Nano air-hole waveguide for photonic integrated circuit

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(フォトニック集積回路に向けたナノエアホール導波路に関する研究)

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論 文 内 容 の 要 旨

Thesis Summary

Global health plays an increasingly crucial role in global security. One of the main challenges to global health security is cancer, which is one of the leading causes of death. At present, human beings still have not found a very effective way to treat cancer. Thus, health monitoring and early treatment is still the most popular way to reduce cancer mortality. Breath gas analysis has attracted strong interest in human health sciences. Certain special gases that are present in exhaled air have been identified and associated with certain cancers. In this case, breath analysis has enabled a promising technique which is serving as biomarkers. Cancer can be detected and treated early via the daily convenient health check, to reduce cancer mortality. We are working on a compact breath sensing system that can be integrated on a cell phone or other mobile equipment, which makes routine health monitoring much cheaper and easier for ordinary citizens.

The refractive index sensing technique utilizing a one-dimensional photonic crystal waveguide is a very sensitive and accurate method for the analysis of a variety of biomarkers. In this way, optical resonances have been widely used in optical sensors, which have attracted considerable interest for gas sensing applications. Therefore, we propose a photonic crystal cavity consisting of a bus waveguide and a tangent air hole array (1D PhCC-TAH). Based on this design, we can tightly confine light in the air region where it fully overlaps with gas molecules to improve the gas RI sensitivity. We theoretically analyzed the gas RI sensitivity and the spectral features of the photonic crystal cavity as a function of the structure parameter and the methane gas concentration. In addition, the coupling efficiency of the waveguide and the influence of the temperature on the proposed structure for sensing applications has been investigated. Finally, the proposed two tangent hole structure simultaneously achieves high sensitivity (353 nm/RIU) and a figure of merit ($FOM=1.2\times10^4$) that is comparable to previously reported results. As these results, the proposed 1D PhCC-TAH structure is a potentially ideal platform for RI-based breath gas analysis and environmental monitoring.

On the other hand, the associated technique of deep learning is thus considered a promising candidate for the design of new nanophotonic devices. To realize a hand-held size breath sensor for the home-use health check, our group proposed a compact high-mesa waveguide-based cavity ring-down spectroscopy (CRDS) sensing system that can be integrated on-chip with the footprint of 1cm ×1cm. One of the serious challenges is; however; the coupling loss between devices including Si-wire waveguide (or laser diode) and fiber. To reduce the coupling loss, spot size converter (SSC) is also commonly used by freely tuning spot size expansion in the lateral and vertical directions. Herein, we propose nano-pixel SSC with changing hole-size and density. We also discuss the concept of vertical field enhancement using nano-pixel density-control and design the optical field in the lateral direction using DNN-based learning to makes an ideal circular field because of the potential of vertical and lateral field tuning. Furthermore, the coupling efficiency and the vertical

filed expansion of the designed SSC structure after combining a SiO_2 window structure (5 × 15 × 10 μm^3) were analyzed. The 1-dB operating bandwidth of the designed SSC structure is 100 nm (1.5 -1.6 μm). Finally, the fabrication tolerance of nano-pixels and window structure length for the designed SSC structure was discussed. As a result, the designed SSC with nano-pixels waveguide based on the high-mesa waveguide to reduce the coupling loss in the CRDS sensing system, to increase the gas detection sensitivity.