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10 GHZ MODELOCKED Ti:Er:LiNbO$_3$ WAVEGUIDE LASER WITH COUPLED CAVITY: SUPERMODE SELECTION AND PULSE REPETITION RATE DOUBLING

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By coupling the active laser cavity to a passive low finesse Fabry-Perot resonator supermode stabilization of a modelocked Ti:Er:LiNbO$_3$ waveguide laser with a SMSR of 55 dB at 10 GHz pulse repetition rate has been achieved as well as pulse repetition rate doubling from 5 to 10 GHz.

Introduction

Optical pulse sources with high repetition rates are attractive devices for high speed optical (soliton-type) transmitters. Therefore, FM-type modelocked Ti:Er:LiNbO$_3$ waveguide lasers with an integrated travelling wave electrode as a modelocker have been developed [1]. These lasers are approx. 7 cm long (FSR (free spectral range) ≈ 1 GHz) to get sufficient pump absorption leading to a slope efficiency of up to 14 %. The devices are diode pumped and pigtailed [1]. To get pulse repetition rates of up to 10 GHz harmonic modelocking had to be used. However, harmonically modelocked lasers usually emit more than one comb of longitudinal modes (called supermode) causing high frequency noise.

Several methods of supermode stabilization have been reported in literature for fibre lasers with a very large number of supermodes. As one approach an intracavity Fabry-Perot filter with a high finesse (>50) has been successfully used to select one supermode [2]. In contrast to this transmission-type filter we coupled the actice laser cavity directly to a passive Fabry-Perot waveguide cavity with a low finesse. In this way we realized a reflection-type filter on the same substrate material with the potential for fully integration. Recently, single supermode emission at 5 GHz pulse repetition rate has been achieved [3].

In this contribution we present a supermode stabilized laser for 10 GHz pulse repetition rate. Long term stability in a broad exceptance frequency range is achieved without any active cavity control as necessary for fibre lasers [2]. The integrated Fabry-Perot filter can also be used for frequency multiplication as has been demonstrated with fibre lasers [4]. We present the generation of a stable 10 GHz pulse stream at 5 GHz modulation.

Laser Fabrication

In order to fabricate the active laser cavity the Z-cut LiNbO$_3$ substrate has been doped by indiffusion of a 30 nm thick layer of vacuum-deposited Erbium at 1130 °C during 150 h. Afterwards photolithographically defined 7 µm wide and 93 nm thick Ti-stripes have been indiffused at 1060 °C during 8.5 h to form the 66 mm long active waveguide.

Three electrodes have been integrated on the laser chip (see Fig. 1). To avoid excess losses of the TM-mode a 0.9 µm thick SiO$_2$-buffer has been vacuum deposited onto the substrate surface prior to the electrode fabrication. The travelling wave phase modulator in the middle of the cavity is a 25 mm long symmetrical coplanar microstrip line used for FM-type modelocking. On both ends of the active laser cavity two lumped-type phase modulators have been integrated. The electrodes have been fabricated by photolithographic lift-off of a sandwich of 30 nm sputtered Ti and 120 nm sputtered Au. Subsequently, the travelling wave electrode was electroplated up to a thickness of 6 μm.

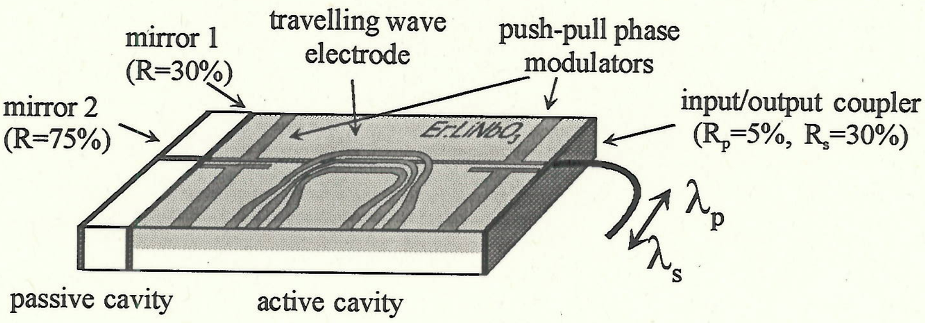

Fig. 1: Modelocked coupled cavity Ti:Er:LiNbO$_3$ waveguide laser

To define the laser cavity an optimized input/output coupler (see [1]) has been evaporated directly to the polished end face. At the back side a passive waveguide cavity with a FSR of 9.8 GHz ($FSR_{pas} \approx 10\ FSR_{act}$) has been glued to the active laser cavity. Its reflectivities of 30 % (mirror 1) and 75 % (mirror 2) have been choosen to get a Fabry-Perot cavity with a low finesse of 4.3.

The laser has been pigtailed directly to the common branch of a fibre-optic wavelength division multiplexer (WDM). We packaged the pulse source including temperature stabilization, an optical isolator and two fibre optic power splitters to get one output tap (1 %) for monitoring and another one (9 %) for deriving a control signal for feedback stabilization [1].

