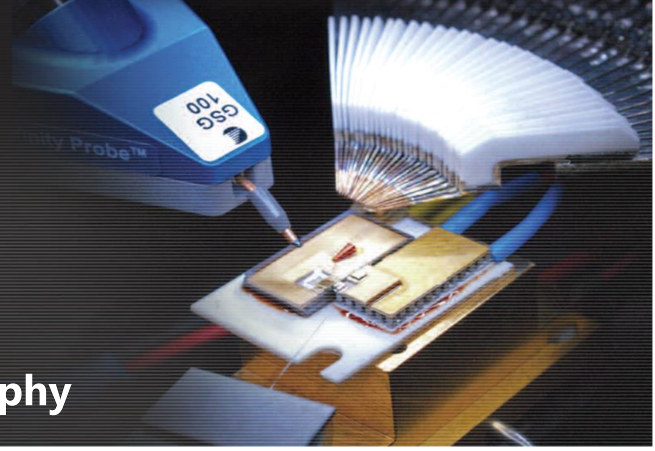


Photonic Integrated Circuits for Optical Coherence Tomography

As a non-invasive inspection technique, optical coherence tomography (OCT) is gaining continuous traction both in research and industry. Since the first commercialization of OCT systems in 1992, the market grew at an impressive 45% compound annual growth until today[1]. According to octnews.org, the ophthalmic OCT market alone reached a volume of over $ 300M in 2012, but OCT is also applied in a variety of other medical disciplines, as well as biology and biophysics. All those applications demand OCT systems to scale in resolution, speed and size, therefore they can benefit greatly from photonic integration.

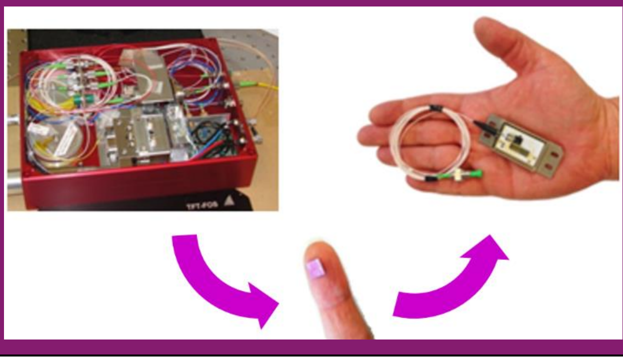
At its core, OCT is completely analogous to ultrasound imaging. The reflection spectrum of an illuminated sample is measured. Then, its Fourier transform gives the depth-resolved refractive index distribution. Employing a scanning mechanism then creates a true 3D image of the sample. The advantage over ultrasound is evident: the optical wavelengths are orders of magnitude smaller than ultrasound wavelengths, with the resolution scaling accordingly.

In practice, two distinct approaches exist to realize an OCT system: spectral-domain OCT (SD-OCT) uses a broadband light source, typically a superluminescent light emitting diode (SLED). In the SD-OCT case, the receiver is essentially a high-speed spectrometer. The second approach is swept-source OCT (SS-OCT). By replacing the broadband source with a wavelength-tunable laser source, SS-OCT does not require a spectrometer on the receiver side. Both methods have some basic relationships in common: the optical bandwidth (i.e. the SLED spectral width or laser tuning range) determines the spatial resolution. The frequency resolution (of the spectrometer or the tuning steps), on the other hand, determines the maximum depth that can be imaged. Typical OCT systems operate at wavelengths of 800 to 1310 nm. They are normally built out of discrete optical components with a rather low degree of integration, thereby being limited in …?.

Photonic Integrated Circuits (PICs)

Also known as optical chips, PICs can contain tens to hundreds of optical components. While electronic ICs consist of transistors, capacitors and resistors, a PIC consists of, for example, lasers, modulators, photodetectors and filters, all integrated on a single substrate. These PICs are nowadays extensively used commercially, mainly in datacom and telecom, becoming popular also in sensing.

PIC technology has now become accessible to users without a cleanroom, through so-called multi-project wafer runs and open foundries. Indium phosphide based technology is commercially available through SMART Photonics and Heinrich Hertz Institute. Access is coordinated by the JePPIX platform: http://www.jeppix.eu/.



