Ultra-compact 266-289 nm pair source for DIAL LIDAR based on hollow-core photonic crystal fiber

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Abstract: We propose an ultra-compact double wavelength source 266-289 nm developed for DIAL LIDAR of Ozone in the troposphere thanks to a hollow-core photonic crystal fiber filled in with Deuterium.

1. Context

Assessing the ozone concentration in the troposphere, and understanding its net photochemical production and dependency with dynamical processes, such as intercontinental long-range transport and stratosphere-troposphere exchanges, is paramount to assess its impact on climate change and air pollution [1,2]. Observations with good spatial (10-100 km horizontally, 100-500 m vertically) and temporal (less than 1 hour) resolution are needed to characterize the ozone distribution and evolution.

A proven technique to measure the troposphere ozone which has been proved to be efficient is LIDAR by differential absorption (DIAL). It consists of using two different wavelengths chosen in the Hartley absorption band from 260-310 nm [3]. The wavelengths must be widely separated (> 10-20 nm) to enable accurate and highly sensitive measurements, i.e. with an ozone differential absorption cross-section higher than 5.10^{18} cm^2. The use of the fourth harmonic of a Nd-YAG laser at 266 nm has been recognized as a good choice for the wavelength highly absorbed by ozone [4]. One of the main difficulties of DIAL ozone monitoring is to use a dual-wavelength emitter in a compact cost-effective system. To produce the off-wavelength weakly absorbed by ozone from a highly energetic laser beam at 266 nm (few mJ), one can use a gas cell filled in with a few bars of Deuterium to generate the first order vibrational Stokes by stimulated Raman scattering (SRS). Another gas used for this application is the H_2 as its first vibrational Stokes is situated at 299 nm, which is in the Hartley band of Ozone. To reduce the size of the instrument, one interesting approach is to use a small size high repetition frequency Nd-YAG laser with an output power of less than 100 mW and to replace the large size steel gas cell by hollow core crystal fiber (HCPCF), which enables to confine gases in a micrometer scale core over long distances, enhancing the SRS phenomena by a factor of more than a million [5]. It provides the capability of generating very high conversion with very low energy. In comparison to the few mJ talked about hereabove, only a few µJ are needed and, thus, a compact laser can be used. Another key feature of these fibers is their resistance to the UV radiation that damages conventional fibers in a matter of an hour. This is due to the fact that the overlap between the core mode and the silica cladding is very low. Also, thanks to the development of hollow-core fibers for this wavelength range their losses have been drastically reduced.

2. Experimental results

The fiber used in this investigation is a one-ring tubular fiber whose cladding is comprised of 8 tubes. The fiber core diameter measures 27 µm. A cut back measurement has been done and record losses were measured to be as low as 10 dB/km at 355 nm (see Fig. 1a). The normalized fiber transmission between 240 nm and 330 nm is shown in Fig. 1b. The fiber has also been tested on a long-term cycle to approve its tolerance to UV light. For this experiment, a laser with a wavelength at 355 nm and an energy of 8 µJ has been coupled in an 8 meters long-piece of fiber. As illustrated by Fig. 1c, no degradation with time was observed over four months, demonstrating that the fiber is free from photochemical UV effects. The fiber has then been sealed into two gas chambers with UV antireflection flat windows. The pressure was monitored thanks to gauges on the chambers. In Raman generation experiments, one has used an EMOPA laser from Crylas with an energy of 40 µJ, a repetition rate of 1 kHz, and a pulse width below 1 ns. The whole system sits on a breadboard of 50 cm long and 30 cm wide. A measurement campaign in changing the fiber length and the gas pressure has been performed in order to obtain 30% of the pump on the first vibrational Raman transition of the D_2 at 289 nm. Notice that for lengths superior to 25 cm the gain is to important and other

Stoke transitions are generated, which are parasitic in this case. For a length beneath 25 cm, the modal content deteriorates. The systematic study with the gas pressure gives us our ratio for 3.2 bar Deuterium as plotted in Fig. 1d. The same study has been done with H_2 to generate the first order vibrational Stokes at 299 nm which is also a wavelength used for DIAL LIDAR in Ozone. It demonstrates the possibility of targeting different off-wavelengths thanks to this source (Fig.1d). The optimum fiber length was found to be 7cm for a pressure of 5 bar.

