Reflected Pump Technique for Saturated Absorption Spectroscopy Inside Photonic Bandgap Fibers

Kevin Knabe, Rajesh Thapa, Brian R. Washburn, and Kristan L. Corwin
Kansas State University, 116 Cardwell Hall, Manhattan, KS 66506.
corwin@phys.ksu.edu

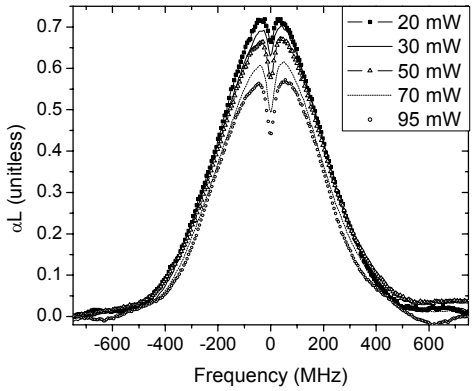
Abstract: Saturated absorption spectroscopy in acetylene-filled photonic bandgap fibers is investigated. A new simplified technique for saturated absorption spectroscopy is described, where pressure and power parameters have been optimized for use as a frequency reference.

OCIS codes: (300.6460) Spectroscopy, saturation; (060.2310) Fiber optics

Photonic bandgap fibers (PBGF) exhibit low loss and facilitate nonlinear interactions between light and gases or liquids confined in the core. Both electromagnetically induced transparency (EIT) and saturated absorption spectroscopy have been observed in various gases in these fibers [1-4]. Sealed fibers have also been developed as vapor cells [5]. Here we demonstrate a novel method of saturation absorption using only one beam inside hollow photonic bandgap fibers.

Previously, we have reported saturated absorption spectroscopy inside acetylene-filled PBGF [4]. Acetylene-filled PBGF exhibit narrow features when used in saturated absorption spectroscopy, as in Fig. 1a. The width and strength of the saturated absorption feature is dependent on pressure, optical power, and fiber core diameter. These parameters have been optimized for maximum signal strength and minimum width.

1a)



1b)

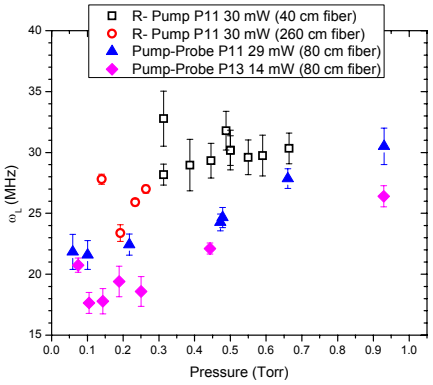


Fig. 1. Absorption spectra and fitting results. a) The above time-averaged spectra were taken of the C_2H_2 $\nu_1+\nu_3$ P(11) vibrational line at an optical wavelength of ~ 1.53 μm at a constant acetylene pressure of 0.50 Torr, for a 40 cm long photonic bandgap fiber, with a 20 μm diameter core. One can see that the overall amplitude of the Doppler-broadened feature decreases as the pump power increase from 20 to 95 mW. b) Sub-Doppler Widths vs. Pressure. These widths are results of the fitting of time averaged saturated absorption spectra of the C_2H_2 $\nu_1+\nu_3$ P(11) and P(13) vibrational lines inside 20 μm PBGF at an optical wavelength of ~ 1.53 μm. The pump power of each measurement was 30 mW except for the P(13) line, which was done at 14 mW.

The transmission through the fiber is measured as a function of laser frequency. The resulting spectra are interpreted using Beer's Law, which describes the transmission of light through matter as $P = P_0 e^{-\alpha_s L}$ where P_0 is the incident power, P is the transmitted power, and L is the length of the fiber. Fig. 1a shows α_s L as a function of laser frequency, for different powers. The signal strength and signal width of the sub-Doppler feature have been measured as functions of both power and pressure inside PBGF diameters of 10 and 20 μm where larger line widths and reduced signal-to noise ratio were observed in the 10 μm fibers, as compared with 20 μm fibers. Interference between the probe beam and undesirable reflections of the pump beam was a significant problem, prompting the insertion of an acousto-optic modulator (AOM) in the probe beam path (Fig. 2b). Half-cells comprised of PBG fibers that are spliced to SMF28 (with only one end attached to a vacuum system) have also been investigated. Spliced fibers also exhibit loss due to reflections at the splice boundary, as well as mode mismatching.

