ON-CHIP SPECTROMETER AND FABRICATION PROCESSES

Optical spectrometer has been one of the most important instruments for spectrum analysis in various applications such as chemical analysis, environment monitoring, remote sensing in satellites and so on. It has been made smaller and smaller for more convenience and less cost as it is critical to bring the chemical/biological sensing, spectroscopy, and spectral imaging into robust, compact and cost-effective devices. A promising way to implement a miniaturized spectrometer is on the photonic integrated circuits platform.

The first part of the thesis reports a high-resolution photonic spectrometer using a tunable MRR filter. The MRR is thermally tunable by exploiting thermo-optic (TO) effect with a high resolution of 0.1 nm and a large tunable range of 19 nm. The model of thermal modulation of MRR is theoretically analysed and built. Thermally tunable MRR can be very effective to finely shifting the resonance wavelength and only needs one detector for a single device. Besides, it has much higher tolerance of fabrication and is more compact compared to the approaches using the stationary MRR array. The implementation of tunable MRR array with an arrayed waveguide grating (AWG) before the array is designed, fabricated and experimentally tested. The AWG functions as a fixed filter to pre-disperse the input spectrum while the following tunable MRRs retrieve the corresponding dispersed spectra with high resolution (0.015 nm) to realize broad band (27 nm). By adoption of AWG before the tunable MRR array, the working band can be broadened while maintaining final resolution of the device thanks to the fine tuning ability of MRR. It is practical for especially high resolution applications.

The second part focuses on the development of a microring resonator cavity-enhanced Fourier-transform spectrometer (CEFTS). In this design, Fourier-transform spectrometer (FTS) is realized with a thermally tunable photonic Mach-Zehnder interferometer (MZI). A MRR with high quality factor is cascaded before the Mach-Zehnder interferometer to pre-filter the input spectrum while the MZI is exploited to reconstruct the filtered spectra. By finely tuning the MRR, the filtered spectrum is shifted for the tunable MZI to reconstruct. Thus, by combining the reconstructed filtered spectra, the input spectrum is obtained. The model of thermal modulation of MZI is theoretically analysed and built. The proposed spectrometer has both high resolution (0.47 nm) and very large bandwidth (150 nm) thanks to the large transparency window of MZI and high quality factor of the MRR. The thermal modulation of MZI is theoretically analysed and built. Low-loss Si slab waveguide is proposed and developed to reduce insertion loss and improve resolution.

The third part presents the fabrication processes using the nano-silicon-photonic (NSP) fabrication technology to fabricate the on-chip spectrometers. Using the advanced NSP technology, single-mode strip waveguide is achieved with low loss (1-2 dB/cm). And low-loss slab waveguides (0.1 dB/m) is also achieved with small footprint. TiN heaters and thermal isolation trenches are also developed and fabricated. TiN as resistive layer for heat generation has the advantages of high resistivity and compatibility with the NSP fabrication technology. Thermal isolation trenches are formed by etching away the top SiO_2 cladding and partial Si substrate removal (with Si substrate isotropic and anisotropic etching). Si_3N_4 waveguides are also developed and fabricated for potential applications of on-chip spectrometers in the visible range.

Publication list

Journal papers

[1] S. Zheng, H. Cai, Y. D. Gu, L. K. Chin, D. L. Kwong, Z. P. Lin, A. Q. Liu, 'High-resolution Microring Resonator Cavity-enhanced Fourier-transfrom Spectrometer on a Silicon Photonic Chip', 2018. (submitted).

[2] S. Zheng, H. Cai, Y. D. Gu, L. K. Chin, D. L. Kwong, Z. P. Lin, A. Q. Liu, 'AWG Pre-dispersed Integrated On-chip Spectrometer with Tunable Microring Resonator Array', 2018. (prepared)

Conference papers

[1] Zheng, S, Cai, H., Gu, Y., Chin, L. K., & Liu, A. Q. "On-chip Fourier transform spectrometer for chemical sensing applications." *CLEO: Applications and Technology*. Optical Society of America, 2016.

[2] Zheng, S., Cai, H., Gu, Y. D., Chin, L. K., & Liu, A. Q. "High-resolution on-chip spectrometer with a tunable micro-ring resonator filter". *Lasers and Electro-Optics (CLEO), 2016 Conference on*. IEEE, 2016.

[3] Zheng, Shaonan, L. K. Chin, and Ai Qun Liu. "On-chip spectrometer enhanced by ring resonator cavity: High-resolution and large-bandwidth." *CLEO: Science and Innovations*. Optical Society of America, 2017.

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