Supercontinuum source based on ion-exchanged Neodymium doped Q-switched laser

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***Abstract*— Supercontinuum generation consists in launching a high peak power pulsed laser in a nonlinear medium, usually a photonic crystal fiber (PCF). It allows obtaining an ultra-wide band spectrum source. In this article, we present a glass integrated optics Q-switched laser, which can be used to directly pump the PCF, without bulk coupling optics. This laser is made by ion-exchange in a Neodymium-doped phosphate glass. The laser emits 2.4 kW peak power pulses with 0.6 ns duration. The laser output is directly coupled to a PCF. A supercontinuum spectrum spanning from 400 nm to 1600 nm is thus generated.**

Glass integrated optics, ion-exchange, Q-switched laser, supercontinuum, photonic crystal fiber.

I. Introduction

Supercontinuum sources have raised a great deal of interest since their first realization by Alfano et al. in 1970[1]. Indeed, sources with a broadband spectrum and high brilliance are useful for numerous applications like spectroscopy, metrology or optical coherent tomography (OCT). Supercontinuum sources using photonic crystal fiber (PCF) as the non-linear medium have enabled huge performances improvements in the past ten years[2]. These fibers have allowed supercontinuum generation with spectra ranging from the UV to the IR when pumped with either mode-locked or Q-switched lasers around 1 µm. However, a special care is required in order to devise an efficient coupling scheme between the pulsed laser and the PCF. The most common solution is to use some bulk optics to couple the pump laser in the PCF. Fiber lasers can be used to avoid this coupling optics. However, the saturable absorber is not integrated in these devices[3], so that bulk optics is needed inside the laser cavity.

An alternative technology that could avoid the need for bulk coupling optics is glass integrated optics. This technology is indeed compatible with optical fibers and allows producing both passive[4] and active devices such as amplifiers[5] and lasers[6]. Moreover, a Q-switched laser realized by ion-exchange has been demonstrated by R. Salas-Montiel et al.[7] and an optimized structure has been recently published, allowing a 1 kW peak power emission[8]. This value of peak power is compatible with supercontinuum generation in PCF.

In this paper, we present a supercontinuum generated using a fully integrated Q-switched laser directly coupled to a PCF. We first present the realization of the laser cavity, designed to allow a direct coupling with the PCF. In the second part, we present the hybridization of the saturable absorber, leading to a pulsed laser operation. The supercontinuum source realized with this laser is then characterized.

II. Device realization and characterization

The laser cavity consists of an amplifying waveguide and two reflectors stuck on the waveguide facets. The waveguides are made by ion-exchange in a commercially available phosphate glass substrate (Schott™ IOG1) doped with 4.7 wt% Neodymium oxide. It is realized by silver/sodium ion-exchange in a (20% mol $AgNO_3$ - 80% mol $NaNO_3$) salt bath. Amplification using the Neodymium system in our glass requires a pump at the wavelength of 800 nm and a signal at the wavelength of 1054 nm. In order to obtain an efficient amplification, the waveguides have been designed in order to provide single-mode operation at those two wavelengths.

After realization, their single-mode behavior was assessed by near field intensity distribution measurement. The propagation losses were also measured and were found to be 0.1±0.1 dB/cm. The mode intensity distribution were used to compute the coupling efficiency of these modes with that of the PCF at the signal wavelength. A value of 70% was found.

Numerical simulations were carried out to compute the output power of Fabry-Perot lasers using the measured waveguide mode field distributions with a 100% reflection coefficient mirror on one side and a variable one on the other side. It appears that a 4% reflection coefficient (corresponding to the reflection on the bare glass facet) leads to an output power value close to the maximum. Since the dielectric mirrors we use are deposited on a 100 µm thick microscope slide, it is not possible to approach the optical fibre close enough to obtain a good coupling with the waveguide. Removing the mirror and using instead the 4% reflection of the facet is thus a very attractive solution which allows a direct coupling with an optical fibre.

The Fabry-Perot structure containing a 100% reflector on one side and 4% reflector on the other side has thus been implemented on a 4 cm long waveguide. 440 mW pump power has been launched inside the structure using two lenses as presented on Fig.1. An output power of 160 mW has been obtained with the maximum pump power.

