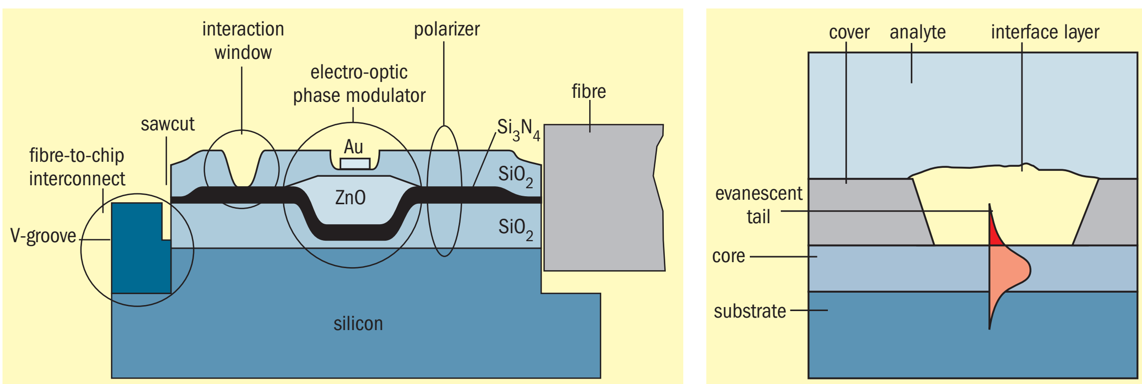
Sensor industry learns lessons from telecoms

The telecoms industry has invested heavily in integrated optics and waveguide-technology research. Now the sensing industry is set to reap the benefits. **Nadya Anscombe** reports on the development of a chemical sensor that is based on integrated optics.



The integrated optical sensor developed at the University of Twente in the Netherlands is based on the design of a Mach Zehnder interferometer (far left). To probe an analyte the device uses the evanescent field of the mode propagating along the waveguide structure (left).

"The telecoms industry thinks that making integrated optical sensors is easy," said Paul Lambeck from the University of Twente's MESA+ Institute in the Netherlands. And at first glance, it seems that the telecoms industry is right: for instance, integrated optical sensors do not have to be made polarization independent; they can tolerate high losses; and they operate at much lower speeds than integrated optical components for the telecoms market.

"However, sensors have a window to the outside world that not only allows contact with the sample, but also makes the sensor vulnerable to disturbances," countered Lambeck. "Integrated optical sensors do not have the protective cladding that telecoms components have."

Counting the cost

Lambeck's group has taken its knowledge of making optical integrated components for the telecoms industry and applied it to the sensors market, using the waveguiding element as the sensing region.

"The fragmented sensors market cannot afford to pay all of the costs of investigating the potential of new device principles. Nor can it afford the investment required to develop the simulation software and technologies for an optimized design," said Lambeck. Fortunately, the sensors field can apply many of the integrated optical functions developed for the telecoms market to both the conditioning of incoming light and the reading out of information.

Waveguiding systems offer a convenient mechanism for transporting light, which eliminates the need to align components. They are also more compact than conventional optical sensors, and cheap, batch-wise production is possible.

Lambeck and his group have made a chemical sensor that can detect a change in refractive index of 10^{-8} – the smallest change ever recorded, says Lambeck. The device is being commercialized by Dutch firm Mierij-Meteo for use in detecting atmospheric gases, such as water vapour, carbon dioxide and ozone. However, the sensor, which is based on a Mach Zehnder interferometer (MZI) design, can also be adapted to detect chemical and biological agents by changing its interface layer.

The change in the optical properties of the interface is probed by the evanescent tail of the mode propagating along the waveguide structure. Interactions with the analyte can either alter the tail's propagation speed, caused by a change in refractive index, or alter its attenuation, effected by a change in the absorption coefficient.

