Photonic integrated common path Optical Coherence Tomography module

Introduction

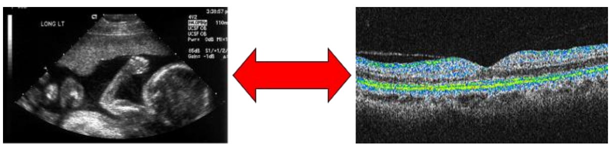
Optical Coherence tomography (OCT) is the optical analogue of ultrasound imaging. This technology is available in the market and used predominantly in ophthalmology. The current systems however are large, bulky and expensive, preventing a breakthrough in other applications fields. Photonic Integrated Circuit (PIC) technology is a key enabler to facilitate the development of OCT systems for handheld applications opening new market areas. Our silicon nitride based waveguide technology (TriPleX™) is extremely suitable for OCT applications due to its low loss over a large wavelength range (from 405 to 2350 nm) enabling OCT also outside the standard telecom windows of the C and O-band. In particular due to absorption properties of the human body other wavelength regimes are interesting.

First fully integrated OCT PIC

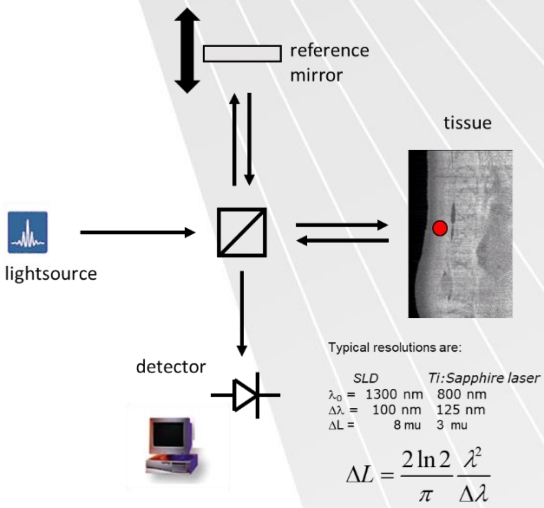
We developed the first fully integrated common path OCT PIC solution for spectral domain OCT around a wavelength of 850 nm based on the TriPleX platform. The chip contains both a common path interferometer and the spectral analysis via an on chip spectrometer resulting in a full handheld OCT probe. A broadband SLED is used as the light-source and the spectrometer is realized by using a cascaded Arrayed Waveguide Grating (AWG) on chip resulting in a 512 channel spectrometer to which the readout CCD is integrated. Combining both the common path interferometer and the spectrum analyser on chip results in a stable system allowing fast OCT analysis.

OCT Principle

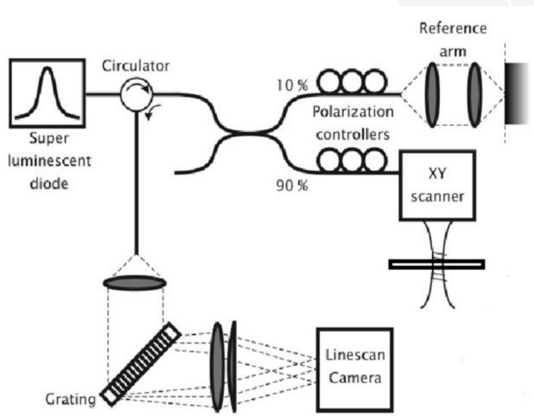
OCT is the optical analogue of ultrasound imaging and enables mm-scale morphological and functional imaging with a contactless technology.



Traditional OCT systems are based on interferometry systems with a narrow linewidth lightsource and a movable reference path. Schematically shown in the picture below. These systems however are slow due to the moving parts in the system (the reference mirror). Alternatives are to create the varying reference path by changing the wavelength.

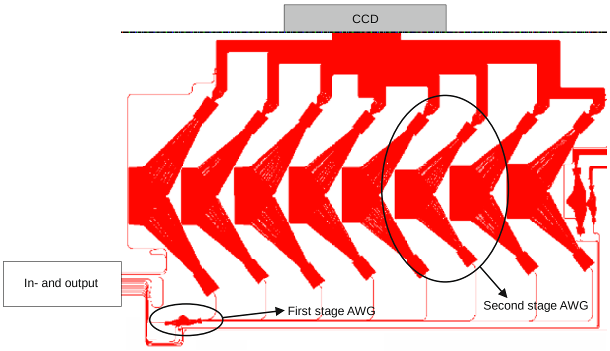


This can be implemented by either using a narrow linewidth laser which is swept in wavelength fast or a broadband lightsource where the spectral information is gathered at the detection side with a spectrum analyzer. This work deals with such a spectral domain OCT system in which a broadband lightsource is used. Schematically this is shown in the picture below.