Single Supermode Operation

The modelocked laser is pumped by a broadband high power laser diode with a central wavelength of 1480 nm. Up to 140 mW of pump power was available in the common branch of the WDM in front of the waveguide laser. For σ-polarized (TE) pumping the laser emits in σ-polarisation at the wavelength 1562 nm. During modelocked operation a threshold of 74 mW and a slope efficiency of 12 % were measured.

To suppress relaxation spiking of the laser during mode locking 9 % of the laser output were detected and used for controlled pumping. The low frequency noise suppression has been supported by the push-pull phase modulation. By phase modulation with a frequency of about 5 MHz and modulation depth of 0.1 rad spatial hole burning effects were suppressed.

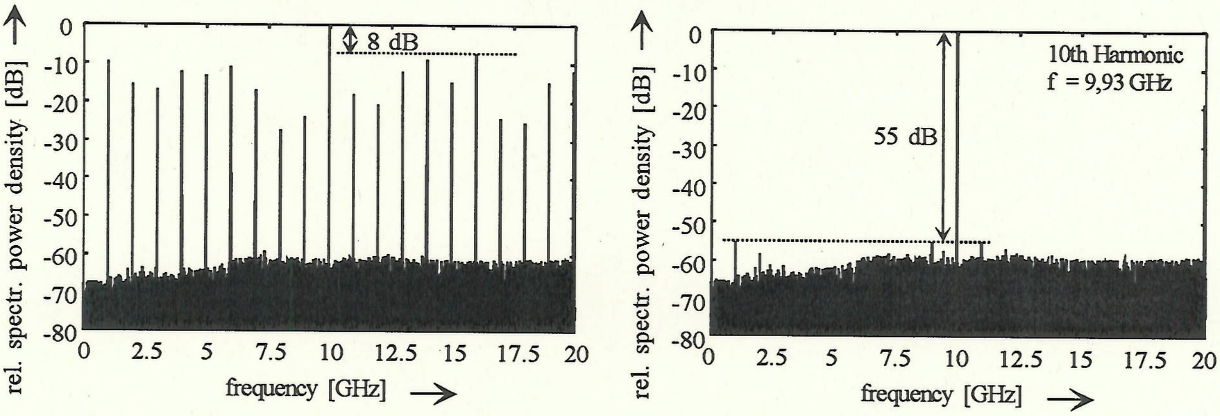

Fig. 2: Electronic spectrum of the pulse train at 10th harmonic modelocking; left: singlc cavity laser; right: coupled cavity laser.

For 10th harmonic modelocking we fed 29 dBm of rf-power at 9.93 GHz to the intracavity modelocker. The output pulses have been detected by a photodiode with 19 GHz bandwidth and analyzed by an rf-spectrum analyzer. The results of the coupled cavity laser are compared with a single cavity modelocked laser (see Fig. 2).

In the output of the single cavity laser strong beat noise components with a frequency difference of the FSR (≈ 1 GHz) are visible. A side mode suppression ratio (SMSR) of 8 dB has been obtained. The coupled cavity laser has a drastically improved performance. Only the neighbouring beat components of the main signal at 10 GHz are appearing in the rf-spectrum. A SMSR of 55 dB has been measured.

Pulse Properties and Detuning Characteristic

The output of the laser has been investigated furthermore by measuring the autocorrelation and the optical spectrum with a resolution of 0.08 nm. These measurements have been done in the whole frequency range where stable modelocking is observed. For the frequency of 9.930 GHz (set as 0 detuning) the smallest pulse width of 4.4 ps has been measured. Together with the spectral width of 0.82 nm a time bandwidth product of 0.44 results - indicating that the pulse is chirp-free, if a Gaussian pulse shape can be assumed.

In Fig. 3 the optical spectrum and the time bandwidth product versus driver frequency detuning is shown. The fine structure of the spectrum results from the single longitudinal modes of the stabilized supermode. Stable modelocking is observed in a total frequency range of 1.3 MHz. Between -0.7 MHz and -0.3 MHz the central wavelength is rising with the frequency. Here the laser is emitting on the so called positive mode. For other driver frequencies the slope is negative and therefore the laser is emitting on the negative mode. It is known from theory, that these two regimes correspond to interleaved pulse trains [5]. The transition from one pulse train to the interleaved one at -0.3 MHz was visible with the sampling oscilloscope. At 0.1 MHz the central wavelength shifts by 1 nm. By analyzing accurately the spectrum at this driver frequency with a Fabry-Perot spectrum analyzer it has turned out that the laser emission jumps from one supermode to the neighbouring one. As can be seen in Fig. 3, the time bandwidth product keeps below 0.56 in the whole locking region. From the theoretical modelling it is clear, that the small chirp is positive for the positive mode and negative for the negative one.

