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MULTIPLE FUNCTION WAVEGUIDE LASER IN Nd-DIFFUSED $Ti:LiNbO_3$.

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A multifunctional, low threshold waveguide laser is demonstrated in $Nd:Ti:LiNbO_3$. Tuning over 2.3nm has been observed using on-chip electro-optic modulators. Applying a sinusoidal modulation to the electrodes results in the formation of a train of 20ns pulses at rates of 1MHz and 120mW peak output power.

Introduction

Rare-earth-doped channel waveguides in glass and $LiNbO_3$ are the basis for the construction of active devices in these material systems, and are becoming increasingly attractive for optical communications and sensor applications. In addition, the integration techniques used in the manufacture and processing of waveguide structures permit a degree of robustness and dense packing that is difficult to achieve with rare-earth-doped fibres. In particular, rare-earth doping of $LiNbO_3$ significantly increases the potential of this material, and attractive device concepts can be realised by taking advantage of the electro-optic and acousto-optic properties of the substrate. Moreover, the localisation of the rare-earth ions by indiffusion techniques enables passive waveguide components to be developed on the same substrate as those with gain. The recent demonstration of periodic poling in Nd-diffused $LiNbO_3$[1] also implies the possibility of the integration of domain reversed sections in rare-earth-doped laser cavities in $LiNbO_3$ for intracavity second harmonic generation.

Monolithically integrated multiple-cavity resonators have recently been the scope of study for several researchers, and more robustness and flexibility towards photonic integration can be achieved with complex interferometric resonator configurations than is possible with fibre devices. The suitability of rare-earth-doped lithium niobate for advanced laser applications has been established with the realisation of Q-switched[2], mode-locked[3,4] and tuneable[5,6] sources. We have recently demonstrated an electro-optically tuned $Nd:Ti:LiNbO_3$ waveguide laser at room temperature in a Y-branch geometry[5], and report in this contribution the observation of Q-switched pulses using this structure, demonstrating the versatility of this simple coupled-cavity configuration.

Laser fabrication and characterisation

Details of the waveguide fabrication and cw laser characterisation have been described previously[5] and will be reiterated here only briefly. An X-cut, 1mm x 50mm x 50mm lithium niobate substrate was doped near the surface by indiffusion of a 13 ± 2nm thick layer of thermally evaporated neodymium. The diffusion was carried out at 1090°C over 240 hours in a dry oxygen atmosphere, resulting in an estimated 1/e depth of $5\mu m$. Five parallel Y-branch waveguide structures were then defined along the Y-axis by conventional lift-off of a 95nm thick layer of titanium, and the waveguides were subsequently fabricated by indiffusing the titanium at 1005°C for 9 hours in an oxygen atmosphere. A typical device is shown in Fig. 1. The coupled cavities were in general designed to be asymmetric, with the widths of guides 1 and 2 being 3μm in all the devices and the width of guide 3 incrementing by 1μm between adjacent devices so that the first device has a guide 3 width of 3μm and the last of 6μm. The asymmetry ensures an intrinsic optical path length difference between the two arms of the Y-cavity. Finally, aluminium electrodes were defined alongside guide 2, as shown in Fig. 1. The electrodes were 50μm wide, 10mm long and spaced apart by 10μm. The waveguide endfaces were polished to yield devices ~45mm long.

Dielectric mirrors with a reflectivity of 95% at 1060nm and a reflection bandwidth of 200nm were attached to the endfaces. The mirrors were index-matched to the substrate using a fluorinated liquid. A $Ti:Al_2O_3$ laser tuned to 816nm was used as the pump source and a x10 microscope objective was used to couple light into the Y-branches via guide 1, with a coupling efficiency of 26±3%[5]. CW lasing was observed at 1092.7nm from all of the devices, and the results presented here are for the device with guide 3 width of 6μm. With no bias voltage applied to the electrodes, lasing set in with ~4.2±0.5mW of launched pump power, and a slope efficiency of 2.6±0.3% was obtained. The laser emission was σ-polarised, with a FWHM linewidth of 0.3nm, as measured on an ANDO spectrum analyser. We have recently also achieved diode pumping of this laser device, and this will be reported elsewhere. Application of a dc voltage in the range -25V to 25V caused the lasing signal to tune between 1091.3nm and 1093.7nm as the cavity response envelope of the Y-branch resonator was moved in frequency[7]. Such is the gain bandwidth in $Nd:LiNbO_3$ that we were, however, unable to extinguish lasing with a dc bias in this particular device. Rather, the lasing wavelength switched to other peaks in the σ-polarised fluorescence spectrum at either 1103nm or 1078.6nm as the applied dc voltage was changed.

