Toward Miniaturized Optical Coherence Tomography

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1. Introduction

Optical coherence tomography (OCT) is a widely used optical imaging technology with an increasing number of applications [1]. It has particular importance in the medical field since it can provide non-invasive, sub-micrometer resolution diagnostic images. Current OCT systems contain fiber-based or free-space bulky components which make these instruments costly. A significant decrease in the size and cost of an OCT system is possible through integrated optics. With a suitable material technology and optimum design, one can fabricate extremely compact and low-cost OCT systems, especially suited for applications in which instrument size may play an important role. In the literature there is only limited data on the implementation of OCT systems on a chip [2-3].

In this work, we present the successful attempt toward miniaturization of a spectral-domain OCT (SD-OCT) system by designing an arrayed waveguide grating (AWG) spectrometer in silicon-oxynitride (SiON) for the 1300-nm spectral range. The AWG spectrometer, with its excellent performance and compactness, has a high potential for various spectroscopic applications. The operation principle of an AWG is explained in detail in Ref. [4].

2. Design

The spectral range of the SD-OCT system near 1300 nm was specifically selected for skin imaging. For this device, we aimed at 18.5-μm depth resolution (determined by the full width at half maximum values of the transmission spectrum of the AWG) and 1-mm depth range (determined by the wavelength spacing per output waveguide). The free spectral range (FSR = 78 nm) and wavelength resolution ($\Delta\lambda$ = 0.4 nm) of the AWG were determined to meet requirements. The remaining design parameters were calculated using the standard equations for AWGs [4].

Single-mode silicon oxynitride (SiON) channel waveguides with 2 μm width and 0.8 μm height were used for the AWG spectrometer. For the upper cladding 4-μm-thick silicon dioxide was used. The core and cladding refractive indices were 1.55 and 1.4485 at 1.3 μm, respectively. The minimum bending radius of curved waveguides was calculated to be 500 μm. The minimum spacings between the arrayed waveguides and between the 195 output waveguides were optimized using the beam propagation method in order to reduce loss and crosstalk values.

3. Measurements and Results

A schematic of the fiber-based SD-OCT system with AWG spectrometer is shown in Fig. 1a. The Michelson interferometer was illuminated using a superluminescent diode which had a partially-polarized Gaussian-like spectrum with a bandwidth of 40 nm and a central wavelength of 1300 nm. Via a circulator the light was coupled into a 90/10 beamsplitter. Polarization controllers were placed into both, sample and reference arm. The backreflected light was redirected through the optical circulator to the spectrometer. The diffraction grating was replaced with the integrated AWG. The collimated beam was imaged with a high numerical aperture camera lens onto a 46 kHz CCD linescan camera. The acquired spectra were processed by first subtracting the reference arm spectrum, then compensating the dispersion, and finally resampling to k-space.

We achieved a depth range of 1mm, as shown in Fig.1b. The measured signal-to-noise ratio (SNR) was 75 dB. The axial resolution (FWHM) determined from a Gaussian fit to the point spread function in amplitude at various depths. A slight decrease in depth resolution was observed at higher depth ranges, which we attribute to misalignment and noise. As an example, an image of a Scotch tape was obtained with a depth range of 600 μm which is quite close to the theoretical value of 700 μm (the refractive index of Scotch tape is ~1.4-1.5). A better image could be obtained with a higher SNR by reducing the sources of noise in the set-up.

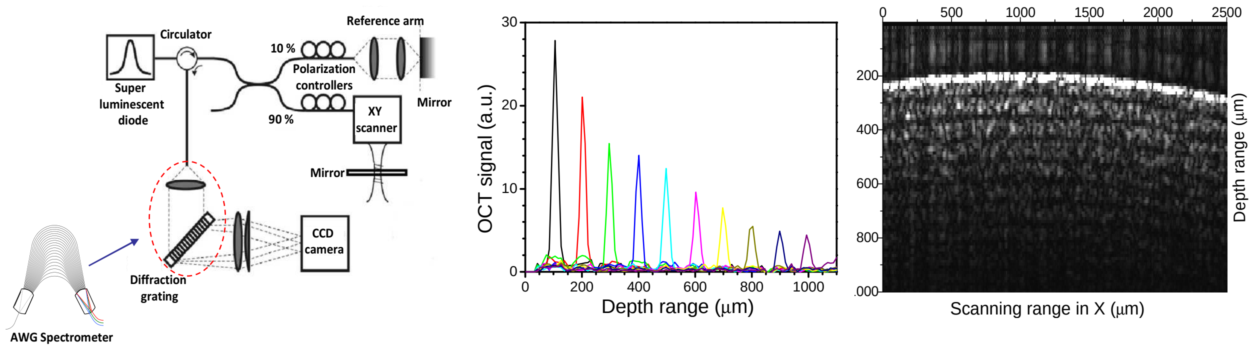

Fig. 1. a) Optical measurement set-up of fiber-based Michelson interferometer with integrated arrayed waveguide grating (AWG) spectrometer. **b)** Point spread function of the 1300 nm-SD-OCT system at different depths. The maximum depth range is1 mm. **c)** Image of a Scotch tape.

4. Conclusions

We have demonstrated the first partially integrated SD-OCT system by designing a SiON-based AWG spectrometer for the 1300-nm spectral region. The measurement results are in good agreement with the theoretical calculations. An imaging depth of 1 mm and an axial resolution of 22 μm (at 100 μm depth) were measured. An image of a Scotch tape was obtained with a SNR ratio of 75 dB. In future work, we will include an integrated Michelson interferometer as well as integrated focusing systems on the same chip with the AWG spectrometer.

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5. References

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