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# Silica based optical fibers with record attenuation in the mid-infrared

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**Abstract:** We demonstrate silica-based hollow core optical fibers with a record minimum attenuation of 0.22 dB/m at 4.6  $\mu\text{m}$  and propose novel optical fiber designs with less than 1 dB/m attenuation above 5  $\mu\text{m}$ . As a result, these can be used in specific optical detection systems, capable of sensing hazardous gases (e.g. NO [8]), with high sensitivity.

## 1. Introduction

The last few years have seen tremendous progress in the area of hollow core optical fibers based on a simple optical design, which are easy to fabricate and have been demonstrated to have a very low overlap between the light travelling within the fiber and the silica forming the cladding. This novel form of optical waveguide is known as the Anti-Resonant Hollow Core Fiber (ARF) [1-4]. It has been demonstrated numerically [3] and experimentally [2] that a modification of the curvature of the core boundary of ARFs can significantly decrease fiber attenuation. By adopting a large fiber core, these fibers have allowed a level of overlap of the guided light with the silica cladding material of <0.01% [3].

These novel and peculiar characteristics of ARFs have driven recent scientific innovations and technological applications in optical beam delivery (higher damage threshold due to the low light/glass overlap), increased optical transmission in the ultraviolet as well as lower latency for optical communication systems transmission links, due to the decreased effective index of guidance [1].

ARFs have been already successfully employed in the 3-4  $\mu\text{m}$  spectral wavelength [2], with relatively low attenuation (100dB/km) and bending loss, which were used for the realization of the first mid-infrared electrically pumped gas fiber amplifier at 3.5  $\mu\text{m}$  [5] and the first optically pumped gas laser at 3.12  $\mu\text{m}$  [6]. However, the optical attenuation of ARFs in the mid-infrared rapidly increases at longer wavelengths, due to the increased absorption of silica glass, particularly above 4.5  $\mu\text{m}$  [7]. It reaches values exceeding 50000 dB/m at wavelengths above 5  $\mu\text{m}$ .

We demonstrate silica-based hollow core optical fibers with a record minimum attenuation of 0.2 dB/m at 4.6  $\mu\text{m}$  and propose novel optical designs with less than 1dB/m attenuation above the 5  $\mu\text{m}$  wavelength range. As a result, these can be used in specific optical detection systems, capable of sensing more than one hazardous gas (e.g. NO [8]), with high sensitivity.

## 2. Record attenuation in the mid-infrared

The hollow core optical fiber shown in the inset of Fig. 1(A) has been fabricated at the University of Lille. Its geometric characteristics have been designed for optimal transmission in the mid-infrared spectral range. The fiber has a large core size of 162  $\mu\text{m}$ , a silica core boundary thickness of 1.3  $\mu\text{m}$  and an overall fiber size of 376  $\mu\text{m}$ . Its attenuation spectrum is shown in Fig. 1 (a) and it can show a minimum loss of 0.22 dB/m at 4.6  $\mu\text{m}$ , the minimum value ever reported at this wavelength.

In order to further improve the attenuation of this fiber type at even longer wavelength (i.e. above 5  $\mu\text{m}$ ) a novel design for hollow antiresonant fibers is proposed in Fig. 1(B) (inset in blue). As compared to other conventional antiresonant hollow core fibers (inset in red), this fiber structure can largely reduce the power overlap between the optical mode travelling within the fibre and the silica struts of the core boundary, i.e. reducing the impact of material attenuation on the overall fiber losses (blue line). Figure 1(B) shows how, theoretically, it could be possible to achieve optical attenuations below 1 dB/m in silica based hollow core fibers, even above the 6  $\mu\text{m}$  wavelength range.

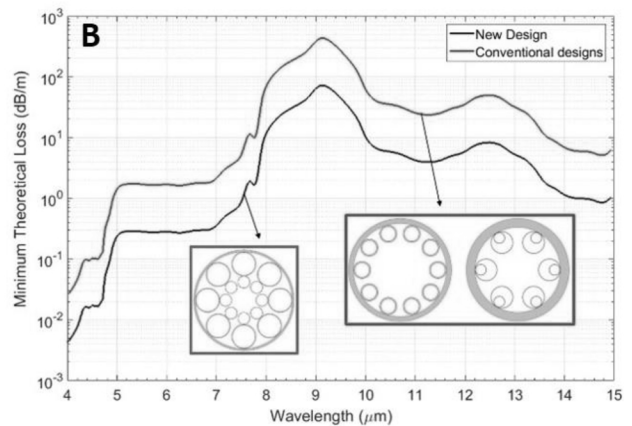
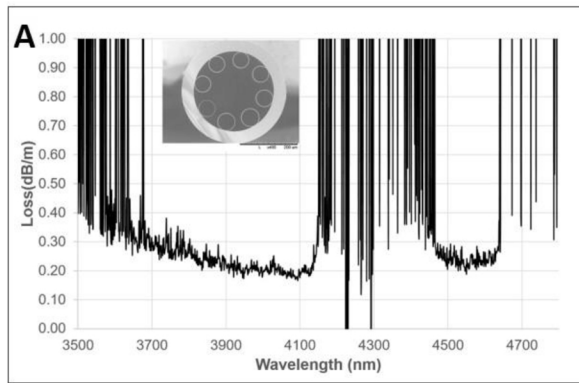


Fig. 1. (A) Record attenuation in the mid-infrared for the hollow core fiber shown in the inset. (B) Novel design for hollow core optical fibers with record attenuation beyond 5 $\mu$ m.

### 3. Novel optical design for high performance hollow core optical fibers

The hollow core optical fiber described above has been incorporated within the detection optical system described in Fig. 2. Thanks to the inscription of a series micro-channels along the lateral section of the hollow core fiber, up to date, the sensing system has allowed the detection of nitrous oxide at 5.26  $\mu$ m with a minimum detection limit of 11 ppbv for an integration time of 144 s.

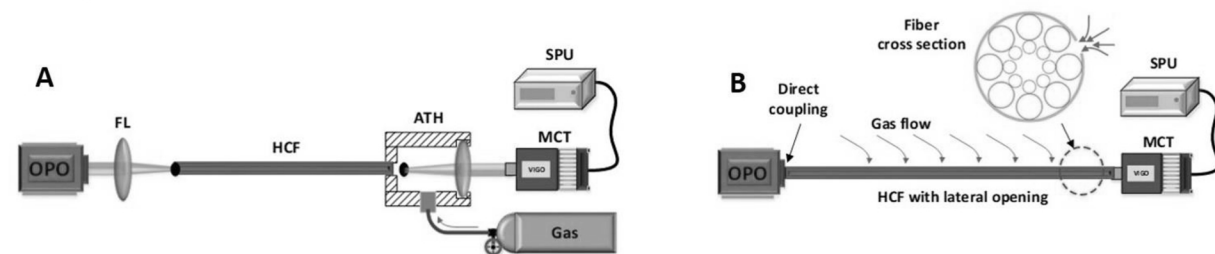


Fig. 2. (A) Setup of a broadband detection optical system employing an hollow core optical fiber. (B) Evolution of the system for high compactness and high sensitivity

### 4. Conclusions

We have discussed the fabrication of a hollow core optical fiber with a record minimum attenuation of 0.22 dB/m at 4.6  $\mu$ m, his implementation in an optical NO detection system with very high sensitivity, the design of novel hollow core fibers with improved performances in the mid-infrared and the developments of improved broadband sensing systems with high compactness.

### 5. References

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