Fully Integrated Optical Frequency Domain Reflectometry

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Optical Frequency Domain Reflectometry (OFDR) [1-5] provides valuable complex information (modulus and phase) in the time and optical frequency domains for characterization of new technologies and integrated devices. The standard approach employing fiber based Mach-Zehnder Interferometers (MZI) [1-5] requires dedicated bulky set-ups, subject to demanding stabilization conditions, in order to preserve the light polarization states and the optical phase variations due to temperature changes over long fiber MZIs (>4-5 meters in some cases due to the required fiber pigtails couple light to/from the photonic chip). Here we propose for the first time to our knowledge a fully Integrated OFDR (IOFDR) approach, where all the required MZI structures are co-integrated with the Device Under Test (DUT). The device was fabricated on a 100mm Si wafer, composed of a SiO_2 buffer (2.5μm thick, n=1.464) grown by thermal, following a LPCVD Si_3N_4 layer with thickness 300nm (n= 2.01) and a 2.0μm thick SiO_2 (n=1.45) deposited by PECVD.

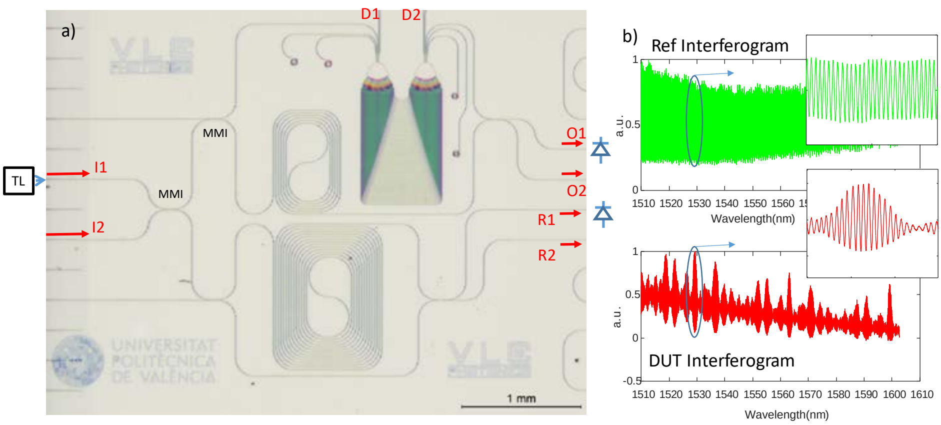

Fig. 1. a) Fully Integrated OFDR layout. b) DUT and Ref interferograms

The IOFDR set up is composed of two on-chip imbalanced MZIs, fed by a scanning Tunable Laser (TL), Fig. 1. The upper MZI embraces the DUT (a 5x5 Array Waveguide Grating (AWG) design as a proof of concept). The lower MZI is used to obtain the reference (or trigger) for the phase error correction due to imperfections during the TL scanning. In both MZIs we employ spirals to adjust the optical path differences ($\Delta L_{DUT}, \Delta L_{ref}$) according to the DUT characteristics. The objective is to ensure that the triggering interferogram provides sampling points of the DUT interferogram subject to the Nyquist criterion, in order to avoid aliasing of the DUT temporal response. We employ 50:50 MMIs for all the MZIs and also at the input signal splitting on the left hand side of the design. Finally, for the IOFDR assessment the TL signal, swept along 100nm (speed 40nm/s), is injected at input port I1 or I2, and the signals from one of the MZI-DUT outputs (O1 or O2), and one of the reference MZI outputs (R1 or R2) are collected and driven to two PIN detectors connected to, Fig.1.

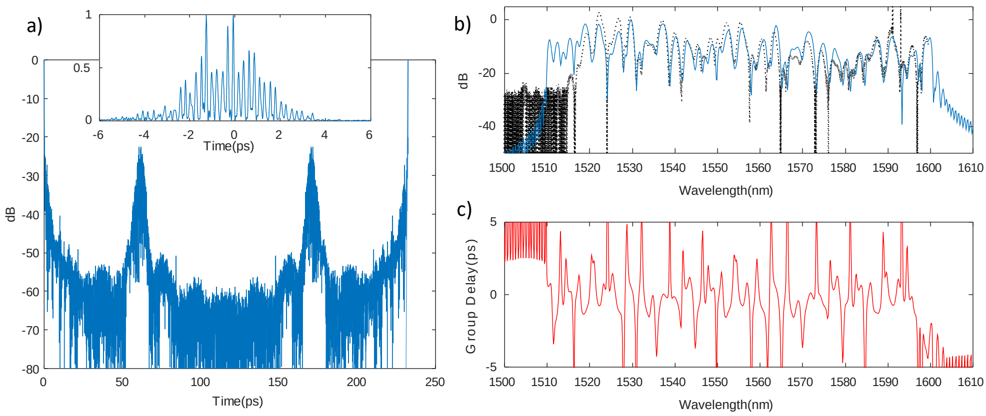

Fig. 2. a) DUT time response, b) Spectral amplitude: Dotted line standard measurement, Cont. line IOFDR, c) Group Delay response from IOFDR data.

After detection, the interferograms, Fig. 1(b), are sampled and acquired (5e4 samples/s per channel) and the DUT interferogram is re-sampled numerically in the reference zero-crossings to perform the correction for scanning errors. Finally, the Fast Fourier Transform (FFT) is employed to obtain the DUT time response $h(t)$, Fig. 2(a). Notice that we are representing the complete transformed signal in time domain ranging from 0 to 232 ps, that corresponds with the designed $\Delta L_{ref} = 36.9\,mm$ ($n_{eff} \approx 1.89$). Time response $h(t)$ appears symmetrically at $\sim 62\,ps$ and $\sim(232-62)\,ps$ corresponding with the $\Delta L_{DUT} = 0.984\,mm$ (calculated for the central AWG waveguide). The AWG was designed with 59 waveguides in the array and a Free Spectral Range (FSR) of 32 nm (4.0THz), so the expected impulsive response is composed by a train of short pulses spaced 0.24 ps, with length 14.5 ps. See Fig. 2(a) and inset showing $|h(t)|^2$ in dB and natural units. We can see on $|h(t)|^2$ the power distribution in the AWG arms, as well as a strong power fluctuation in some waveguides of the array, due to fabrication imperfections. Notice that phase propagation errors between waveguides can be obtained also [3]. Additionally the spectral response in IOFDR was obtained by slicing the $h(t)$ around the 62 ps band along ±6ps and performing the Inverse FFT. Amplitude and the group delay responses are shown in Fig. 2(a) and (b). In order to verify the IOFDR results we took a standard spectral amplitude measurement with an ASE source and an Optical Spectrum Analyzer. For this, we employed available direct ports on the AWG (D1 and D2 in Fig. 1(a)). The amplitude responses from the IOFDR setup and the standard measure are compared in Fig. 2 (b), with the required manual wavelength shift since we are using a different in/out combination. Overall, the IOFRD chip provides a very good agreement with the classic measurement, but it provides full-field information of the DUT in the time and optical frequency domains.

References

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