Compact and Robust Refilling and Connectorization of Hollow Core Photonic Crystal Fiber Gas Reference Cells

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Abstract: A simple method for evacuating, refilling and connectorizing hollow-core photonic crystal fiber for use as gas reference cell is proposed and demonstrated. It relies on torch-sealing a quartz filling tube connected to a mechanical splice between regular and hollow-core fibers.

Active laser frequency stabilization is used in metrology, lidar, optical communications and other applications. Gas-filled cells are attractive frequency etalons, because, unlike Fabry-Perot cavities, they provide an absolute frequency standard corresponding to a molecular resonance. Conventional gas cells made of glass or metal are typically tens of cm long, take up significant volume and mass. They are also awkward to make compatible with fiber optic components. Thus, they make the overall frequency-locking system large, heavy, and often fragile, and do not allow using weaker molecular resonances as their practical length is limited.

Recently, there have been several demonstrations of Hollow-Core Photonic Crystal Fibers (HC-PCF) evacuated of air, filled with a gas to the desired pressure, and used as reference cells [1-4]. Some demonstrations did not attempt to connectorize HC-PCF [1,2], while other did. In Ref. 3, one end of HC-PCF was spliced to SMF, while the other one had a mechanical splice sealed with epoxy inside a vacuum chamber. It appears the connectorized cell was never taken out of the vacuum chamber. In Ref. 4, one end of HC-PCF was fusion spliced before and the other after evacuation and refilling. One drawback is that the second end was likely exposed to atmosphere in the time after it was taken out of the gas chamber and before the splicing was complete. Moreover, fusion splices of HC and index-guiding fibers results in ~4% Fresnel reflections, which cause output intensity noise. Angled splicing was attempted previously but the effort was abandoned due to mechanical weakness of the resulting splice [5].

We implemented a simple technique for refilling and connectorizing HC-PCF to produce a gas cell that is devoid of these drawbacks. One end of HC-PCF is mechanically spliced to a standard fiber in a silicon v-groove, insuring optical coupling yet leaving space for gas exit/entrance into HC-PCF. This is similar to the mechanical splice in Ref. 3, but the fibers are angle cleaved to avoid back reflection. However, instead of placing the v-groove inside a gas chamber, we epoxied a quartz tube above the junction and mated it to an "Ultra-Torr" connection of a gas chamber (Fig. 1a), which had a pump, gas cylinder, and pressure gauge connected to it. The air was then evacuated out of HC-PCF and gas refilled through the tube to the desired pressure. This took several hours depending on the length of the fiber. Afterward, the quartz tube was torch-sealed, resulting in a compact package (Fig. 1b). Unit in Fig 1b was an early try which will become smaller and more refined with process improvement; in particular, the leftover tube length will be reduced. In fact, we intentionally made this unit larger than necessary for ease of handling.

An alternative configuration would include fitting a quartz or metal tube with a valve, gaining the option of reusing the gas cell by varying gas type and/or pressure inside. The opposite end of HC-PCF can either be fusion-spliced to a single-mode fiber prior to evacuation or mechanically spliced in a similar manner. In our test item we used the fusion splice because we could tolerate one Fresnel reflection without inducing interferometric fringes. Fitel S182PM arc splicer was used, resulting in ~1.5 dB typical splice loss.

For the reference cell, we used 4 meters of HC-1550-2 hollow core fiber from Crystal Fibre A/S. To detect the presence of gas, we tuned New Focus Velocity laser with 10 pm step between 1570 and 1583 nm to observe the (2201–0000) band of CO_2 [6]. The obtained transmission spectrum is shown in Fig. 2. The intensity fluctuations seen with or without gas in HC-PCF are due to a cleaving defect, which we are currently correcting. Since this band of CO_2 is relatively week, the pressure in the fiber was ~500 Torr.

In summary, fiber gas cells offer notable advantages over short, bulky and fiber-incompatible conventional ones, particularly for aerospace applications where mass and size are at a great premium. One of the factors constraining their practical application has been the difficulty of filling and connectorizing these cells. Existing approaches either require the connectorization to be performed in a vacuum chamber which is difficult, or expose one end of HC-PCF for a period of time, potentially contaminating the gas inside. The approach we demonstrated solves these issues and is remarkably simple to implement. Instead of connectorizing HC-PCF inside a gas cell, we connect the mechanical splice to the gas cell and then seal the connecting tube leaving behind a compact hermetic junction. This approach also avoids Fresnel reflections. We present the first realization of this connectorization technique and there is room for ongoing improvement of its robustness and compactness. We believe it will further enhance the attractiveness of hollow-core fiber gas cells for a variety of applications.

