including both the sample and reference images, and M is the number of resolved spectral elements, estimated as the total bandwidth of the measurement divided by the spectral resolution, i.e. 5 THz /1.1 GHz~4500. Consequently, the NEA is ~1.2×10^{-9} $cm^{-1}Hz^{-1/2}$ per spectral element for the current experimental conditions. This sensitivity level is about two orders of magnitude above the shot noise limit [7, 8] and is due to the mechanical noise, laser intensity noise, etc. The mechanical noise, such as acoustic vibrations, disturbs the high-finesse cavity, which causes a slight nonlinearity of the cavity scan and results in changes of the integration times, intensities and positions of recorded fringes of spectra. Also because of the pulse to pulse jitter, the intensity profile fluctuates, which adds noise to different portions of the normalized spectrum, since the absorption and reference spectra are not recorded simultaneously. Provided an acoustic noise isolated cavity, a fully stabilized frequency comb and good linear control over the scanning elements of PZT and galvo, it would be possible to average several vernier images to further reduce noise and increase the detection sensitivity.

Our Er:fiber laser covers the wavelength range from 1500 nm to 1700 nm; with the development of InGaAs cameras of larger array and broader wavelength range, it is possible to utilize the whole wavelength range of the Er:fiber laser for rapid and broadband trace gas detection. Many other molecules have absorption lines in this range, such as CO_2 (1560~1620 nm), CH_4 (1620~1690 nm), CO (1560~1620 nm), and NH_3 (1500~1550 nm). Our near infrared frequency comb vernier spectrometer can be used for detecting these gases in various applications, such as atmospheric analysis, breath analysis and combustion diagnostics.

In summary, we built a femtosecond frequency comb vernier spectrometer in the Er:fiber laser wavelength range with an InGaAs camera. The performed spectroscopic measurements have broad applications for sensing greenhouse gases in this fingerprint near infrared region with a simple apparatus. We achieved an absorption sensitivity of ~8×10^{-8} cm^{-1}, corresponding to a detection limit of ~70 ppbv for acetylene, with a resolution of ~1.1 GHz by using single images taken in 0.5 s and covering a frequency range of ~5 THz. Provided a higher resolution spectrometer with a larger grating and a spot size better matching the camera pixel size, it seems possible to resolve the single frequency comb modes of a few hundreds MHz spacing with the future development of cameras. An image with resolved single comb modes not only provides precise calibration of the frequencies, but also can be fitted to retrieve phase information [6].

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