Integrated Spectrometers for Spectral-Domain Optical Coherence Tomography

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Optical coherence tomography (OCT) [1] is a non-invasive optical technique for high-resolution cross-sectional imaging of biological systems. Current OCT systems are bulky and costly. A significant decrease in the size of OCT systems is possible through integrated optics. In this work, we present the design and fabrication of arrayed waveguide gratings (AWGs) at 800 and 1300 nm as these wavelengths are commonly applied to retina and skin imaging, respectively. We perform interferometric depth ranging measurements with AWG spectrometers in a spectral-domain OCT (SD-OCT) set-up thus demonstrating the first important step toward miniaturization of an OCT system in silicon-oxynitride (SiON) for the 800-nm and 1300-nm spectral ranges.

For SD-OCT, the axial resolution and maximum imaging depth are mainly determined by the spectrometer. We aimed at a maximum imaging depth of 1 mm and an axial resolution of 24 μm and 19 μm for the 800-nm AWG and 1300-nm AWG, respectively. To meet these requirements the AWGs need a free spectral range (20 nm and 78 nm) and wavelength resolution (0.16 nm and 0.4 nm) of the 800-nm AWG and 1300-nm AWG, respectively. The remaining design parameters were calculated using the standard equations for AWGs [2]. Both spectrometers were fabricated with single-mode SiON channel waveguides with the parameters provided in [3].

The schematic of the SD-OCT system with the integrated AWG spectrometer is shown in Fig. 1a. The light from a superluminescent diode enters a free-space Michelson interferometer (MI) through a 50:50 beam splitter. The sample mirror is moved during the experiments, while the reference mirror is kept stationary. The AWG resolves the optical spectrum, which is imaged onto the camera by a high numerical aperture (NA) lens with 50-mm focal length. The acquired spectra are further processed by firstly subtracting the reference-arm spectrum, then compensating the dispersion of the imaging system, and finally resampling to k-space.

We achieved a depth range of 1 mm, as shown in Figs. 1b and 1c. The measured maximum signal-to-noise ratio is 75 dB. The full width at half maximum values of the point spread function at various depths are plotted in the insets of Figs. 1b and 1c. Experimental axial resolutions of 25 μm and 20 μm were obtained for the 800-nm and 1300-nm wavelength ranges, respectively. At larger depths, a decrease in resolution was observed for both AWG spectrometers, which may be due to imaging aberrations caused by the high NA lens.

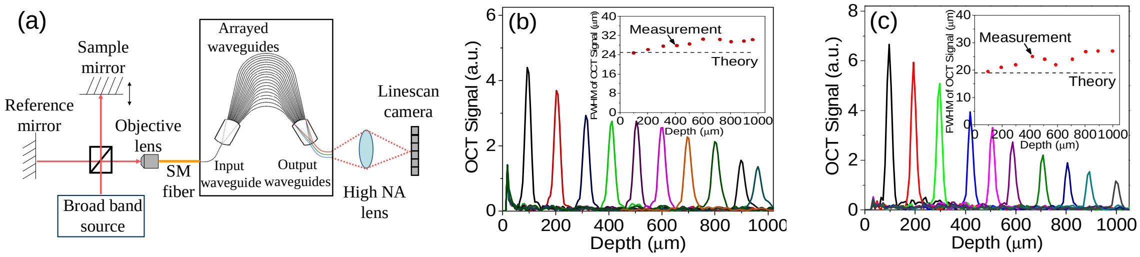

Fig. 1 (a). Optical measurement set-up of the free-space MI with an integrated AWG spectrometer. **(b) & (c)** OCT signal as a function of depth for a mirror reflector. The insets show the measured OCT axial resolution (solid circles) in comparison with the theoretical axial resolution (dashed line), for the 800-nm and 1300-nm wavelength ranges, respectively.

We have demonstrated the first partially integrated SD-OCT system by replacing a bulky free-space spectrometer by a SiON-based AWG spectrometer for the 800-nm and 1300-nm spectral regions. An imaging depth of 1 mm and an axial resolution of 25 μm and 20 μm (at 100 μm depth) were measured in the respective wavelength ranges. In future work, a MI will be integrated on the same chip with the AWG spectrometer.

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References

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J. G. Fujimoto, "Optical Coherence Tomography," Science **254**, 1178-1181 (1991).

[2] M. K. Smit and C. van Dam, "PHASAR-based WDM-devices: Principles, design and applications," IEEE J. Select. Topics Quantum Electron. **2**, 236-250 (1996).

[3] B. I. Akca, N. Ismail, G. Sengo, F. Sun, J. Kalkman, A. Driessen, M. Pollnau, K. Wörhoff, and R. M. de Ridder, "High-resolution silicon-oxynitride arrayed waveguide grating spectrometers operating around 800 nm and 1300 nm," submitted.