Stabilization of Q-switched operation in glass waveguide lasers

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Abstract: In this paper, we study the stability of integrated pulsed lasers. The devices are realized on rare-earth-doped glasses by the ion-exchange technique. The influence of the cavity design on the pulsation regime (Q-switching, mode-locking or Q-switched mode-locking) is analyzed. We show that unwanted Q-switched mode-locked operation is obtained in Fabry-Perot waveguide lasers. However, when replacing one of the mirrors by a Bragg grating, the mode-locking is suppressed and a stable Q-switch operation can be obtained. The behavior has been observed for Er/Yb co-doped and Yb doped laser.

Introduction: Q-switched lasers are used in many applications, ranging from sensing to micro-machining. In sensor applications such as LIDARS, either time-of flight[1] or Doppler[2] measurements can be used. However, depending on the parameters of the laser cavity, unwanted mode-locking can appear within the Q-switched pulses (referred to as Q-switched mode locking operation), leading to a more complex pulse envelope and a higher optical bandwidth. This mode of operation is detrimental for both types of LIDARs: the leading edge of the pulse is not smooth, decreasing hence the accuracy of time-of flight measurements, while the higher optical bandwidth is detrimental for Doppler measurements. It is thus interesting to realize devices in which the Q-switched mode locking regime cannot be attained.

In the literature, tailoring of the mode of operation of pulsed lasers is generally made through the design of the saturable absorber[3]. In this paper, we show that the mode of operation can be chosen thanks to the cavity design. For this purpose, we present the design, realization and characterization of different Q-Switched lasers with different cavity configurations (Fabry-Perot, distributed Bragg reflectors, distributed feedback). All these lasers are based on ion-exchanged waveguides made in rare-earth-doped phosphate glasses since this versatile technology already allowed the realization of compact and efficient CW and pulsed lasers[4].

Realization: All lasers use a channel waveguide realized by ion exchange in a doped glass as the optical amplifier element. Phosphate glass substrates are provided by Schott™, they are either doped with Ytterbium (4,6 wt%) or co-doped Erbium (2,2wt%) and Ytterbium(3,6 wt%). Diffusion apertures are formed by a standard photolithographic process in a 30 nm Silicon thin film deposited by RF sputtering. This process allows the realization of 4 cm-long straight waveguides with 3µm wide diffusion apertures. The ion exchange was carried-out at 330 °C in a molten salt bath containing 20% of $AgNO_3$ and 80% of $NaNO_3$. The exchange time was set in order to obtain single mode waveguides at the signal wavelength (λ=1534 nm for Erbium/Ytterbium codoped glass and λ=1030 nm for Ytterbium doped glass).

To obtain a passively Q-switched operation, a saturable absorber element has been added to the laser cavity. In the case of Erbium lasers, a commercially available SESAM element was stuck on the output facet of the waveguide. The relaxation time of the SESAM was 10ps and its modulation depth was 50%. For Ytterbium lasers, a dye (BDN) was embedded in a polymer and cast on top of the waveguides. In this case, the saturable absorber interacts with the evanescent tail of the guided mode[5]. The BDN relaxation time is 5ns and its concentration in the polymer was set to $4.2\times10^{23} m^{-3}$, which corresponds to an 80% modulation depth. Finally, the laser cavity was closed by a mirror or by a Bragg grating. Four different lasers have thus been realized. They will be referred to with letters A, B, C and D. Device A is a Fabry-Perot Erbium laser using a 4% reflection mirror on one facet and the SESAM on the other. B is a DBR Erbium laser identical to A, but the 4% mirror was replaced by a 1cm long, 10% reflection Bragg Reflector realized on top of the waveguide. C is a Fabry-Perot

Ytterbium laser terminated by 4% and 84% reflection mirrors, the saturable absorber is a BDN-doped polymer deposited on top of the waveguides. Finally, D is identical to C except that the 4% mirror is replaced by a 50% reflection Fiber Bragg Grating (FBG). The reflection of the FBG is centered on λ=1030 nm.

Characterization: Both spectral and temporal characteristics of lasers A, B, C and D have been measured. For spectral measurements, an OSA with a 0.07nm-resolution is used. Temporal measurements are carried-out with a fast photodetector (10 GHz bandwidth for 1.5 µm wavelength lasers and 25 GHz for 1µm lasers). The photodetector is connected to a 6 GHz bandwidth oscilloscope.

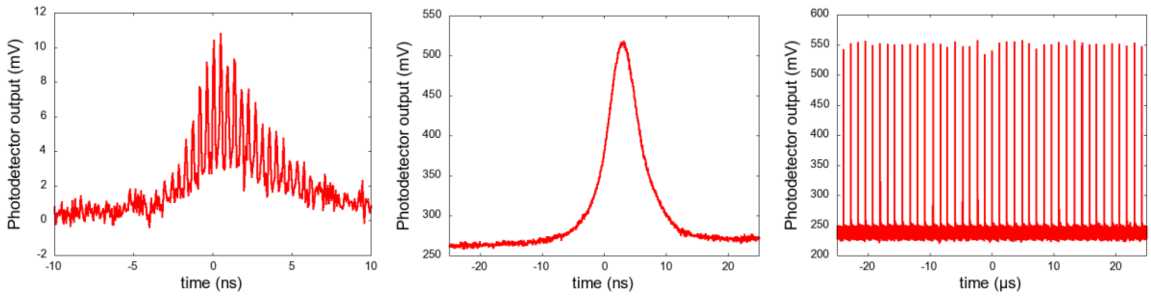

Figure 2: temporal characteristics of lasers. a): device A exhibits a Q-switched mode-locked operation. b) and c): device B is purely Q-switched.

Devices A and B both operate at a 1.53 µm-wavelength and are similar, except that A is a Fabry-Perot and B is a DBR laser. Both devices have an output power of 10 mW for an injected pump power of 300 mW. However, their spectra are different: for A it is 1 nm-wide whereas for B it is limited by the resolution of the OSA (0.07 nm). The results of the temporal measurements are presented on figure 2: a) is the pulse shape obtained with device A, b) is the pulse shape obtained with device B and c) is a pulse train from device B. In both cases, pulse width is about 4 ns and repetition rate varies from a few tens of kHz to 1 MHz depending on the pump power, but it can be clearly seen that device A presents a Q-Switched Mode-locked operation, while a pure Q-switched operation is ensured for laser B thanks to the integrated Bragg reflector.

Devices C and D have been realized in an Ytterbium-doped glass and were characterized with the same setups. The spectrum obtained with device C presents several emission lines between 1000 and 1020 nm, which respective power fluctuates randomly. This behavior is attributed to the very wide inhomogeneous emission linewidth of Ytterbium combined with the low spectral filtering of the Fabry-Perot cavity. On the other hand, the spectrum obtained with device D consists of a unique emission line at 1030 nm (the reflection wavelength of the FBG). The pulse width of both devices is around 9 ns and a repetition rate of 10 kHz can be observed under pumping at 300 mW. As with the Erbium lasers, Q-switched mode-locking is observed for device C whereas device D exhibits a pure Q-switched operation.

Conclusion: In this paper we reported the realization and characterization of Yb-Er and Yb integrated passively Q-Switched lasers for LIDAR application. We showed experimentally that the use of a Bragg Reflector for closing the laser cavity allows obtaining quite high power densities while maintaining a pure and stable Q-switched operation. Current work is focused on the realization of single-frequency passively Q-switched lasers thanks to the implementation of a DFB cavity

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