Saturated Absorption Signals from Acetylene Gas Inside Photonic Bandgap Fiber

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Abstract: Saturated absorption spectroscopy signals inside a 20 μm diameter acetylene-filled photonic bandgap fiber are optimized for use as optical frequency references. Modeling of the light propagation along the fiber reveals a low saturation intensity.

OCIS codes: (060.2310) Fiber Optics ; (300.6460) Saturation Spectroscopy;

Acetylene is used extensively for frequency standards in the near-infrared [1-4]. Photonic bandgap (PBG) fiber allows light and gas to be confined to a small area over long interaction lengths, facilitating nonlinear interactions such as Raman scattering [5], electromagnetically-induced transparency [6] , and saturated absorption spectroscopy [7]. Here, we demonstrate saturated absorption inside PBG fibers with high signal-to-noise ratio, and measure a low saturation intensity (~35 mW). We also identify the optimum operation parameters for a given fiber length and diameter. In Fig. 1, the transmitted probe power versus frequency reveals saturated absorption features inside PBG fibers at a variety of pressures, for a pump power of 29 mW.

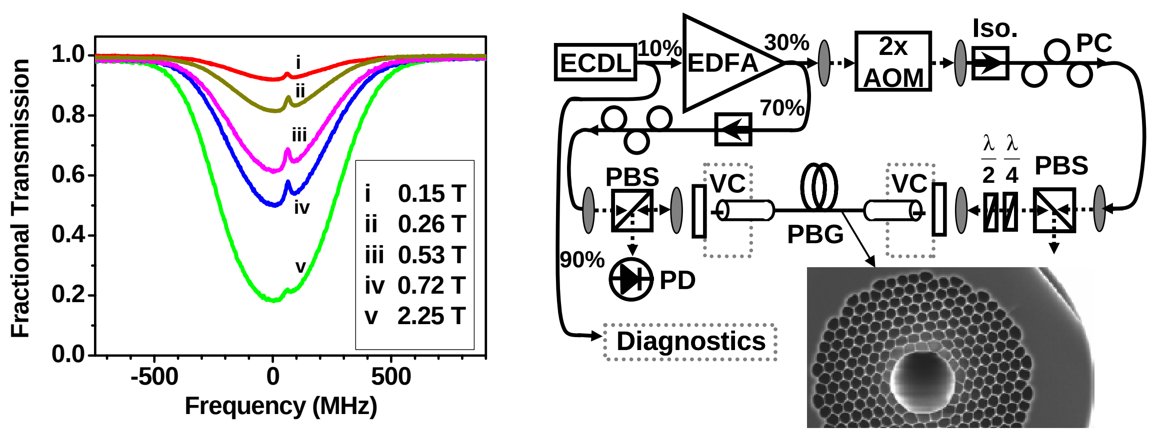

Fig. 1. (left) Fractional transmission versus optical frequency detuning at different gas pressures, for the $^{12}C_2H_2$ P (11) transition with a pump power of 29 mW incident on the fiber. The narrow saturated absorption feature is offset from zero frequency because there is a frequency different between the pump and probe beams, imposed by an acousto-optic modulator (AOM). (right) Schematic of the experimental setup.

The experimental set-up used to realize the saturated absorption spectra is shown in Fig. 1. An extended cavity diode laser (ECDL) emitts ~5 mW, 10% of which is amplified by an IPG Photonics® Erbium-doped fiber amplifier (EDFA) to up to 500 mW. Also shown are an isolator (Iso.), a polarization controller (PC), a polarizing beam splitter (PBS), the vacuum chambers (VC), and a photodetector (PD). The frequency diagnostics include a glass cell filled with $^{12}C_2H_2$ at 50 Torr, in order to locate the relevant transitions, and a Michelson interferometer, used to monitor the laser frequency as it is swept across the transition under study. The polarization is corrected using a half-wave and a quarter-wave retarder before the pump beam is separated from the probe with a PBS.