The opportunity for photonic integration

Photonic integrated circuits (PICs) have the potential to greatly enhance OCT systems. As with many PIC applications, they address issues that revolve around scalability. In the case of SD-OCT, one parameter that continues to scale is the spectrometer channel count to allow for wider imaging ranges. Today's SD-OCT systems rely on CCD detectors, which cannot scale arbitrarily without sacrificing performance. Waveguide-

[1] https://spie.org/membership/spie-professional-magazine/spie-professional-archives-and-special-content/2014_jan_archive_spie_pro/oct_anderson?SSO=1

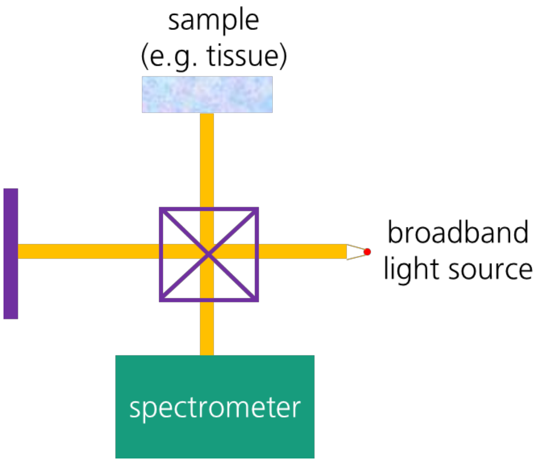


Figure 1. Spectral-domain OCT (SD-OCT) is based on a broadband light source (e.g. SLED) and a spectrometer put together in a Michelson interferometer.

integrated photodetectors can be used to form a complete spectrometer with below 1 cm^2 foot print[2]. Semiconductor photodiodes are also much faster than CCDs, allowing for the OCT scan rate to scale.

For SS-OCT, the PIC comes in not on the detector side but as the source. Modern tunable laser sources are mature PICs that benefit from many years of development for telecommunication applications. Specifically for OCT, important parameters are coherence length, tuning range and scan rate. Low linewidth lasers can deliver good coherence lengths, with tuning ranges of up to 80 nm in monolithic InP devices. Those devices typically use thermal tuning as a scanning mechanism, limiting the scan rate to below 1 MHz. PIC-based devices could rely on electro-optic tuning, unlocking scan rates well into tens of GHz with existing technology.

Of course, all types of OCT systems can benefit from the sheer size reduction that is enabled by photonic integration. PIC technology can enable handheld OCT devices without sacrificing performance.

Challenges

Since OCT is used for medical applications, getting new technologies accepted in the field is a major hurdle. Getting the supply chain certified and accepted is an ongoing effort, that is being put into place now[3].

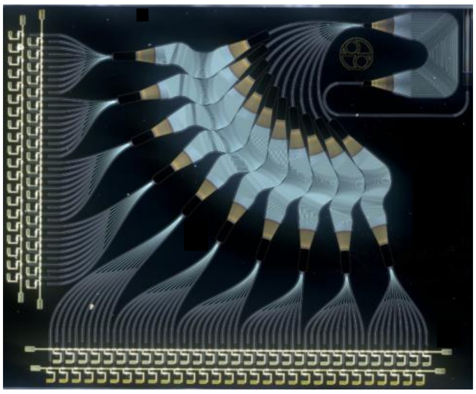


Figure 2. Fully integrated spectrometer in InP with 100 channels. Courtesy of Bright Photonics BV.

On the technical side, the intrinsic polarization dependence can be issue. We are currently investigating ways to make polarization independent PICs for OCT applications. Another area of research is implementing polarization diversity on chip to resolve not only amplitude information but also polarization sensitive information like birefringence. It has been shown that such schemes have the potential to greatly enhance the diagnostic value of retrieved images[4].

Discuss your application with us

If you are interested to know more about PICs for OCT applications, please contact Moritz Baier, coordinator of the PICs4All Application Support Center (ASC) at the Technical University of Berlin (TUB). We are actively engaged in applying PIC technology for OCT systems[5] and many other applications. We are prepared to do a feasibility study for the application you have in mind.

The PICs4All[6] consortium is funded under the Horizon 2020 framework and brings together expertise to support end-users with PIC technology. We help you connecting to the ecosystem of designers, foundries, packaging and test services.

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