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INTEGRATED OPTICAL RING LASER IN Er:LiNbO$_3$

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ABSTRACT

Fabrication and properties of an integrated optical ring laser of 60 mm diameter with Ti:Er:LiNbO$_3$ waveguides are reported. Without any intracavity wavelength selective devices the laser emits at $\lambda = 1603$ nm. The potential of laser, passive and loss-compensated ring resonator as optical gyroscope is briefly discussed.

KEYWORDS

integrated optics, ring lasers, Ti:Er:LiNbO$_3$, optical gyroscope

INTRODUCTION

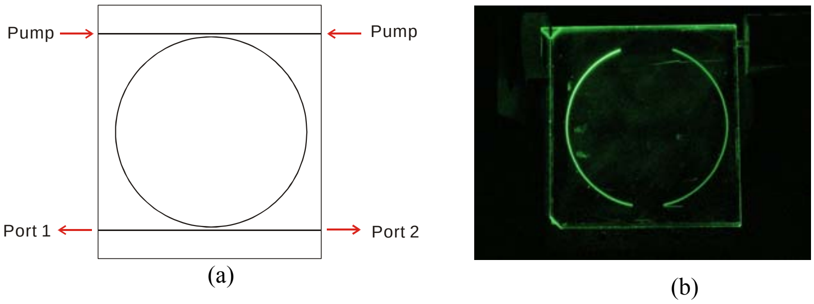
During the last years there was a considerable interest in Erbium doped LiNbO$_3$ (LN) waveguide lasers emitting in the wavelength range 1530 nm < λ < 1603 nm. Free running lasers of the Fabry Pérot type, harmonically mode-locked lasers (5 ps / 10 GHz), Q-switched lasers (4 ns / 1 kHz / 1 kW), Distributed Bragg Reflector- (DBR-) and Distributed FeedBack- (DFB-) lasers, self-frequency doubling devices, and acoustooptically tunable lasers have been reported for applications in optical communications, sensing and instrumentation [1,2]. All these devices had a linear cavity defined by gratings or dielectric multilayer mirrors.

Diffusion doped Er:LiNbO$_3$ is an excellent laser material for integrated optics [3]. It can be easily fabricated as surface layer in a LiNbO$_3$ substrate by indiffusion of a thin vacuum-deposited Erbium layer. Afterwards, single mode channel waveguides can be defined by the standard indiffusion technique of Ti-stripes. If optically pumped by $\lambda = 1480$ nm radiation, a wavelength and polarization dependent gain of up to 2 dB/cm results in the wavelength range 1530 nm < λ < 1603 nm. These waveguides have very low scattering losses not only as straight channels but also as curved waveguides, if the bending radius exceeds 15 mm. As a consequence, even ring lasers of relatively large diameter can be developed with weakly guiding Ti:Er:LiNbO$_3$ waveguides.

We report in this contribution fabrication and properties of an integrated optical ring laser as the latest addition to the laser family mentioned above. It has a diameter of 60 mm; without any intracavity wavelength selective devices the laser emits at $\lambda = 1603$ nm. Due to its large diameter the laser – and, moreover, the passive and slightly pumped (loss-compensated) ring resonator below threshold – are excellent candidates for the development of integrated optical gyroscopes [4 -7].

LASER STRUCTURE AND FABRICATION

The structure of the ring laser is shown in Fig.1 (a). It consists of one Er-doped ring waveguide of a diameter of 60 mm and of two undoped straight waveguides tangential to the ring forming two directional couplers. One



(a)

(b)

Fig. 1. (a) Schematic structure of the ring laser of a diameter of 60 mm and (b) photograph of the Er-doped ring emitting green upconversion light when pumped from both upper inputs.

serves as pump coupler allowing to couple the pump light (λ = 1.48 µm) clockwise and counter-clockwise into the ring. The other one serves as laser output coupler to observe the guided spontaneous fluorescence and the laser emission, if threshold is surpassed, propagating in both directions. The absorption of the pump light in the ring can be observed indirectly via the green upconversion light excited by a three step excitation of the Er-ions (see Fig. 1 (b)). On the photograph the ring seems to be discontinuous; however, this impression is simply due to the fact that both coupler regions have not been doped with Erbium.

