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Erbium–Doped Lithium Niobate Waveguide Devices

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During the last years there has been a growing interest in erbium–doped optically pumped amplifiers and lasers in $LiNbO_3$ [1]. They operate in the wavelength range $1.52\,\mu m < \lambda < 1.62\,\mu m$, and are for that reason most attractive for fiber optical communication. $LiNbO_3$ has excellent electro– and acoustooptical properties allowing not only the development of modelocked, Q–switched and tunable lasers, but also of amplifying tunable filters, of loss compensating spectrum analyzers and of amplifying modulators. A whole range of new waveguide devices can be developed by combining optical amplification with nonlinear, electro– or acoustooptically controlled functions in the same structure.

There are different methods to fabricate erbium–doped waveguides in $LiNbO_3$. The most versatile, reliable and simplest technique 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). It is possible to photolithographically define heavily doped, single–mode Ti–diffused channel guides of low scattering losses down to $\sim 0.1\,dB/cm$ [2].

Erbium–doped waveguides can be operated as optical amplifiers by pumping with sufficient power levels. Pumping at $\lambda_p \approx 1480\,nm$ is preferred to pumping at $\lambda_p \approx 980\,nm$, as single–mode propagation for both, pump and signal waves, can be ensured. Up to 13.8 dB single–pass gain has been demonstrated in a 7 cm long amplifier at $\lambda_s = 1531\,nm$ operated with $\sim 200\,mW$ pump power [3].

Erbium–doped waveguides have also been used to develop acoustically tunable, amplifying, polarization–dependent and –independent wavelength filters of a bandwidth around 1.5 nm [4]. These filters can also be considered as narrowband, tunable amplifiers, which are the basis of tunable lasers.

Optical gain in erbium–doped channel guides can also compensate the internal losses of an electrooptically tunable waveguide cavity yielding a finesse > 200 [5]. Such a device is attractive for high resolution ($\Delta f \approx 7\,MHz$) optical spectrum analysis.

Also electrooptical phase– and intensity–modulators with internal gain have been demonstrated, using erbium–doped channels.

By depositing dielectric mirrors on the polished end faces of erbium–doped waveguide amplifiers, a variety of cw Fabry–Perot type lasers have been fabricated with emission lines at 1531, 1546, 1563, 1576, 1602 and 1611 nm [6,7]. Thresholds as low as 9 mW ($\lambda_p \approx 1480\,nm$), slope efficiencies up to 37 %, and output power levels up to 60 mW (at $P_p = 210\,mW$) have been achieved [8]. Moreover, fully packaged, fiber pigtailed devices pumped by a laser diode have been demonstrated [9].

By integrating a travelling–wave electrooptic phase modulator in the laser cavity mode-locking has been achieved [10]. Recently, the generation of 3.8 ps pulses has been demonstrated in a harmonicallly modelocked Ti:Er:$LiNbO_3$ waveguide laser with repetition frequencies up to 10.28 GHz [11,12].

With a double–stage acoustooptical wavelength filter in the laser cavity tunable operation has been obtained around 1531, 1546 and 1561 nm wavelength over a total tuning range of 12 nm [13]. By reducing the intracavity losses an extension of the tuning range up to more than 50 nm can be expected.

Very recently, even single–frequency Distributed Bragg Reflector (DBR–) Ti:Er:$LiNbO_3$ lasers have been reported [14,15]. Their emission wavelength of 1531 nm and 1561 nm, respectively, is determined by the Bragg–wavelength of a grating reflector etched into the waveguide surface as one of the cavity mirrors. With 100 mW pump power up to 3 mW output power has been produced. These lasers are ideal candidates for an integration with further devices on the same chip; a laser–modulator–combination is currently developed.

In conlusion, a variety of erbium–doped waveguide devices has been developed in $LiNbO_3$ mainly for applications in fiber optical communication systems. There is still a great potential to improve the performance of these devices. They allow the development of a more complex, monolithic integrated optics in $LiNbO_3$ by combining lasers, amplifiers and further active and passive devices on the same chip to optical circuits of higher functionality.

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