Ti:Sapphire Channel Waveguide Lasers Produced by Femtosecond and Picosecond Laser Writing

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Ultra-short pulse laser writing is a widely adopted method for rapid prototyping of channel waveguide lasers and amplifiers in the bulk of different types of transparent glasses, crystals and ceramic materials [1, 2]. The writing process in laser crystals relies on engineering either depressed-cladding structures or two parallel tracks to confine the mode in the spacing in-between, by stress-induced increases in the refractive index. Ti:sapphire (α-Al_2O_3:Ti^{3+}) with its broad emission bandwidth (650-1100 nm) is a benchmark solid-state gain medium for ultrashort laser pulse generation and broadly tuneable lasers. Here, we report on the continuous wave (cw) laser operation of Ti:sapphire channel waveguides fabricated by fs- and picosecond (ps) laser writing.

Waveguides were produced using mode-locked regenerative amplified Yb:KGW lasers operating at 1030 nm, at two different pulse duration/repetition rate regimes, 180 fs / 1 KHz and 320 fs / 200 kHz, and a Nd:YVO_4 (1064 nm, 8 ps, 200 kHz). Laser pulses with polarization parallel to the writing direction were focused ~150 µm below the surface of a Ti:sapphire crystal, uniformly doped with 0.12 wt.% Ti_2O_3, by a microscope objective lens with a NA of 0.65. By scanning the crystal transversally to the incident pulses in the same direction, pairs of parallel tracks were formed in its bulk with spacings from 15 to 24 µm. The scanning speed v_{sc}, and pulse energy E_p, for each of the lasers used were as follows: (i) v_{sc} = 15 µm·s^{-1}, E_p = 1.5 µJ, (180 fs, 1 kHz, 1030 nm), (ii) v_{sc} = 2 mm·s^{-1}, E_p = 0.065 µJ (320 fs, 200 kHz, 1030 nm), and (iii) v_{sc} = 0.5 mm·s^{-1}, E_p = 0.3 µJ (8 ps, 200 kHz, 1064 nm). In Fig. 1 the profiles of two waveguides written with 320-fs and 8-ps laser pulses are shown indicating that the tracks produced in the ps-regime were broader and had a depth that was larger by a factor of ~2.5.

Waveguides were optically pumped with a diode-pumped solid-state laser emitting at 532 nm. The laser cavity was formed by attaching a high-reflective (HR) incoupling mirror (R = 99.5%), and outcoupling mirrors with a transmission, T, of 0.5%, 2%, 10%, and 35% at the signal wavelength, in different combinations at the endfaces of the 4-mm-long waveguides. The fluorescence spectra obtained from the waveguides were similar to that of the unprocessed crystal, indicating the absence of any fluorescence quenching of the Ti^{3+} ions by irradiation-induced stress. The lasing spectra exhibited emission peaks at 798.25 nm, and the laser output was π polarized regardless of the polarization state of the pump beam. For a cavity formed by two HR mirrors a laser threshold of P_{th} = 84 mW of absorbed pump power, which is reduced by a factor of >3 in comparison to their counterparts produced by other methods [3, 4]. The maximum output power, 143 mW for about 1 W of absorbed pump power and highest slope efficiency, η = 23.5% were obtained with 35% outcoupling (Fig. 2) from a waveguide defined by two fs-laser-machined (180 fs, 1 kHz , 1030 nm) tracks at a spacing of 24-µm. Waveguides with the same spacing characteristics produced by fs-laser pulse trains at higher repletion rates (200 kHz) consistently exhibited ~20% lower output powers for the same outcoupling level.

The lasing threshold for waveguides defined by a pair of 24-µm spaced, ps-laser-written tracks was 189 mW. The output powers (45 mW) and slopes efficiencies (7.1%) obtained were considerably lower for this writing regime (Fig. 4), due to the stronger interaction of the modal field with the tracks. An upper loss of 0.6 and 2 dBcm^{-1} was estimated from the η values obtained for the fs- and ps-laser written waveguides, respectively.

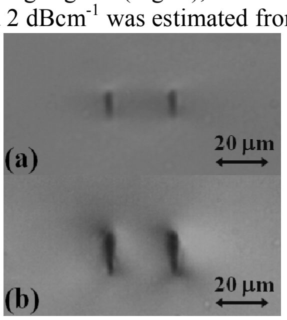

Fig. 1 Microscope images of tracks written by (a) 320-fs and (b) 8-ps pulses.

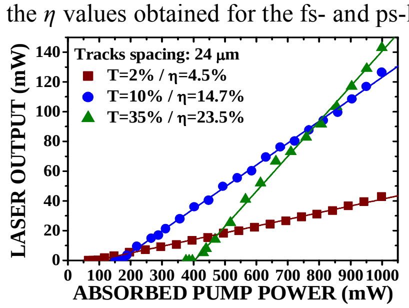

Fig. 2. Power characteristics for a channel waveguide laser inscribed by fs-laser pulses.

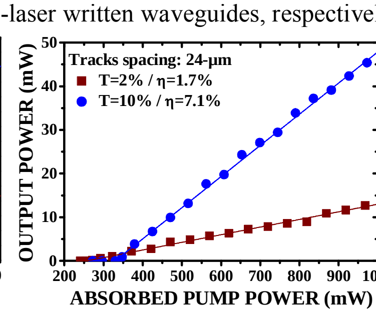

Fig. 3. Laser power dependence on absorbed power for a ps-laser-written waveguide.

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