Low Loss Waveguides and AI-designed Optical Couplers for Breath Sensing

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(呼気センシング用低損失導波路とAI 設計光カプラーに関する研究)

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論　文　内　容　の　要　旨

Thesis Summary

Population ageing is becoming one of the most significant issues in twenty-first century. One of the consequences of a population aging is its challenge on public health care. Compared to the traditional blood or urine tests, breath content detection is less stress to human body to collect and real time for health-monitoring. As a result, for the early detection of lifestyle diseases, breath sensing is gaining more attention.

For home-use, breath sensor based on infrared absorption spectroscopy has the possibility to sense several kinds of gases at the same time. This is because each gas has its own eigen absorption peak in wavelength. To achieve the effectively long length sensing path (corresponding km order) within a cavity, CRDS (cavity ring-down spectroscopy) has been proposed. One issue of the traditional CRDS system as home-use sensor is its large size.

For bring the possibility of integrating the whole CRDS system into a cell phone for real-time health-monitoring, we propose a future version of CRDS photonic integrated circuits. On the circuits, the optical devices, including the sensing waveguides, optical power couplers and polarization rotators, are critical for realizing compact and highly sensitive CRDS. In previous work, we have proposed low-loss SiO_2 high-mesa waveguides for the breath sensing. One issue of preventing further ppm-order detection is the low portion of evanescent light (Γ_{air}=2.2%). In order to realize low propagation loss α and high Γ_{air} simultaneously, we have researched 100 nm thick Si high-mesa waveguides in this work. Si has much higher refractive index (3.45) than that of the doped SiO_2 (1.48) at the wavelength of 1.55 μm, which enables a narrower waveguide width and a larger fraction of the mode residing beside the sidewalls. The calculated results confirm that Γ_{air} of Si high-mesa waveguides is much higher than that of the previous SiO_2. After fabrication, α of the Si waveguides is still high and the thermal oxidation technique is applied to further reduce α. After thermal oxidation, α is effectively reduced from 1.45 to 0.84 and 0.29 to 0.2 dB/cm for the 0.5 and 3μm-wide waveguide, respectively. The reduction of α is attributed to the decrease of the sidewall scattering loss and the damaged Si absorption loss. The high Γ_{air} and effective loss reduction show a promising potential of applying Si high-mesa waveguides to realize ppm-order sensing.

Optical power coupler is one of the well-used components in integrated photonics. Although couplers with an output power ratio 1:1 have been widely studied in the past, constructing asymmetric-ration optical power couplers is still an issue, which is difficult to be addressed by using traditional Y-branch waveguides. Artificial intelligence (AI) assisted design is an effective technique for realizing complex optical structures. In this work, two asymmetric couplers with a splitting power ratio of 1:9 and 1:99 have been designed via AI assisted inversely design method. To realize the asymmetric ratios, the coupler region was divided into discrete nano-pixels in the shape of circular holes with the same dimension. AI program was utilized to decide the

material of each hole to be waveguide or air one by one and FDTD simulation was introduced to evaluate the performance of the AI designed couplers. After 1452 trials, the splitting power ratio of 1:9.007 and 1:99.004 has been realized in the two couplers with a same footprint of 3.4 × 3.2 μm^2. In addition, the positions and widths of the output waveguides were further optimized as the excess loss of the AI-designed coupler is a bit high of more than 3.50 dB. Through the optimization of the configuration, a scattering loss reduction of 1.7 dB by position optimization, and a coupling loss reduction of 1.6 dB by width widening were confirmed. The achieved design exhibited an operation wavelength from 1500-1600 nm and a sufficient fabrication tolerance of ±10 nm (± 11%).

In the development of photonic integrated circuits (PICs), polarization management is an important research topic because of the polarization-dependency of the optical waveguide devices. Polarization rotators, therefore, are often used to manipulate the polarization state of optical wave. Traditional rotators are either with a large size, a complex fabrication or a high excess loss. In this work, a polarization rotator designed with artificial intelligence (AI)-assisted design has been proposed and demonstrated. The total footprint of the rotator is 2.1 × 12.58 μm^2 with the polarization extinction ratio of 25.8 dB and the excess loss of 0.17 dB. Furthermore, the proposed rotator exhibits sufficient fabrication tolerance of ±10 nm (±6.7%).

The demonstrated optical devices will pave the way for developing compact CRDS integrated photonic circuits.