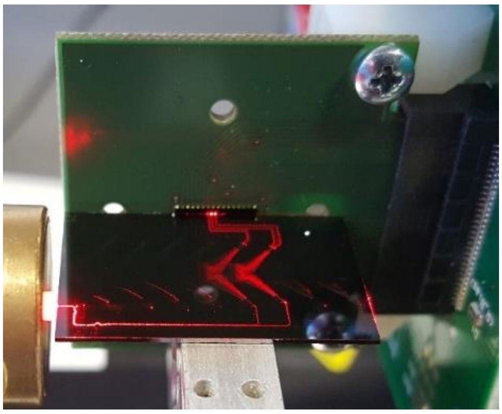
TriPleX implementation

The PIC with spectrometer is realized in the silicon nitride based waveguide technology TriPleX and is realized with Low Pressure Chemical Vapor (LPCVD) deposition of Si_3N_4 and SiO_2. Both materials are end-products of a chemical reaction resulting in stable materials in production. LPCVD is a batch processing enabling cost effective volume manufacturing also. The TriPleX process results in low propagation loss waveguides in a broad wavelength range (from 405 nm to 2350 nm), making it extremely suitable for OCT applications. Broadband AWG operation from visible to 1700 nm has been shown in the platform and Process Design Kits (PDK) are available enabling custom made designs in a system level design environment. This allows a low threshold entry for designing new designs for a broad wavelength range. With a mature manufacturing process different applications can be addressed by varying the waveguide geometry. The TriPleX process contains low loss spot size converters resulting in full control of the mode profile over the chip. This enables a low loss coupling to fibers (with a large mode profile) and a high confinement on the chip (allowing tight bend-radii and a small chip footprint).



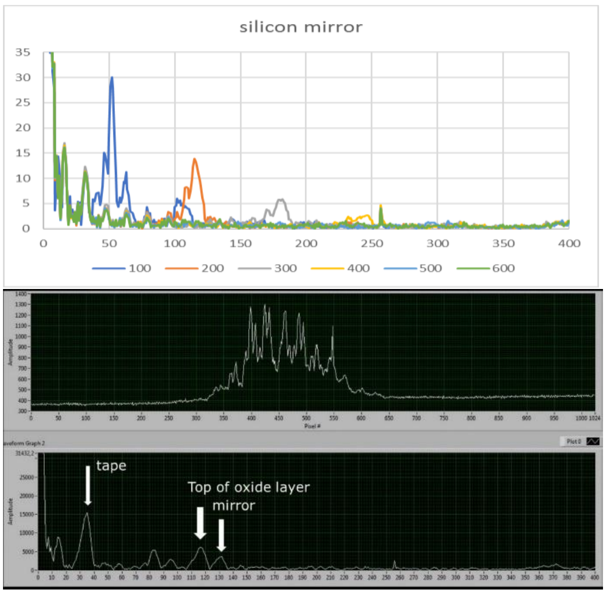
With the building blocks in the PDK a PIC was made with a cascaded Arrayed Waveguide Grating (AWG) as spectrometer and a common path interferometer was integrated on the chip as the schematic chip layout above demonstrates.

Next to the PIC with interferometer and AWG also the integration of the CCD to the chip was realized and combined with the readout electronics. The electronics and the packaged chip were packaged into a handheld enclosure with a fiber output operating as an OCT probe. The content of that box are schematically shown in the picture below.



CHARACTERIZATION

The assembled demonstrator was used to measure the OCT signal from different samples and generate an A-scan of these samples. The position of these samples was varied and tracking of the interface in the A-scan was shown. In Figure 9(a) the first experiment with a silicon mirror is shown. By moving the mirror further away from the sample probe the peak in the Fourier transformed spectrum is shown. With a labview software tool a live image of the spectrum and Fourier transformation is generated and the same measurement was done with the mirror replaced by a silicon wafer with thermal oxide and 1 or 2 layers of scotch tape. In the Fourier transformations clearly the peaks of the top of the oxide layer, the reflection on the silicon wafer and the reflection on the layers of tape can be seen. These initial results are show in the figure below.



LioniX International
PO Box 456
7500 AL Enschede
The Netherlands
Email: info@lionix-int.com
Phone: +31 53 20 30 053
www.lionix-international.com