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Surface Waveguide Technology and Applications for a Nanotechnology Era

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Surface waveguides are widely used in telecommunications applications, providing the base technology in devices such as the wavelength add-drop switch, the dynamic gain equalizer, and the ubiquitous passive waveguide router. Requirements in telecommunications are dominated by a need for low optical attenuation and minimal polarization effects such as polarization-dependent-loss (PDL) and polarization-mode-dispersion (PMD). The guiding properties of silicon dioxide are well suited to the 1.3-1.6 micron wavelengths used in telecom, and can yield very low attenuation per centimeter – as low as 0.05 dB/cm. Therefore, waveguides based on SiO_2 have become the *de-facto* standard telecom waveguide technology.

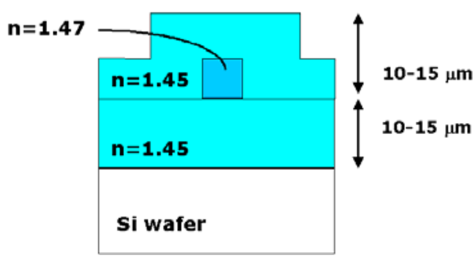

Fig 1: *Cross-section of a conventional SiO_2-based waveguide. For telecom applications, the core is typically 8 mm-square.*

SiO_2 waveguides are typically formed using core and cladding layers with only a slight difference in index of refraction. As a result, optical circuits based on SiO_2 tend to be large due to a large minimum bending radius that results from the low index contrast. In addition, some of the layers that comprise the waveguides can be up to 20 microns in thickness (Fig. 1). It is difficult to control doping level and the mechanical stress (which leads to modal birefringence) in films this thick, which in turn makes control of the polarization characteristics of the waveguide difficult. These factors make optical circuits expensive to produce and use. As a result, alternative material systems that can provide the required performance, but with higher contrast between core and cladding, have become increasingly attractive.

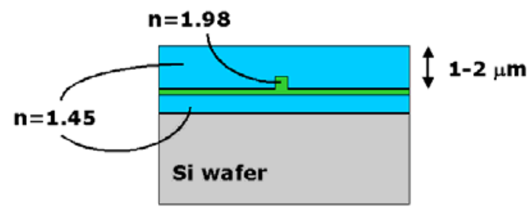

Fig. 2: *Cross-section of a high-contrast waveguide comprising a SiN core layer. Cladding layer thickness is roughly an order of magnitude thinner than in conventional SiO_2-based waveguides.*

LioniX, BV, of the Netherlands, has been active in the development of optical circuits based on silicon nitride (SiN) and silicon oxy-nitride (SiON). These material systems offer much smaller bending radii and stronger confinement of the optical mode to the core. As a consequence, waveguides can provide effective guiding with a core that can be sub-micron (Fig. 2).

Representative devices have been developed for telecom applications and biochemical sensor applications. A Mach-Zender Interferometer (MZI) has been developed for biochemical sensing and has been proven to have extreme sensitivity. Furthermore, the MZI is designed to have a large TM polarization rejection. The sensor is also generic, *i.e.* becomes selective through applying a thin layer of an appropriate transducer material to a measurement window that exposes a portion of its surface (Fig. 3). The MZI provides the sensing technology on which a LioniX customer is basing a suite of environmental monitoring sensors.

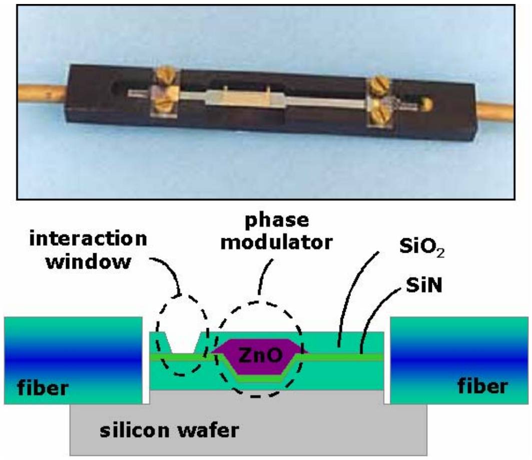

Fig. 3: *A Mach-Zehnder Interferometer-based sensor for detecting biological or chemical agents. A layer of zinc-oxide provides electro-optic modulation capability to increase the signal-to-noise ratio of the sensor.*

A device that demonstrates telecom capability has been developed that relies on “surface treatment” of an SiO_2 waveguide core with a nanometer-scale layer of silicon nitride (Fig. 4)ew technology enables design of a waveguide that has the low attenuation property of conventional SiO_2 with independently-determined polarization characteristics. Attenuation of 0.12 dB/cm and modal birefringence as low as 10^{-4} has been demonstrated.

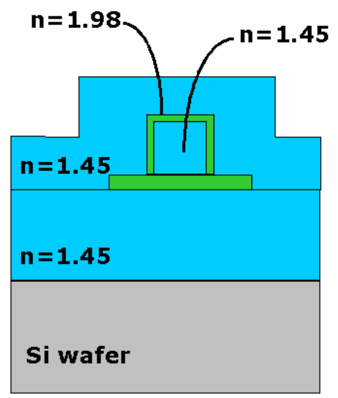

Fig. 4: *A new composite-core waveguide that has recently been developed by LioniX. The light-guiding core comprises a central region of conventional SiO2, which is surrounded by a thin layer of SiN. The inherent residual stresses in the two materials can be used in designs that compensate the stress configuration of the core. As a result, modal birefringence can be designed to be very low (10-4) through very high (to enable the stripping of one propagation mode).*

For sensor and telecom applications, the surface waveguide geometries allow for very efficient fiber-to chip coupling. Furthermore, as these waveguides are manufactured at very high temperatures, their properties are extremely stable. Finally, in contrast to Si based waveguides, for example, these materials are not restricted to the conventional telecom wavelengths, but are transparent from 400 nm up to 2 micron and above, which is very attractive in future LAN systems.