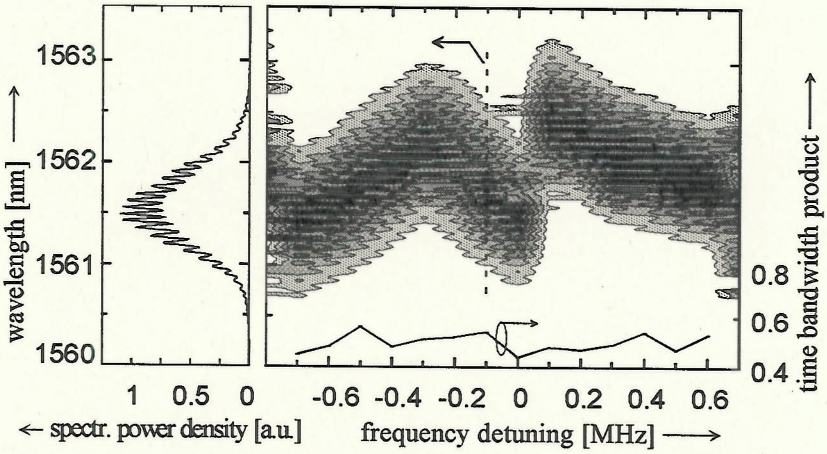

Fig. 3: Detuning characteristic of the coupled cavity Ti:Er:LiNbO$_3$ waveguide laser including the optical spectrum of the laser pulses and the measured time bandwidth product; left side: optical spectrum close to zero detuning (section along dashed line).

Pulse Repetition Rate Doubling

Besides the supermode stabilization the coupled cavity can also serve as a repetition rate multiplicator. If the modelocked laser is driven at the 5th harmonic of the laser FSR an optical spectrum with a mode spacing of 5 GHz is generated. The 10 GHz Fabry-Perot cavity suppresses every second mode leading to a spectrum with a mode spacing of 10 GHz. In this way the pulse repetition rate is doubled.

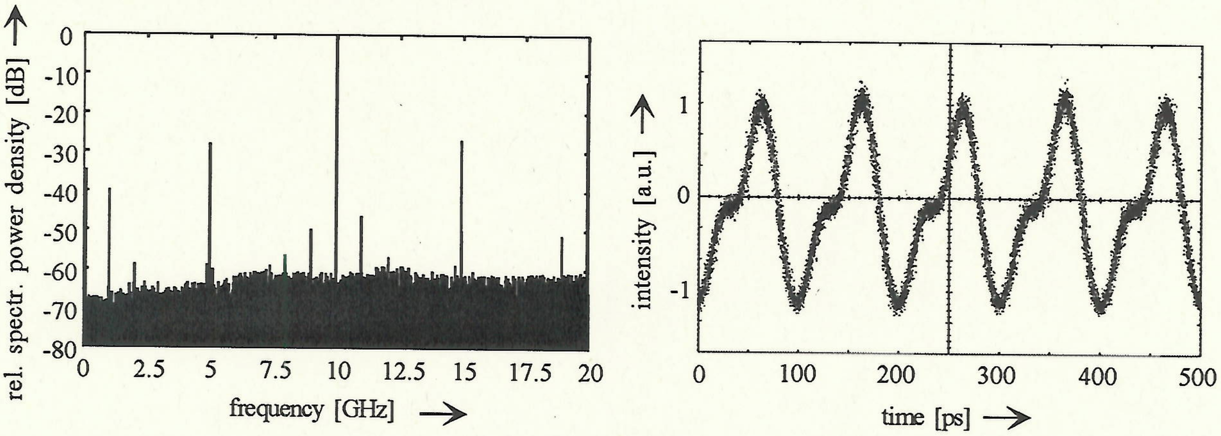

Fig. 4: Repetition rate doubling of the Ti:Er:$LiNbO_3$ waveguide laser; left: rf-spectrum; right: electronically detected pulse train

With 30 dBm rf-power at the frequency of 4.965 GHz a 9.93 GHz pulse train has been obtained. Fig. 4 shows the rf-Spectrum and the pulse train measured with a fast photodiode and a sampling scope. The 5 GHz rf-component is 28 dB smaller than the signal at 10 GHz. A low noise pulse train has been detected with long term stability.

Conclusions

In conclusion we have demonstrated a coupled cavity modelocked Ti:Er:$LiNbO_3$ waveguide laser for 10 GHz pulse repetition rate. Supermode stabilization with a SMSR of 55 dB has been achieved. The pulse laser emits transform limited pulses at a wavelength of 1562 nm with a pulse width of 4.4 ps. The frequency range for stable mode locking is 1.3 MHz. Stable repetition frequency doubling is demonstrated from 5 to 10 GHz. This method can be used for generating pulse trains for high capacity OTDM systems, e.g. synchronized pulse repetition rates in the 40 GHz range using only a 10 GHz drive signal.

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