Development of a pulsed quantum cascade laser based CO sensor using advanced signal processing techniques

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Abstract: A pulsed, thermoelectrically cooled 4.6μm DFB-QCL CO sensor, incorporating a 100m multipass cell and HgCdTe detector, is used to evaluate various processing schemes and their effects on temporal resolution, sensitivity, and selectivity of the spectrometer.

OCIS codes: (280.3420) Laser sensors; (300.6360) Spectroscopy, laser;

High precision gas sensing techniques utilizing tunable laser absorption spectroscopy are finding many applications in industrial, environmental, homeland security, space, and medical applications. Some of these applications (i.e. spacecraft air quality monitoring, medical breath analysis, sensor network air monitoring, volcanic emission monitoring) require a small footprint, low power consumption, and autonomous operation. Pulsed quantum cascade (QC) lasers are convenient mid-infrared coherent sources that can be used in compact sensor platforms to reach parts-per-billion (ppb) to parts-per-trillion (ppt) detection levels of gas concentrations in short timescales (less than 1 second) with no consumables required (i.e. liquid nitrogen).

Sensors based on tunable diode laser absorption spectroscopy (TDLAS) rely on signal processing and specialized electronics to reach the optical detection limit for a specific application. The hardware and algorithms required to perform fast real-time processing for autonomous measurements in the field will be reported. The issues with developing such autonomous hardware and software are: 1) data processing with limited resources and 2) laser optical pulse acquisition effects on the noise background.

Short data acquisition times are generally preferred so that short-term fluctuations in gas concentration can be monitored and quantified. In autonomous systems, even with short data acquisition times, processing time can be a limiting factor, due to limited resources (such as processing power and memory). Efficient software algorithms developed for fast processing enhance the temporal resolution of the sensor and are described in this report.

In order to further reduce the acquisition time, the accuracy of the data acquisition system and the spectral resolution of the instrument must also be optimized. Operating the distributed feedback (DFB) laser in a pulsed mode produces a frequency chirp within each pulse, and therefore different sampling techniques can cause differences in the effective laser linewidth. Two sampling methods for detecting the optical pulse power are compared: gated integrators (GI) as in [1] and high temporal resolution sample and hold (SH) as in [2].

The GI approach integrates the total laser pulse power. This maximizes the total optical energy used for the measurement of a single pulse, but results in a larger effective laser spectral linewidth acquired by the system in a wavelength scan, since the intrinsic intra-pulse frequency chirp data for each pulse is lost due to integration.

Fast SH acquires a single point within the pulse (Fig. 1). With good stability and low jitter of the hold trigger timing, the system samples a narrow time region within each pulse. Consequently, the effective frequency chirp the system measures is lower. However, only a small part of the available optical energy is contributing in the sampling process. Using a custom digital signal processor (DSP) fast data acquisition system, the SH output is over-sampled at the maximum analog-to-digital-converter (ADC) speed of 12.5 mega-samples per second (MSPS) to increase accuracy for data from a single pulse. The extent to which this improves performance will be reported, as well as establishing a relationship to GI performance with the same pulse parameters.

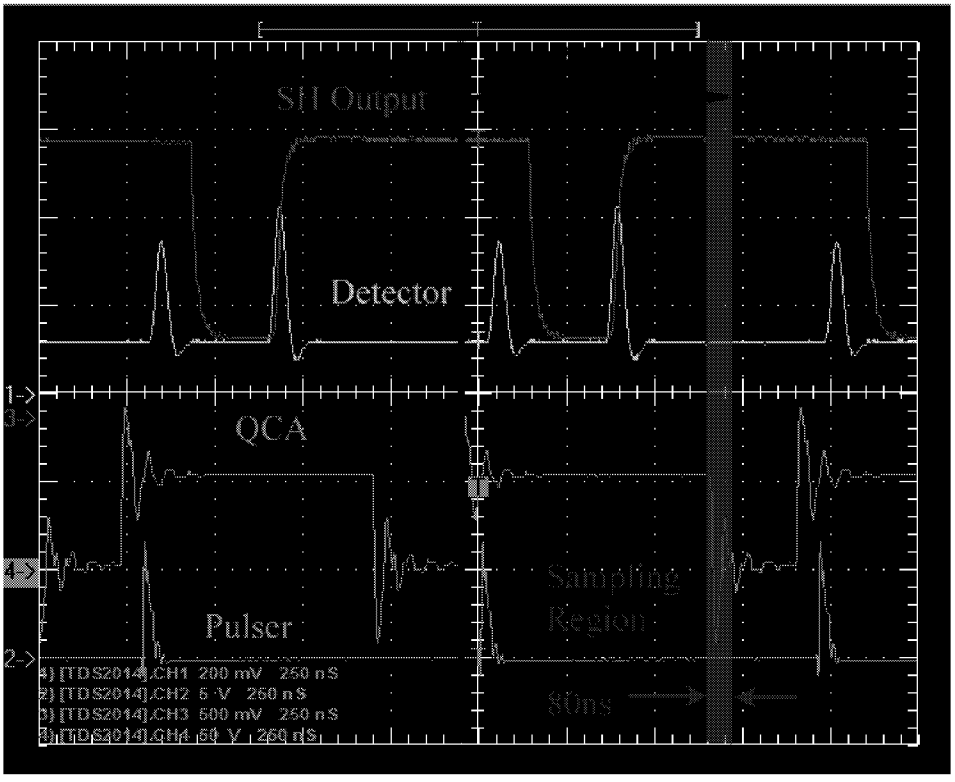

Figure 1. Single Point Sample and Hold trace for a 1MHz pulse repetition rate (100m multipass gas absorption cell), with signal and reference beams detected by a single detector.

The custom DSP based system is compared to systems based on a commercially available NI-DAQ (National Instruments Data Acquisition) card [1,2] to explore the system design issues stated above for a pulsed thermoelectrically cooled 4.6μm DFB-QC laser absorption spectroscopic sensor based on an astigmatic Herriott multipass optical absorption cell with an effective 100m optical pathlength, and a single HgCdTe detector with time-resolved measurement of sample and reference beams.

References

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