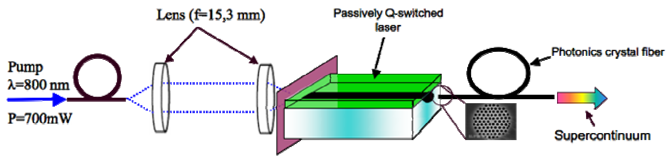

Figure 1. Schematic view of the supercontinuum source.

III. Q-SWITCHED OPERATION AND SUPERCONTINUUM GENERATION

The element used as a saturable absorber is a dye termed BDN for bis(4-dimethylaminodithiiobenzil)nickel[9]. This dye is included in a cellulose acetate matrix so that it can be shaped as a 100 µm thick film which is cast on the glass wafer containing the waveguides. In this configuration, the saturable absorber is distributed all along the laser cavity. However, only the evanescent top part of the transverse photon flux interacts with the saturable absorber, since the refractive index of the cellulose acetate cladding is lower than that of the glass wafer.

An experiment was then conducted using polymer films with different BDN concentrations. The structure of these pulsed lasers is presented on Fig. 1. The pulse duration τ, repetition rate T, and average output power P_{avg} have been measured. The peak power P_{peak} of the pulses could then be inferred using (1).

$$P_{peak} = T.P_{moy}/\tau. \qquad (1)$$

For the optimal BDN concentration of $6x10^{23}\,m^{-3}$, pulses with an average power of (37 ± 1) mW, a pulse duration of (0.65 ± 0.1) ns and a repetition rate of (50 ± 2) µs were measured. This corresponds to a pulse energy of (1.86 ± 0.2) µJ and a peak power of (2,8 ± 0.6) kW. The polymer cladding of devices with BDN concentrations above $6x10^{23}\,m^{-3}$ have been irreversibly damaged due to the too high value of the intra-cavity peak power. Taking into account the 70% coupling coefficient of the device with the PCF, a peak power of (2.0 ± 0.5) kW is available in the PCF, which is adequate for supercontinuum generation.

The supercontinuum source has been realized by directly coupling the Q-switched laser output to an 8 m long PCF as shown on Fig. 1. A quantitative measurement of the spectrum emitted by the supercontinuum source has been carried out in three steps. First, the visible wavelengths were measured using 10 nm wide optical filters centered on 450, 500, 550 and 600 nm and a calibrated photodetector. The first part of the IR spectrum was measured directly through an OSA. The second part was measured through the same OSA. However, a low-pass optical filter has been inserted to prevent the second order of the 1054 nm or 800 nm signal to interfere with the measurement. The complete spectrum is represented on Fig. 2.

The spectrum presented on Fig. 2 shows that a supercontinuum was indeed generated. It spans from 450 to 1600 nm and is comparable with the state of the art[10]. This work thus proves the feasibility of an integrated supercontinuum source which does not require any coupling optics between the pump laser and the PCF.

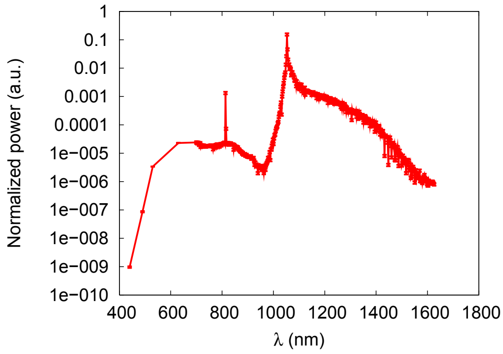

Figure 2. Spectrum emitted by the supercontinuum source.

IV. CONCLUSION

The realization of a supercontinuum source based on a glass integrated optics laser is presented in this paper. The Q-switched laser is based on an ion-exchanged waveguide designed to let one bare facet that can be used for direct coupling with the PCF. This device is then free of coupling optics and is thus more efficient while less subject to vibrations. A BDN-doped cellulose acetate film deposited on the glass wafer acts as the saturable absorber and allows a Q-switched operation. With this structure, pulses of 2.8 kW peak power and 0.6 ns duration have been obtained. Once coupled in the 8 m long PCF, these pulses have produced a large spectral output ranging from 450 to 1600 nm.

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