Integrated Optical Distributed Bragg Reflector and Distributed Feedback Lasers in Er:$LiNbO_3$ with Photorefractive Gratings

Thesis
By
Bijoy Krishna Das, M.Sc
Applied Physics / Integrated Optics, Department of Physics
University of Paderborn, Warburger Strasse 100, Paderborn, D-33098, Germany

ABSTRACT

A family of narrow linewidth integrated optical distributed Bragg reflector (DBR), distributed feedback (DFB), and DFB-DBR coupled cavity lasers (1530 nm < ë < 1575 nm) have been developed in $LiNbO_3$, using thermally fixed photorefractive Bragg gratings. They all have a Ti:Er:$LiNbO_3$ waveguide amplifier section. Photorefractive gratings in passive Ti:Fe:$LiNbO_3$ waveguide segments or in an amplifying Ti:Fe:Er:$LiNbO_3$ waveguide sections are used to form the laser cavities. Antireflection and high-reflection coatings are also deposited on the polished end faces according to their requirements. For laser operation, the pump light ($ë_p$ = 1480 nm) is fed into the laser resonator through the grating via the common branch of a fiber-optic wavelength-division de-multiplexer (WDM). The laser output is extracted through the second branch of the WDM and isolated to protect the laser from optical feedback.

The lasers are fabricated in 1-mm-thick optical grade X-cut $LiNbO_3$ crystals with the Z-(optical-) axis aligned parallel to the direction of the optical waveguides. All the three types of waveguides, Ti:Er:$LiNbO_3$, Ti:Fe:$LiNbO_3$, and Ti:Fe:Er:$LiNbO_3$ have been investigated. They were characterized in terms of losses, size of the guided mode(s), optical gain, and the photorefractive sensitivity. Analyzing these results, the optimized fabrication parameters have been determined. First, a ~20-nm-thick, vacuum deposited Er-layer is indiffused to prepare the laser-active substrate followed by a selective indiffusion of Fe to create photorefractive centers in the material for the grating fabrication to come. A photolithographically defined Ti-stripe is indiffused to form the single-mode (1470 nm < ë < 1580 nm) optical channel guide in the conventional way. The photorefractive susceptibility of the Fe-doped waveguide sections is enhanced by an annealing procedure in a reducing atmosphere. An argon-ion laser (ë = 488 nm, P = 1 W) is used to write holographically photorefractive gratings of a length of up to 18 mm with a periodicity of ~350 nm. The holographic exposure (<10 min) is done at an elevated temperature (~180 ^oC) to enhance the mobility of protons in the sample and to get in this way a fixed ion (H^+) grating at room temperatures. Finally, the fixed gratings are developed by a redistribution of the electronic space charge using a uniform illumination with blue light either from an argon laser or an array of blue LEDs.

Two types of DBR-lasers have been developed with photorefractive gratings written in passive Ti:Fe:$LiNbO_3$ waveguide sections. The first type has a cavity consisting of one Bragg-grating, a gain section with Ti:Er:$LiNbO_3$ channel guide and a multi-layer dielectric mirror deposited on one polished end face. The cavity of the second type consists of two gratings on both sides of the Er-doped waveguide. Their power characteristics, spectral properties and dynamics were investigated. Single-frequency operation could be achieved in the latter case at various wavelengths in the Er-band (1530 nm < ë < 1580 nm) with up to 1.12 mW output power. Emission wavelength of this laser could also be tuned by temperature with a slope of about 8 pm/K. For the first time, a DFB-laser has been demonstrated with a photorefractive grating in an Er/Fe co-doped waveguide combined with an integrated optical amplifier. The laser output spectrum revealed the two characteristic DFB-frequencies. The laser emission (ë ~ 1531 nm) could be extracted from both sides: about 0.1 mW at the grating side and 1.1 mW at the amplifier side. Moreover, an attractive DFB-DBR coupled cavity laser has been developed and investigated. Its cavity consists of a photorefractive Bragg grating in the Ti:Fe:Er:$LiNbO_3$ waveguide section close to one end face of the sample, a Ti:Er:$LiNbO_3$ gain section and a broadband dielectric multi-layer mirror of high reflectivity on the other end face. The laser runs in single-frequency (ë ~ 1557.2 nm) with a maximum output power of 8 mW. The emission wavelength of this type of laser is temperature tuned with a slope of about 5 pm/K and electro-optically tuned with a slope of ± 0.75 pm/V.