Amplified spontaneous emission injection into an optical fiber with the aid of a nematicon

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Amplified Spontaneous Emission (ASE) has become popular for applications like spectroscopy, fiber sensors and imaging that require incoherent light. In our setup ASE is generated in a dye-doped nematic liquid crystal cell and it is then collected into an optical fiber to integrate into the device. We demonstrate that, generating a nematicon from the same fiber, the ASE collection efficiency is increased of almost one order of magnitude thanks to the wave-guiding action of the nematicon that induces the injection into the fiber. Moreover the collected emission is highly linearly polarized parallel to the direction of the liquid crystal director.

Introduction

When using an elongated pumping stripe to excite an amplifying material, the photons emitted along the major axis of the rectangle experience a spectral selection of the amplified light: the emission is almost monochromatic at the wavelength with the highest gain [1, pp. 71-76]. This phenomenon is known as Amplified Spontaneous Emission (ASE) and, since the spectral selection takes place without feedback, it is also improperly known as “mirrorless lasing”. ASE is characterized by a quite low coherence and, for this reason, it can be used in imaging applications in order to reduce speckle from images with respect to broadband and narrow-band lasers [2].
ASE was demonstrated in solid state films [3, 4], capillaries [5] and liquid crystals (LC) [6, 7]. LC are particularly interesting since they support the formation of solitons. Indeed the electric field of a light beam that propagates in LC induces reorentation of the LC molecules. Since these molecules are anisotropic, this translates into the formation of an optical waveguide that not only maintains the beam confined (soliton formation), but also allows to guide a second beam [8]. When solitons occur in nematic LC they are called *nematicons*. The ability of LC to be reoriented by an external electric field can be used to switch on and off the ASE [6]. However it is quite difficult to efficiently collect ASE from such LC cells.
In our setup we demonstrate the use of a nematicon to collect ASE and guide it into a fiber integrated in the LC cell.

Sample preparation and experimental setup

The LC cell is composed of two Indium-Tin-Oxide (ITO) coated glass plates that have been spin-coated with a nylon alignment layer. The two glasses are then assembled with

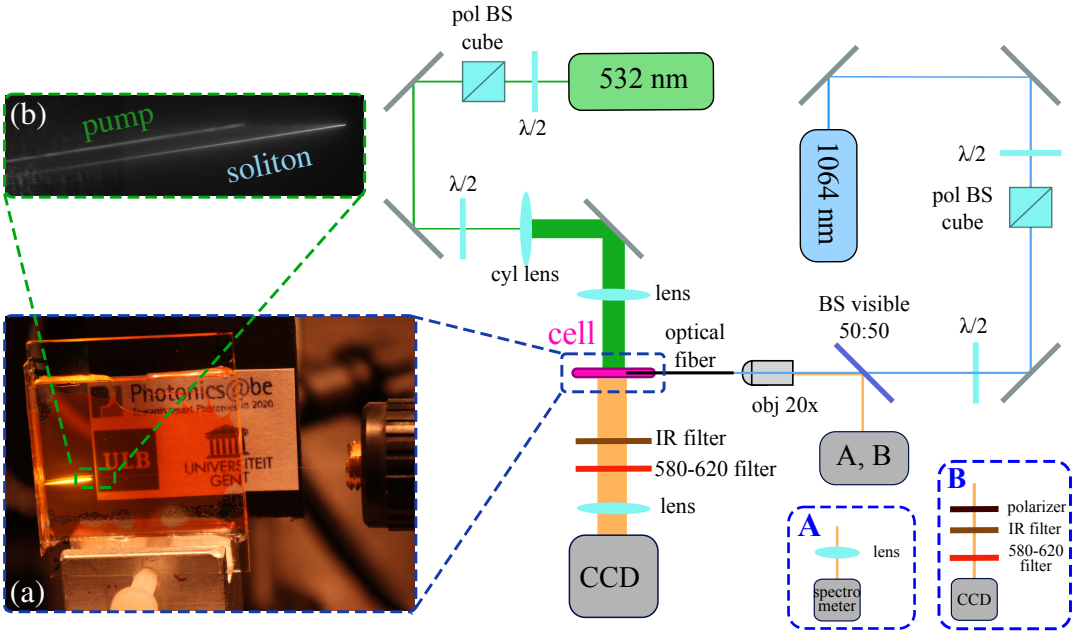

Figure 1: Scheme of the nematicon injection and the ASE generation in the dye-doped nematic LC cell. Inset (a): Picture of the cell with the fiber slid inside it and the pump stripe coming orthogonal to the cell surface. The fiber, coming from the right is horizontal and at 45° to the rubbing direction. Inset (b): image from the CCD camera showing the fluorescence from the pump stripe (visible) and the nematicon (IR) formation (not overlapping for clarity).