Evanescent-field sensing has several advantages over bulk optical methods. For example, if the interface layer is very thin, the evanescent field can probe a sample over a long interaction length, which makes the sensor extremely sensitive.

"Our device also has a sensitivity that is many times greater than that of conventional sensors and other optical techniques," said Lambeck. "For example, if there was a single bacterium in the sensing area, it would be detected. Also, unlike conventional immunosensors, our MZI device does not need to use labelled antigens because it can detect viruses directly."

Flexibility wins

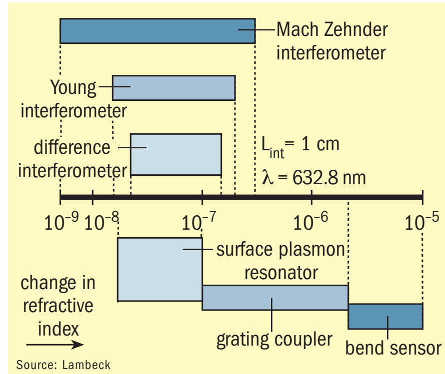
The MZI sensor is made using silicon oxynitride (SiON). This material system was chosen because III–V compounds and lithium niobate have proven too expensive in the past, and silicon dioxide (SiO_2) only offered low refractive-index contrasts. "With SiO_2, you need to make bends with large radii of curvature to avoid losses," said Lambeck. "With SiON we have much more flexibility with both the material and the layout. For example, the higher the refractive index of the core layer, the higher the sensitivity of the device. The SiON family is limited by Si_3N_4, which has a refractive index of two."

Lambeck's group at the MESA+ Institute also has good contacts with fellow Dutch company Lion Photonix – a foundry that ▷

was spun out of the Institute and that specializes in SiON technology. Lambeck says that this relationship was essential for the project to succeed: "If you want to develop sensors, you must have good contacts at a foundry. Manufacturing equipment is expensive and sensors are only made in small quantities. This means that the equipment will not be continuously in use and it is uneconomical for you to buy it yourself."

Lambeck admits that some aspects of designing the sensor have been easier than designing a telecoms component. He said: "In integrated optical sensors, losses are not so important because there is a difference of five or six orders of magnitude between the incoming power and the detectable power. This means that the fibre-to-chip coupling can be lossy. In our systems we have a standard efficiency of about 50%. For telecoms, that is too low, but for sensors it is acceptable."

Also, while the polarization dependence of the system makes it easier to manufacture, this can present a problem for sensing applications. "The TE and TM modes have different propagation constants and evanescent fields. In our systems we can control the polarization state of the light that is coming in because the laser can be put in front of the integrated optical system."



There are many types of integrated optical sensors, but the Mach Zehnder interferometer can measure the smallest change in refractive index.

However, other aspects of developing the sensor have presented the group with considerable challenges. "Small temperature differences between the branches of the MZI influence measurements because refractive indices are always temperature dependent. Intrinsic problems also include fringe ambiguity, direction ambiguity and sensitivity fading," said Lambeck. "In addition, to obtain maximum sensitivity the optimum thickness of the core layer is completely different from the optimum thickness of an efficient fibre-to-chip coupling."

In spite of these challenges, Lambeck's group has developed a sensor that it believes will succeed on the market because it offers greater sensitivity than conventional sensors. "For chemical sensors based on integrated optics to penetrate the market, we believe the best they can offer is a sensitivity that is better than any other method. We also believe that they could be used to make sensor arrays on a chip."

Lambeck and his group are also investigating the use of three-dimensional photonic crystals to make multisensing arrays on a chip. He commented: "The systems look promising because the dimensions of the functions can be decreased to one-tenth of the size of those on our current design. For example, bends in integrated optical sensors need to have a minimum radius of curvature, but in photonic crystals you can have bends of almost 90°." □

For more information

Mierij-Meteo **www.mierijmeteo.nl**
University of Twente **www.el.utwente.nl**
Lion Photonix **www.lionphotonix.nl**