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Integrated Frequency Shifted Feedback (FSF) Laser for Optical Frequency Domain Ranging (OFDR)

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The integrated, wavelength tuneable Frequency Shifted Feedback (FSF) laser, recently developed [1], is further improved and applied for Optical Frequency Domain Ranging (OFDR). The laser is fabricated in an Erbium-diffusion-doped Lithium Niobate substrate and has Titanium-diffused optical channel waveguides (Fig. 1). An acousto-optical (AO) filter inside the laser cavity is used as wavelength selective element and as frequency shifter simultaneously. The laser resonator is formed by dielectric mirrors deposited directly on the polished waveguide end faces. During each round trip the laser field undergoes two polarization conversions with two frequency shifts in the same direction. So the total frequency shift (ν_{FS}) per round trip is equal to twice the frequency of the surface acoustic wave (SAW) driving the AO mode converter/filter. The FSF laser output consists of a comb of frequency chirped optical waves under a broad spectral envelope (Fig. 2). The components of the comb are separated by the free spectral range (FSR) of the laser cavity and they are strongly correlated in phase. Each is generated with a time interval equal to $1/\nu_{FS}$ and has a frequency chirp rate $\gamma = \nu_{FS}/\tau_{RT}$, where τ_{RT} is the round trip time in the cavity ($\tau_{RT} = 1/FSR$).

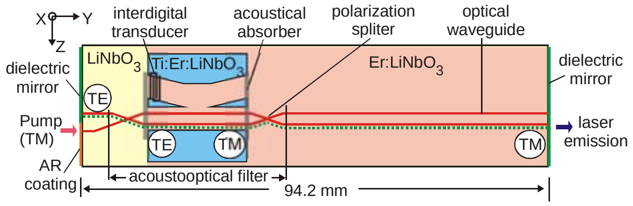

Figure 1: Schematic diagram of the acoustooptically tunable frequency shifted feedback $Ti:Er:LiNbO_3$ laser. The waveguide path of the intracavity laser field is indicated by the dotted line when the laser is pumped with a TM polarized wave. The corresponding states of polarization of the internal laser field are shown inside the circles. X, Y, Z (≡ optical c-axis) are the crystal axes.

The integrated FSF laser has a cavity of 94.2 mm length resulting in a FSR of 711 MHz. To get lasing at 1560 nm wavelength, a SAW frequency (ν_{SAW}) of 171.70 MHz is adjusted. The frequency chirp rate is ($\gamma = 2\nu_{SAW} \times FSR$) 2.43×10^{17} Hz/s. The spectral width of the filter for net intra-cavity gain determines the effective number of round-trips and, therefore, the spectral width of the laser emission. For 95 mW optical pump power at 1480 nm wavelength (TM-polarized) the FSF laser output power is 130 µW. The observed spectral width is 240 pm corresponding to an equivalent frequency chirp range (ν_{chirp}) of 30 GHz.

Its unique spectral properties allow to apply the FSF laser for optical frequency domain ranging (OFDR) in a Michelson interferometer to measure the distance z between a reference mirror and a target mirror. Due to the interference of the frequency combs, multiple beat signals ν_{Bm} are formed [2]: $\nu_{Bm} = \{(4z\nu_{SAW})/(c\tau_{RT})\} - m/\tau_{RT}$, with $m = 0, \pm1, \pm2, \pm3, \ldots.$, where m is an integer termed "beat order" equal to the difference of the mode numbers of the comb components producing the beat signal. Fig. 3 shows as example for $2z = 29.5$ cm the RF spectrum of the resultant photodiode signal. The beat order m is derived from the slope $d\nu_{Bm}/d\nu_{SAW}$. The spatial resolution (Δz) is limited by the spectral width of the beat signal which is a function of ν_{chirp} and γ. The theoretical limit of our laser is $\Delta z = 5$ mm in good agreement with the experimental results. Details of the measurement technique and further results will be presented in the talk. Moreover, the potential of this laser for long distance OFDR measurements with high resolution will be discussed.

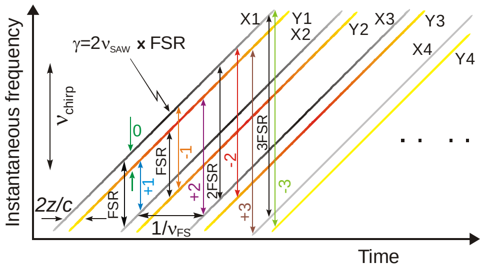

Figure 2: FSF laser spectra in time-frequency plane. Gradient in colour represents the amplitude variation. X and Y combs are from two branches of the interferometer arriving at the photodiode with a time delay $2z/c$.

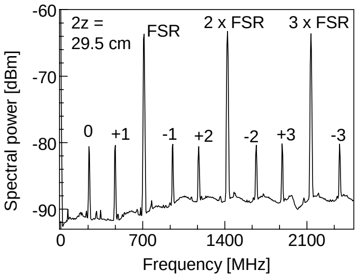

Figure 3: RF spectrum of the photodiode signal for 2z=29.5 cm.

[1] S. Reza, H. Herrmann, V. Quiring, R. Ricken, K. Schäfer, H. Suche, and W. Sohler, "Frequency Shifted Feedback $Ti:Er:LiNbO_3$ Waveguide Laser of Wide Tunability", Proceedings of 11th European Conference on Integrated Optics (ECIO '03), Prague, Czech Republic, paper: ThA2-4, pp. 167-170, April 2003.

[2] K. Nakamura, T. Hara, M. Yoshida, T. Miyahara, and H. Ito, "Optical Frequency Domain Ranging by a Frequency Shifted Feedback Laser", IEEE Journal of Quantum Electronics, vol. 36, pp. 305-316, March 2000.