A new technique has been discovered that utilizes the splice in these half-cells. This technique is similar to methods previously explored in glass vapor cells [6] and optical fiber setups using retro reflectors [3], but to our

knowledge has never before been realized by utilizing reflections from the fiber cavity itself. Instead of using a traditional pump and probe beam setup, only a pump beam is present (Fig. 2a and 2b). This new method, called the reflected pump technique, uses about half the optics that the traditional method calls for, and has an added benefit of having much less pump-probe interference than the traditional pump-probe technique does (when the pump-probe technique is used without interference reduction methods such as AOMs or careful polarization management). The reflection at the splice caused by the glass-to-air interface acts as a probe. This probe is less than 10% of the pump beam, which differs from the retro reflecting techniques where the entire pump beam is reflected. Also, in the fiber based retro reflecting setup [6], free-space coupling is required to obtain this reflection, wherein our technique inherently creates the reflection within the fiber.

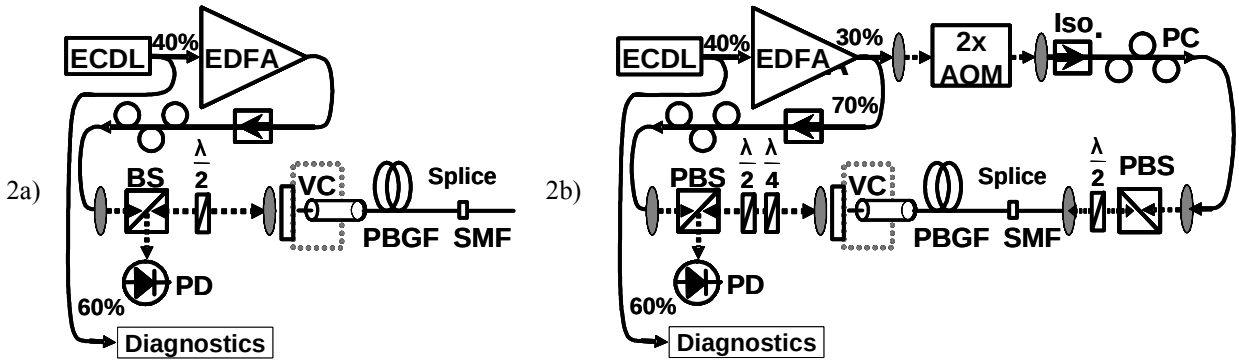


Fig. 2. Reflected Pump setup compared to a typical setup. a) Simplified schematic of this invention, in which the probe beam is created at the splice interface between the PBGF and SMF. b) Schematic of the traditional pump-probe configuration for saturated absorption spectroscopy. The probe beam, after being frequency-shifted by means of a double-passed AOM, is spatially coupled into the SMF end of the spliced half-cell.

Some interesting features arise from this new technique. The most prominent difference is that if one performs both techniques on the same spliced fiber, the amplitude of the absorption profile (α_s L) of the R-Pump technique is twice as large as that of the traditional technique at low powers. This is due to the fact that we are using the pump to create the probe, which therefore has twice the overall path length compared to the path length of the probe in the traditional pump-probe technique. In contrast, however, the width and the depth of the sub-Doppler feature remains approximately unchanged between the two methods (Fig. 1b illustrates the comparison of the widths). The amplitude of the Doppler broadened profile also decreases as pump power increases because the pump saturates the acetylene molecules reducing absorption (Fig. 1a). The probe beam, because it is weak compared to the pump, does not appreciably saturate the sample, maintaining a narrow line.

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