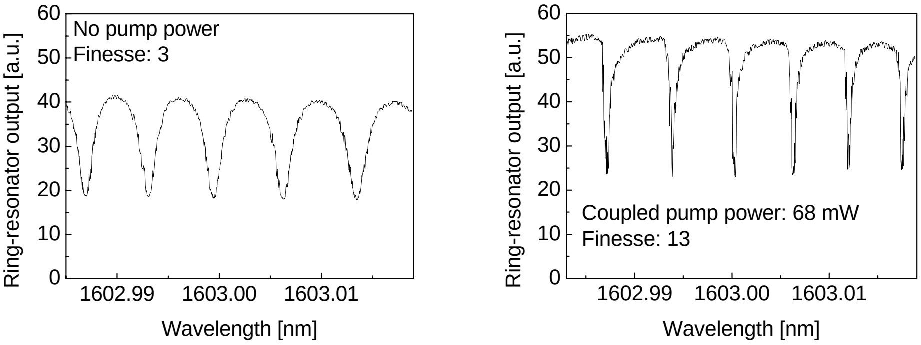
To fabricate the laser a 20 nm thick Erbium layer was deposited as a 2 mm wide ring on the surface of the Z-cut substrate using e-beam evaporation; the directional coupler sections remained uncovered. The diffusion was performed at 1130°C for 150 hours in a dry Argon atmosphere. Afterwards, the optical waveguides were fabricated by an indiffusion of photolithographically defined 7 µm wide, 95 nm thick Titanium stripes at 1060°C for 7.5 hours. Waveguide propagation losses and mode size were measured in some additional straight waveguides simultaneously fabricated besides the ring.

To reduce the laser threshold a new version of this ring laser has been fabricated with one straight waveguide only serving as a input and output coupler simultaneously; in this way the resonator losses have been reduced as only one directional coupler contributes to the round trip losses.

RESONATOR PROPERTIES

The resonator properties were first investigated with a tunable extended cavity (ECL-) semiconductor laser at λ = 1650 nm i.e. in a wavelength range without any absorption by the Erbium-ions; a finesse of 6.5 was observed. Taking waveguide losses of 0.1 dB/cm into account (measured in the straight channel guides besides the ring) a coupling efficiency of 28 % of the directional coupler could be derived (TM-polarization). Around λ = 1603 nm a reduced finesse of about 3 was measured (see Fig. 2a); however, this reduction is due to the residual absorption by the Erbium-ions at this wavelength.

If pumped by a laser diode of λ_p = 1480 nm wavelength in TE-polarization (to get a better coupling efficiency for the pump and in this way a higher optical gain) the resonator finesse grows as function of the pump power before lasing sets in (see Fig. 2b).



(a) (b)

Fig. 2. A study of finesse of the ring cavity, (a) when there is no pump power and (b) observed maximum finesse before the laser sets in.

LASER OPERATION

The ring laser was studied using the experimental setup as shown in Fig. 3. Fiber optical wavelength division multiplexers (WDM) of appropriate wavelength characteristics were used to couple the pump light (λ_p = 1480 nm) into the ring and to extract the laser emission (λ_p = 1603 nm) from both ports. A fiber Bragg grating stabilized laser diode was used as pump source. The fiber optical polarization controller (PC) allowed to adjust the preferred pump polarization (TE).

Lasing sets in at about 70 mW pump power (λ_p = 1480 nm; TE-polarization) coupled into the straight channel guide from one side only (see Fig. 4a). As the coupling efficiency of the directional coupler at the pump wavelength in TE-polarization is about 25 %, laser threshold corresponds to about 17.5 mW pump power coupled into the ring. The laser emission at λ_L = 1603 nm is TM-polarized, mainly due to the smaller mode size resulting in lower coupling losses per round-trip than in TE-polarization. Nevertheless, an optimization of the directional coupler(s) has still to be done to get a high coupling efficiency at the pump wavelength for TE-polarization, but a low efficiency at the laser wavelength for TM-polarization. The small slope efficiency of the power characteristics is a consequence of the non optimized laser design.

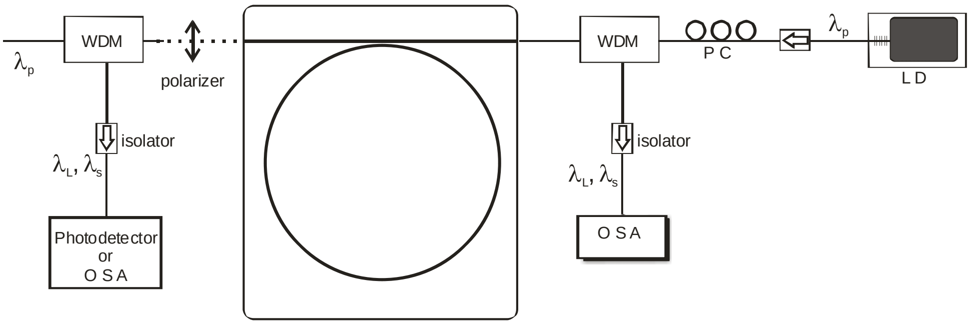
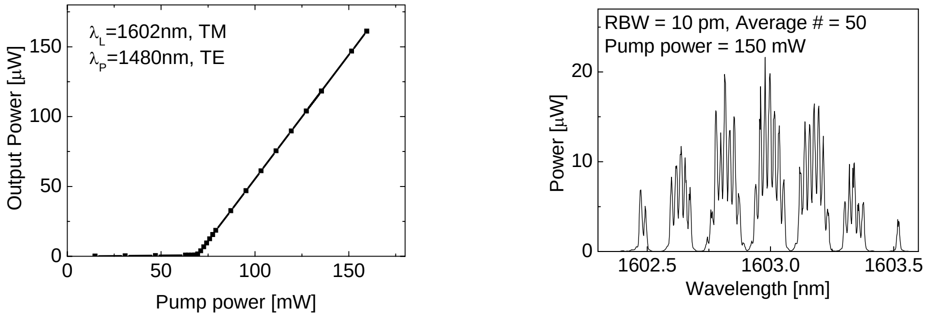


