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OPTOFLUIDIC SENSORS USING PHOTONIC CRYSTAL WAVEGUIDES

Optofluidics refers to optical systems that integrate nanophotonics and microfluidics. Such systems comprise of optical and fluidic devices. They can open up new application avenues in the field of optical technology, one such application being sensors. This optofluidic sensor can be used to detect, manipulate, and sort cells, viruses, and biomolecules in fluidics. Most of the optical sensors operate by measuring the change in the refractive index at the surface of the sensor via surface-plasmon resonance, colorimetric resonances, and interferometry methods. However, these methods can require large-area beams and a large sensing area.

Photonic crystals are excellent optical materials that can be used to control and manipulate the properties of light. Recently, they have attracted interest for optoelectronics applications due to the unique light confinement provided by the photonic bandgap. Researchers have already demonstrated an ultracompact sensor using a two-dimensional (2D) photonic crystal microcavity. Some of the potential applications of optoelectronics using photonic crystals are high-quality-factor filters, low-threshold lasers, optical switches, optofluidics and many more.

In optofluidics, photonic crystals have voids, which enable fluid injection. Waveguides using photonic crystals are highly dispersive; and this property is used to reduce the propagation velocity of light. Researchers from the Department of Micro and Nanotechnology, Technical University of Denmark, Europe, have proposed a simple optofluidic sensor structure using photonic crystal waveguides. The structures are highly sensitive to the refractive index of the liquid, which is used to manipulate the dispersion of photonic crystal waveguides.

The study involved 2D photonic crystal waveguides with a triangular array of air holes in a dielectric medium such as gallium indium arsenide phosphide (GaInAsP) or indium phosphide (InP). The dielectric medium is considered to be nonabsorbing. A photonic crystal waveguide is thus formed by reducing the radius of the air holes in a single row. The holes are useful for local refractive index modulation by selectively filling them with liquid. The researchers calculated the photonic band structure using a plane-wave method. The results indicated a wide photonic band for magnetic fields parallel to the air holes.

The current methods for local index modulation, such as weak nonlinearities, mechanical deformation, thermo-optics, and liquid crystal infusion, tend to not offer proper refractive index modulation (either low or nonlocal in nature). However, nanofluidics provide localized as well as high refractive index modulation. Some of the other researchers have previously demonstrated nanofluidic tuning of photonic crystal circuits. Hence, the researchers at Denmark Technical University have analyzed the transmission spectra for the photonic crystal waveguides. The central air holes were filled with different liquid with varying refractive indices.

The analysis indicates the propagation of light is subdued in the mode-gap region of low-frequency region. The photonic crystal waveguide is a loss-less device, but the efficiency is never close to the unity due to the coupling loss at the two boundaries to the slab waveguides. Oscillations at the boundaries cause peaks in transmission. However, the researchers were interested in the examining the spectral position of the mode-gap edge. The low-frequency mode-gap edge does not change with the refractive index of the liquid due to the property of the surrounding photonic crystal, while the high-frequency mode-gap edge is highly dependent on the refractive index of the liquid. It is also found that with the increase in the central hole size, the sensitivity improves. However, there is a discrepancy of 4% between the calculated and experimental results. The experimental results indicate that a simple photonic crystal waveguide can be used as a sensitive sensor.

The dispersion of the photonic crystal waveguide in the absence or presence of a fluid was also analyzed. Again, the air holes are filled with different liquids with varying refractive index. The test results were consistent with the transmission spectra characteristics. Also, experiments were performed using an air channel waveguide. The high-frequency mode-gap edge varies with the increase in the refractive index of the liquid, while the low-frequency mode-gap edge depends on the liquid. The results indicated higher sensitivity.

The sensor is based on the dispersion of the photonic crystal waveguide mode and the presence of the mode gap. The sensitivity of the device can be improved by varying the radius of the structure. Thus, the sensor structure depends on the refractive index of the liquid, which is used to tune the dispersion of photonic crystal waveguides. The channel waveguide in the photonic crystal has better sensitivity compared to the air-hole waveguide. The research could be extended by using 2D photonic crystal slabs, which would be more useful in chemical sensing applications.