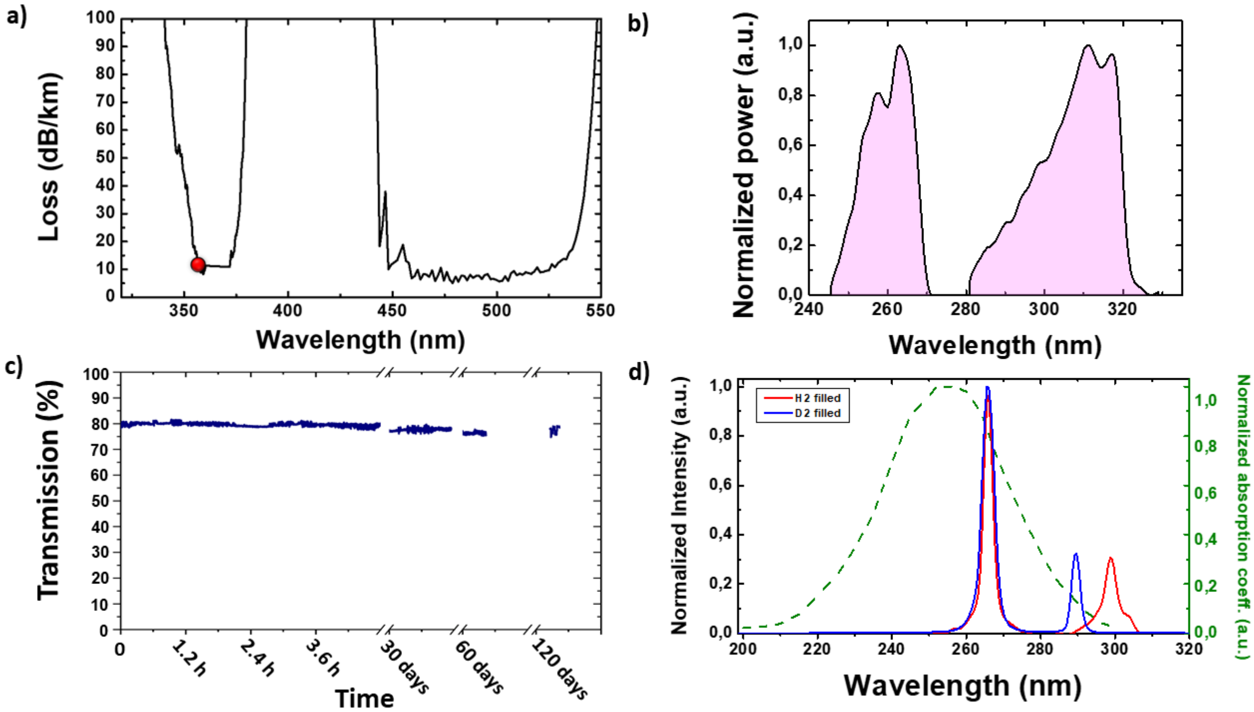

Fig. 1: (a) Cutback measurement results. The red spot represents the result from a cut back made with a 355 nm laser. (b) Normalized transmissions in the UV measured with a plasma lamp. (c) Fiber lifetime measurement under UV radiation over 120 days. (d) Raman generation plots in a 25 cm D_2-filled fiber (blue curve) and in a 7 cm H_2-filled fiber (red curve). The green curve represents the normalized absorption coefficient of the ozone in the Hartley band.

3. Conclusion

Thanks to the development of an optimized HCPCF for the UV range with record losses as low as 10 dB/km at 355 nm, we have proposed this innovative source emitting at 266 nm and 289 nm targeted for DIAL LIDAR for Ozone. Indeed, the source can also be tuned to emit at 299 nm by changing the D_2 by H_2. The footprint has been reduced to a 50x30x15 cm breadboard compared to the cumbersome conventional sources. We hope that this kind of source will permit to monitor this key indicator of our environment on a wider scale and give us a better overview of the evolution of the low atmosphere.

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4. References

[1] Monks, P. S., Archibald, A. T., Colette, A., Cooper, O., Coyle, M., Derwent, R., Fowler, D., Granier, C., Law, K. S., Mills, G. E., Stevenson, D. S., Tarasova, O., Thouret, V., von Schneidemesser, E., Sommariva, R., Wild, O., and Williams, M. L.: "Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer", Atmos. Chem. Phys., 15, 8889–8973, (2015).

[2] François Ravetta Gérard Ancellet, Augustin Colette and Hans Schlager, "Long-range transport and tropospheric ozone variability in the western Mediterranean region during the Intercontinental Transport of Ozone and Precursors (ITOP-2004) campaign",Journal of Geophysical Research: Atmospheres, American Geophysical Union, 112 (D10), pp.D10S46, (2007)..

[3] Ancellet, G. and F. Ravetta. "On the usefulness of an airborne lidar for O3 layer analysis in the free troposphere and the planetary boundary layer." Journal of environmental monitoring, JEM 5 1, 47-56, (2003).

[4] A. Papayannis, G. Ancellet, J. Pelon, and G. Mégie, "Multiwavelength lidar for ozone measurements in the troposphere and the lower stratosphere," Appl. Opt. 29, 467-476 (1990).

[5] F. Benabid,J. C. Knight, G. Antonopoulos, and P. St. J. Russell, "Stimulated Raman Scattering in Hydrogen-Filled Hollow-Core Photonic Crystal Fiber", Science 298, 399, 2002