UV-curable glue mixed with spherical spacers (75 µm) that fix the thickness of the LC layer. The cell is infiltrated by capillarity with a solution of 0.99%wt of pyrromethene (PM) 597 dye (Sigma-Aldrich) in E7 (Merck) LC. Then an optical fiber (64.4 µm of cladding diameter and 2.9 µm of core diameter, cut-off wavelength of 550 nm) is slid inside the cell. The rubbing direction is at 45° with respect to the fiber injection.
The optical setup is reported in Fig. 1 and a picture of the cell in Fig. 1a. The nematicon is formed with an IR laser (Nd:YAG, 1064 nm, CW). The power of the beam is controlled through a half-wave plate followed by a polarizing beam splitter. A second half-wave plate controls the polarization angle of the beam launched into the fiber. A microscope objective (20x, NA 0.5) focuses the light into the fiber that then guides it into the LC cell. The pump laser is a frequency doubled Nd:YAG laser (532 nm) that delivers 400-ps pulses at a repetition rate of 100 Hz. Another polarization control stage is used on the pump beam, but this beam is focused with a spherical achromatic and a cylindrical lens in order to obtain a elliptical spot of around 20 µm × 7 mm on the cell. The ASE threshold is as low as 0.4 µJ/pulse. All the measurements are taken well above the ASE threshold (6.6 µJ/pulse). Since the ASE is emitted along the long axis of the elliptical spot, and since the nematicon experiences a walk-off due to the anisotropy of the LC, the pump stripe is tilted with respect to the fiber in order to facilitate the injection of the ASE into the nematicon (Fig. 1b). Two filters are used to remove the IR and the pump radiation before entering the CCD camera placed on the side of the cell. On the IR path a beamsplitter for the visible light (BS) is used to select the light emitted by the dye that comes out of the fiber and to send it either on a spectrometer (A in Fig. 1) or on a CCD camera (B).

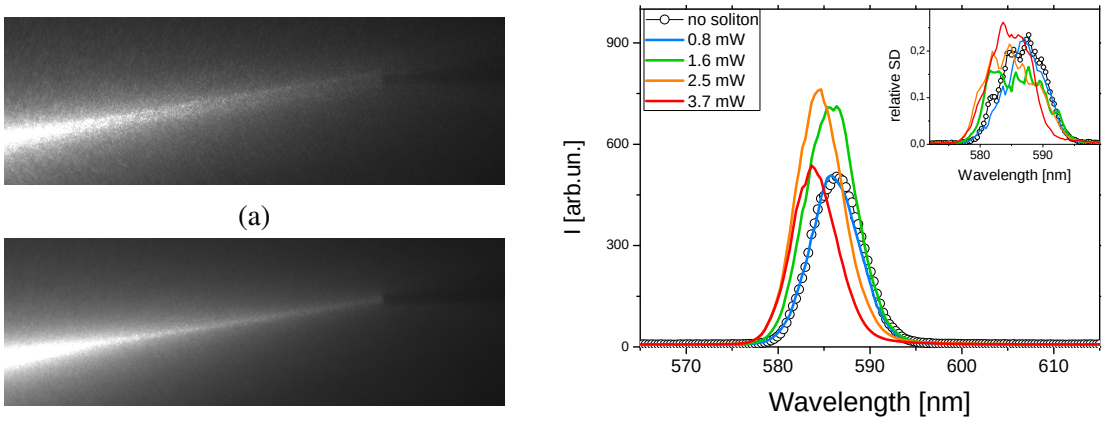

Figure 2: Images of the ASE light from the dye in the cell (532 nm and 1064 nm are filtered out) in the case where (a) no nematicon is present; and (b) a nematicon of 2.5 mW is present. (c) Spectra collected at the output of the fiber, each spectrum is an average of 200 scans. Inset: relative Standard Deviation (SD) of the collected intensity as a function of the wavelength recorded at different nematicon powers.