The modulators were then driven by a sinusoidal wave in the MHz regime, with a peak-to-peak magnitude of 20V, using a 5MHz Wavetek waveform generator. The laser output was fed into a Tektronix Optical Converter (7GHz bandwidth) connected to a 1 GHz oscilloscope. As the driving frequency was varied between 200kHz and 5MHz a periodic train of Q-switched pulses was observed, as shown in Fig. 2. At a driving frequency of 2.2MHz, we observed pulses with an average power of 2.5mW, for coupled pump powers of ~165mW. A typical pulse is shown in Fig. 3. The minimum pulse duration was 20ns and the peak output power was ~120mW. The symmetric nature of the pulses, with rise times and decay times approximately equal, implies that the inversion level at the time of switching was low[8]. This is not entirely surprising as the pulse separation of 0.9μs is considerably shorter than the 100μs metastable state lifetime, the characteristic time scale for inversion to build up at low pump levels. We note also that the period of the Q-switched pulses was approximately twice that of the modulation period, indicating that each pulse depleted the inversion such that it required two modulation periods for the gain to recover to its prepulse level. Under different conditions, pulse periods of between two and six times the driving period were seen. The pulses showed good amplitude stability and low jitter. Modulation of the Q-factor of a Y-branch waveguide laser can be explained by the shifting of the resonant frequency of the coupled cavity within and out of the gain band[9]. However, in this device it was not possible to suppress the lasing indefinitely, implying that the Q of the laser cavity is always maintained at a high enough level to allow cw oscillation. As a result, optical pulse generation by conventional Q-switching, where the Q-factor of the laser cavity is deliberately kept low for long periods, typically of the order of the lifetime of the excited ions, before being rapidly switched back to the high state, is difficult to implement here. By applying a sinusoidal modulation to the electrodes we are nonetheless able to see Q-switched pulses forming in the slow switching regime[8]. Further investigations are underway to determine precisely the dynamics of formation of these pulses in our device. We believe we can increase the peak power of the Q-switched pulses by at least an order of magnitude by optimising the output coupling of the cavity, and experiments are being carried out to demonstrate this.

Conclusions

We have demonstrated a versatile waveguide laser in Nd:Ti:$LiNbO_3$. The waveguide laser, which consists of a Y-branch cavity, has a threshold of ~4.2mW of launched pump power and a slope efficiency of ~2.6% with 95% reflectivity mirrors butted to its endfaces. On-chip modulation of the optical path length of one arm of the Y-branch has been used to demonstrate tuning over a range of 2.3nm. Q-switching has been observed by applying a sinusoidal modulation to the electrodes, and peak pulse powers of 120mW with pulse widths of 20ns have been observed with a repetition rate of 0.9μs. We are at present working on improving the quality of the pulses.

We believe that multifunctional devices in $LiNbO_3$, for which electro-optic switching can be used to provide intracavity modulation and in which the gain may be localised to specific areas, may find applications in many areas of optics.

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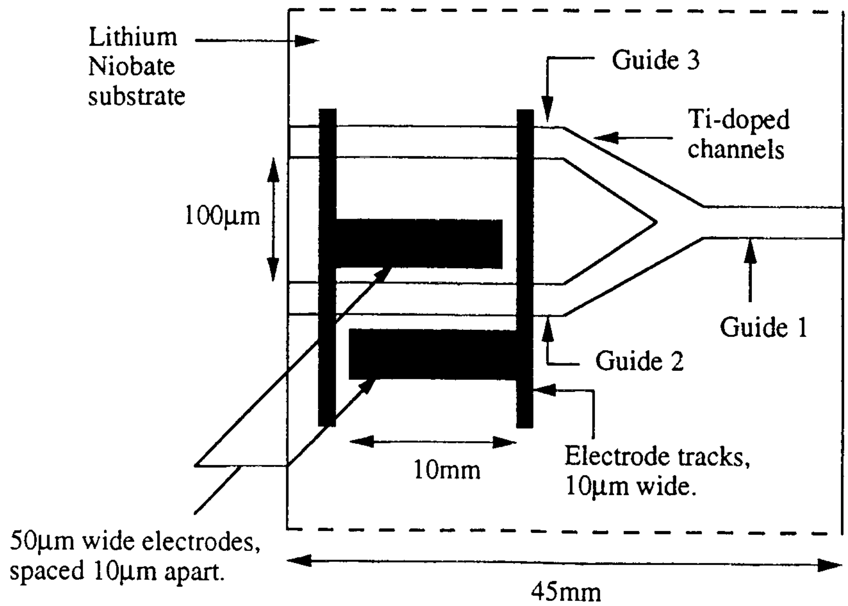

Fig. 1. Schematic of a Y-branch waveguide laser device.

Fig. 2. Q-switched pulse train, observed on a 1 GHz oscilloscope. The time base is 200ns per division. The pulse repetition rate is 0.9μs.

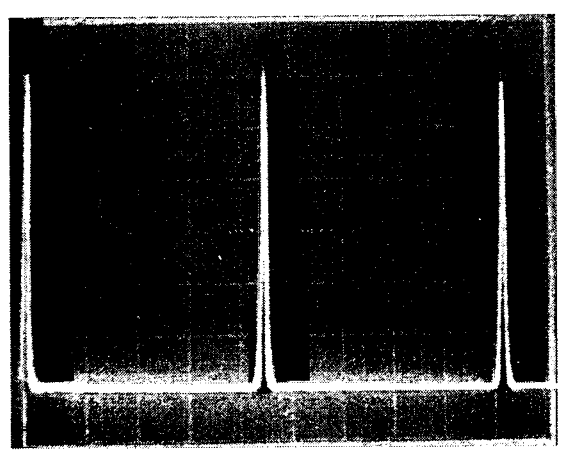

Fig. 3. Oscilloscope trace of one Q-switched pulse. The time base is 20ns per division. The peak power is 120mW and the pulse width is 20ns.