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High Resolution Optical Frequency Domain Ranging with an Integrated Frequency Shifted Feedback (FSF) Laser

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Optical Frequency Domain Ranging (OFDR) is a well-known technique for contact-free distance measurements of high resolution and large dynamic range. Usually, a Michelson interferometer, operated with a frequency modulated (chirping) laser, is used to measure the difference of the lengths of both arms. The light reflected back from the target mirror of the measurement arm is superimposed to the light from the reference arm. In this way the detector at the output measures the frequency difference becoming an accurate measure of the path length difference. The faster the frequency chirping and the broader the chirp range are the better is the potential accuracy of the measurement. Therefore, Frequency Shifted Feedback (FSF) lasers with an inherent fast, wide and linear frequency chirp are attractive candidates to be used as light source for OFDR. Impressive results have already been reported using bulk and fiber FSF-lasers without and with phase-modulated seed [1, 2]. In this contribution we report the first demonstration of high resolution OFDR with an integrated tuneable Ti:Er:$LiNbO_3$ FSF-laser ($\lambda_L \approx 1550$ nm). Even without seeding a resolution of up to 2.5 μm has been achieved.

The laser is fabricated in an Erbium-diffusion-doped X-cut Lithium Niobate substrate and has Titanium-diffused single mode optical channel waveguides with vacuum-deposited dielectric mirrors on the polished waveguide end faces (Fig. 1). Its key element is an intra-cavity acousto-optical (AO) filter used as wavelength selective element and as frequency shifter simultaneously. Due to the acousto-optical interaction, the laser field undergoes two polarization conversions during each round trip with two frequency shifts by ν_{SAW} (frequency of the Surface Acoustic Wave) in the same direction. In this way the spectral width of the laser emission is broadened, limited by the spectral width of the AO filter. λ_L can be tuned with a slope of –8.2 nm/MHz by changing the SAW frequency [3]. Fig. 1 shows the route of the laser field through the waveguide structure in the cavity by the dotted line; the corresponding states of polarization are indicated. Here the laser is pumped with TM polarized light (λ=1480 nm; dashed line). The observed linewidth of the laser emission is 180 pm or 22.5 GHz (ν_{chirp}). As the length of the laser cavity is 94.2 mm, the round trip time (τ_{RT}) is 1.4 ns yielding a free spectral range (FSR) of 711 MHz. For the OFDR experiments ν_{SAW} = 170.70 MHz has been chosen resulting in λ_L = 1560 nm and a chirp rate of 2.43×10^{17} Hz/s ($\gamma = 2\nu_{SAW}/\tau_{RT}$). Under the 22.5 GHz wide envelope a moving comb of frequencies evolves with components separated by the FSR of the cavity. The comb as a whole linearly changes its frequency with the chirp rate γ, which is very stable as function of time.

An optical path difference of Δz between the two arms of the interferometer leads to beat signals of frequency $\nu_{Bm} = \gamma(\Delta z/c) - m/\tau_{RT}$, with m = 0, ±1, ±2, ... [1]. m is an integer termed as "beat order" equal to the difference of the mode numbers of the comb components producing the beat signals. A specific m can be unambiguously determined from the slope $d\nu_{Bm}/d\nu_{SAW}$. Fig. 2(left) shows as example for Δz = 23.0 cm the RF spectrum of the resultant photodiode signal and the corresponding m numbers are given. The beat frequencies change with a slope of 800 kHz/mm. Due to the limited chirp range (ν_{chirp}) a beat signal is broadened to about 8 MHz (Fig. 2(right)), which limits the resolution of the measurement. Just by using a frequency counter to determine the beat (centre) frequency an accuracy of ±40 (±2) kHz has been achieved with a 1 ms (1 s) long gate time. This corresponds to a resolution of the measured optical path difference of ±50 (±2.5) μm. As the resolution is nearly independent on the length of the path difference, the relative accuracy of the measurement grows with increasing Δz.

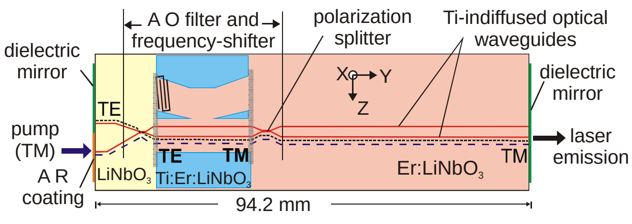

Fig. 1: Scheme of the integrated Ti:Er:$LiNbO_3$ frequency shifted feedback (FSF) laser. X, Y, Z (≡ optical c-axis) are the crystal axes.

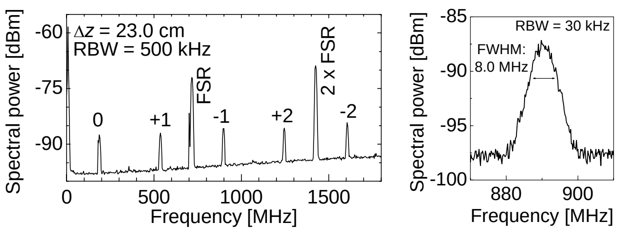

Fig. 2: Left: RF spectrum of the photodiode signal for Δz = 23.0 cm. Right: m = –1 beat signal used for distance measurements.

References

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