This work was funded by JPL R&TD program.

References

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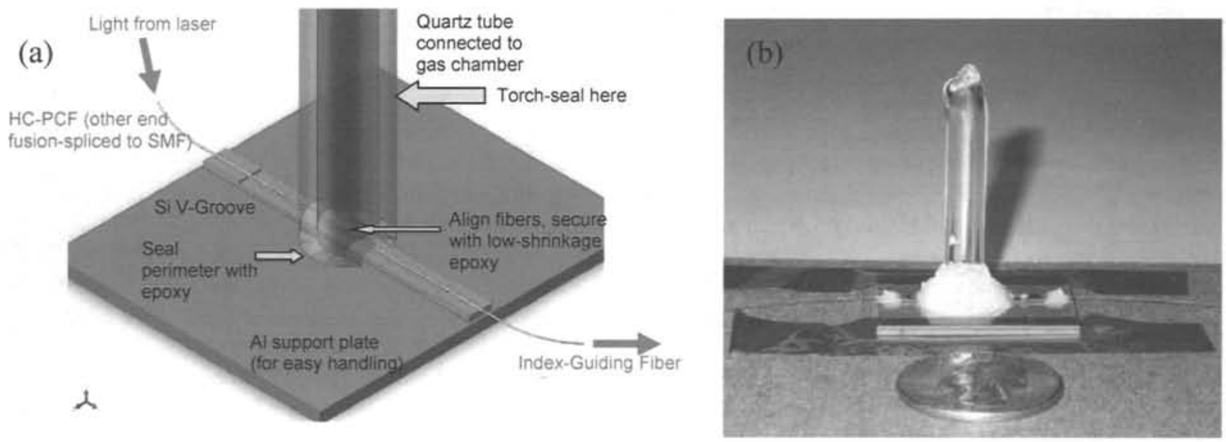

Fig. 1. a) Schematic of a mechanical splice of HC-PCF and MMF with a quartz tube connected to a gas chamber and b) an actual refilled and torch-sealed test item with a quarter as a scale reference.

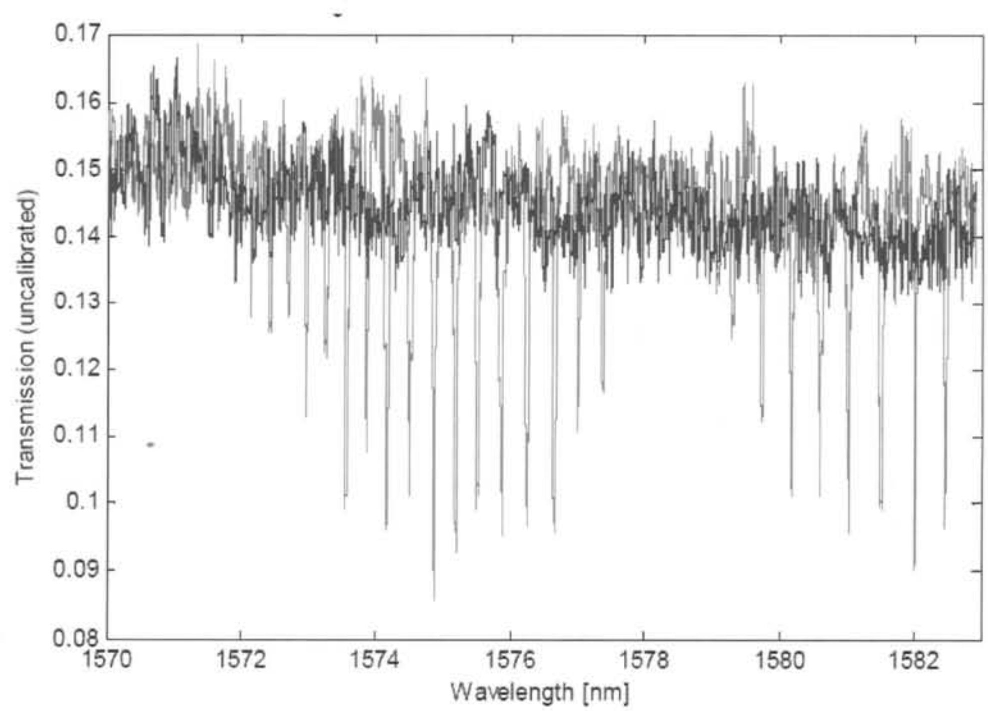

Fig.2. Transmission through 500 Torr of CO_2 in 4 m of HC-PCF – (2201–0000) band of CO_2 is observed.