The theory of saturated absorption spectroscopy is well-known in vapor cells [8]. Beer's law describes the transmission of light through a medium as $I = I_0\, e^{-\alpha s(\nu) l}$, where I_0 is the incident intensity, I is the transmitted intensity, and l is the length of the medium. From the transmitted intensity, we calculate $l\, \alpha_s(\nu)$, as shown in Fig. 2. then $l\, \alpha_s(\nu)$ is fit to an appropriate function, taking into account the Gaussian nature of the Doppler broadened signal and the Lorentzian saturation dip. Figure 3 shows the dependence of the Lorentzian full-width-half-maximum on optical power. Figure 3 also shows the frequency discrimination of the saturated absorption feature, which is the signal height in fractional absorption divided by the signal width in MHz. Larger values indicate increased suitability for an optical frequency reference.

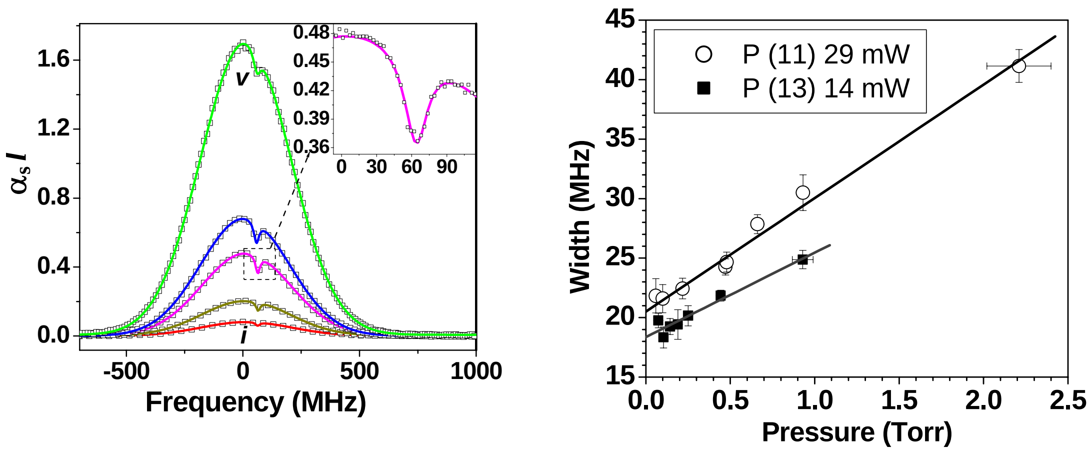

Fig. 2. (left) $\alpha_s l$ calculated with pressure varying from v to i according to the legend of Fig. 1. Solid lines represent fits to the above equation, using the function described above. (right) Width vs. pressure resulting from fits at left.

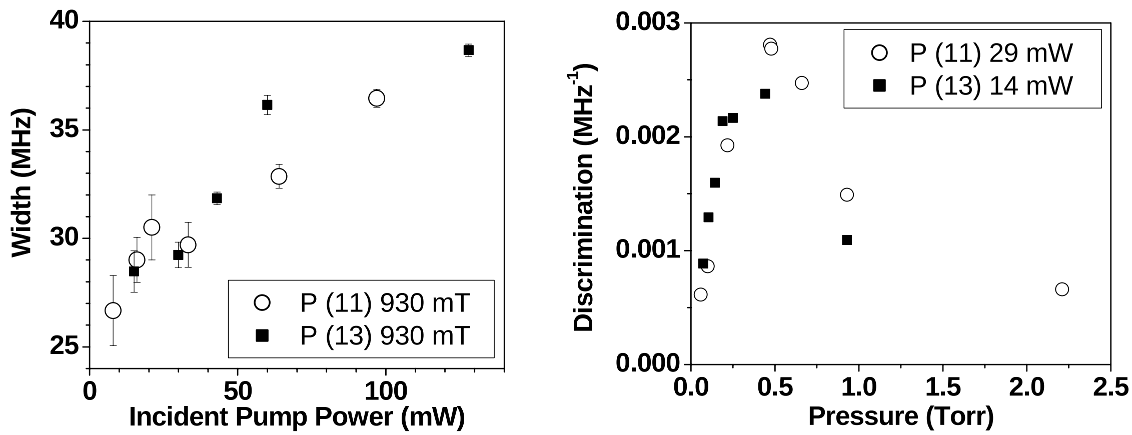

Fig. 3. (left) Width as a function of pump power for both P (11) and P (13) at 0.93 T pressure. (right) Frequency discrimination of the saturation dip, indicating the suitability of the standard for a frequency reference.

We gratefully acknowledge funding from NSF and AFOSR.

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