in: Optical Fiber Communication Conference (OFC '96), Vol. 2, 1996 Technical Digest Series
(Optical Society of America,Washington, D.C., 1996), p. 251 (invited)

Integrated Optical Circuits with Er:$LiNbO_3$ Amplifiers and Lasers

W. Sohler

Angewandte Physik, Universität GH Paderborn
Warburger Str. 100, D-33098 Paderborn
Tel.: +49 5251 60-2712 Fax: +49 5251 60-3422
e-mail: SOL-IZ@physik.uni-paderborn.de

Erbium-doping of $LiNbO_3$ allows to develop optically pumped waveguide amplifiers and lasers of attractive properties [1]. They are operating most efficiently in the wavelength range 1.52 $\mu m < \lambda < 1.62\ \mu m$ well suited for applications in fiber optical communications.

The most reliable and simplest technique to fabricate erbium-doped waveguides in $LiNbO_3$ proved to be erbium-diffusion doping of the surface of optical grade $LiNbO_3$ wafers, followed by the waveguide fabrication using standard titanium-indiffusion (or proton exchange). Moreover, it is possible to locally dope selected (photolithographically defined) sections of the surface; even strip-like doping of a few micrometer wide channels has already been demonstrated. Using the diffusion doping technique, single-mode, titanium-diffused strip guides of low scattering losses down to $\approx$0.1 dB/cm have been fabricated in $LiNbO_3$ surfaces of high erbium concentration [2]. They are the basic structures of waveguide amplifiers, lasers and even more complex integrated optical circuits with additional active and passive devices on the same chip.

By combining optical amplification and electro- or acoustooptically controlled functions in the same waveguide structure several attractive integrated optical devices and circuits have been developed. Examples are amplifying electrooptical phase- and intensity modulators, high finesse Fabry-Perot type optical spectrum analyzers and tunable, acoustooptical, polarization-dependent and -independent wavelength filters. Additional functions can be expected by combining optical amplification with different nonlinear effects. All-optical switching, bistable behavior and parametric frequency conversion might be achieved in well-designed erbium-doped structures.

By integrating electro- or acoustooptical devices in the cavity of erbium-doped, Fabry-Perot type lasers with dielectric end face mirrors modelocked and tunable devices have been developed. The former are capable to generate 3.8 ps pulses with repetition rates up to 10.3 GHz [3]. The latter have a total tuning range of $\approx$12 nm distributed over 3 wavelength bands; more than 50 nm can be expected by a further optimization.

Very recently, also Distributed Bragg Reflector (DBR-) lasers have been demonstrated with single-frequency emission at a wavelength defined by the grating periodicity; the spectral linewidth of the emission can be as low as < 8 kHz [4]. These lasers can be easily combined with additional active and passive devices on the same chip to form optical circuits of higher functionality. Laser - modulator combinations are the first examples. They include cw-lasers with phase- or/and intensity modulators for fiber-optical, digital communications and analog CATV-distribution, respectively. More sophisticated circuits will be modelocked lasers as soliton sources with an intensity modulator for signal coding. Even more complex will be a heterodyne interferometer circuit for optical metrology and vibration analysis with a DBR-laser and up to 11 additional devices [5].

It is a challenge for the near future to design and to develop a complex, optically powered, monolithic integrated optics in (partically) erbium-doped $LiNbO_3$ with new application specific optical circuits.

References:

[1] W. Sohler in Integrated Photonics Research, vol. 7, 1995 OSA Technical Digest Series, pp. 212-214 (invited) and references cited therein

[2] I. Baumann et al., J. Quantum Electr., vol. **30**, no. 10, 2356-2360 (1994)

[3] H. Suche et al., Opt. Lett., vol. **20**, no. 6, 596-598 (1995)

[4] J. Söchtig et al., Electron. Lett, vol. **31**, no. 7, 551-552 (1995) and to be published

[5] F. Tian et al. in "Laser in der Technik", Proc. Congress Laser '93, W. Waidlich (Ed.), Springer Verlag, 725-728, 1993