Fig. 3. Schematical experimental setup to investigate the ring laser: OSA: Optical Spectrum Analyzer; WDM: Wavelength Division Multiplexer; PC: Polarization Controller; LD: Fiber Bragg Grating Stabilized Laser Diode.

The ring laser emits several lines with a spectral fine structure, centered around $\lambda_L = 1603$ nm (see Fig. 4b). As it is operated without any wavelength selective intracavity components its emission wavelength corresponds to electronic transitions of lowest energy difference from the $^4I_{13/2}$ to the $^4I_{15/2}$ manifolds of Er^{3+} in $LiNbO_3$. This mode of operation is similar to that of a standard 4-level laser-system; population inversion is obtained at lowest pump power. Thus the long wavelength emission of this laser is qualitatively understood. The spectral fine structure of the laser output consists several groups of emission lines separated by 18 pm, which corresponds to three times the free spectral range of the ring resonator. The group separation is about 180 pm. The number of lines inside each group increases with increasing pump power level. Up to now we were not able to interpret the spectral fine structure.



(a) (b)

Fig. 4. (a) Power characteristics of the integrated ring laser as output power versus pump power coupled to the straight channel guide; (b) Emission spectrum of the ring laser (TM-polarization) measured with a resolution bandwidth (RBW) of the optical spectrum analyzer of 10 pm.

We have also observed lasing at $\lambda_L = 1575$ nm by increasing the resonator losses; a short section of the ring was covered by a silver paste. As the increased losses can`t be compensated at $\lambda_L = 1603$ nm by harder optical pumping the emission wavelength shifts to $\lambda_L = 1575$ nm, where a higher gain can be achieved.

TOWARDS A LASER GYROSCOPE

Passive [6,7] and loss-compensated [4] ring resonators as well as active ring lasers [4,5] can be used for rotation rate sensing exploiting the relativistic Sagnac effect. In comparison with a fiber optical gyro a rugged integrated optical solution has several advantages if a sensor of moderate sensitivity is to be developed. As the nonreciprocal phase shift induced by a rotation of the ring is proportional to the enclosed area devices of large diameter such as the Ti:Er:$LiNbO_3$ ring laser or (loss-compensated) ring resonator are preferred. Moreover, LN-devices offer the possibility to monolithically integrate modulators and phase shifters for signal processing on the same substrate.

To explore the potential of our devices as optical gyroscope in more detail, one laser was fiber-pigtailed after angle polishing the end faces of the straight waveguide to avoid back reflections into the ring. The device was temperature stabilized and packaged and is now ready for first rotation rate sensing experiments (see Fig. 5).

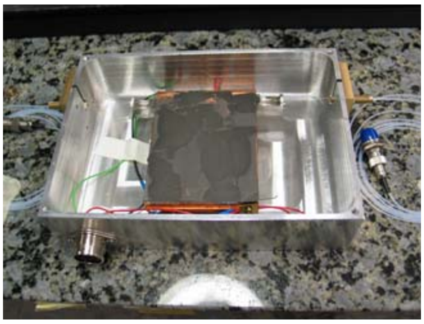


Fig. 5. Photograph of a fiber pigtailed and packaged Ti:Er:$LiNbO_3$ ring laser.

CONCLUSIONS

The development of an integrated optical ring laser of 60 mm diameter with Ti:Er:$LiNbO_3$ waveguides was reported. Due to the low waveguide losses a finesse of 6.5 was measured if operated as a passive resonator at wavelengths longer than 1650 nm avoiding in this way absorption by the Erbium ions. At shorter wavelengths absorption and scattering losses can be compensated by optical pumping to enhance the resonator finesse before lasing sets in at about 17.5 mW pump power (λ_p = 1480 nm, TE-polarization) coupled to the ring. Without any intracavity wavelength selective devices the laser emits at λ = 1603 nm in TM-polarization. To improve the device an optimization of the directional coupler(s) has still to be done to get a high coupling efficiency at the pump wavelength for TE-polarization, but a low efficiency at the laser wavelength for TM-polarization. Moreover, the potential of laser, passive and loss-compensated ring resonator as optical gyroscope has to be investigated.

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