Experimental results

In Fig. 2a we show the ASE fluorescence scattered by the LC molecules and collected on the side of the LC cell. We can clearly see that the ASE emission in this configuration is already directional, but when the nematicon is present, the emission is clearly confined in the nematicon-induced waveguide (Fig. 2b).
Looking at the spectra collected at the output of the fiber (Fig. 2c), it is clearly visible that, when increasing the nematicon power, the guiding effect increases. This is due to the reorientation of the molecules that modify the index contrast of the guide, leading to a more efficient guiding effect at higher power. However, at even higher nematicon powers, we observe an abrupt decrease of the collected light because the nematicon starts to oscillates in space [9], which makes light collection less efficient.
The optimal coupling efficiency is obtained for the highest power at which the nematicon is still stationary in space. This is clearly visible from the evolution of the relative Standard Deviation of the collected intensity as a function of the nematicon power (Inset of Fig. 2c), for which the optimum occurs around 1.6 mW.
If now we look at the far field intensity profile of the light coming out of the fiber, we see the profiles shown in Fig. 3. In these measurements we separate the emission polarized along the thickness of the cell (orthogonal to the substrate surface) from that one polarized in the plane of the cell (parallel to the substrate surface). It is clearly visible that the presence of a nematicon considerably increases the collected light. Moreover the collected ASE is strongly polarized parallel to the substrate surface.

Conclusion

We demonstrated experimentally that the presence of a nematicon can efficiently improve the collection and the injection of polarized ASE into an optical fiber. This can be useful for the realization of fibered or integrated ASE sources.

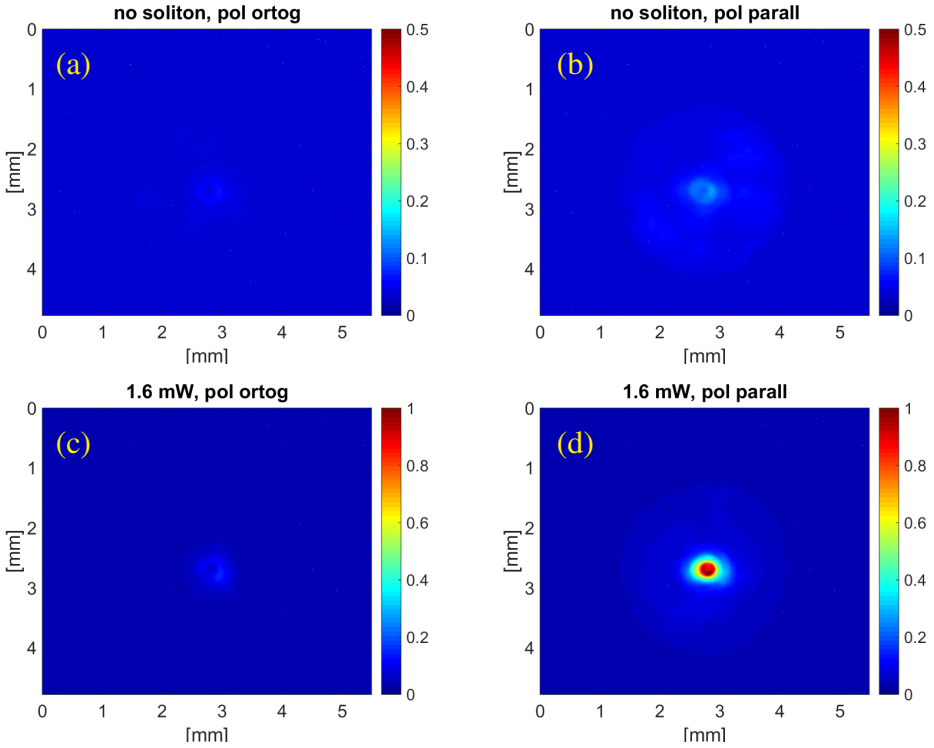

Figure 3: ASE coming out of the fiber for the case (a)-(b) without nematicon and (c)-(d) with a nematicon of 1.6 mW, polarized parallel or orthogonal to the substrate surface. The images are taken at 35 cm from the objective lens.

Acknowledgement

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