Accuracy Improvement for Waveguide CRDS toward Compact Breath Sensing

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1. Introduction

Breath sensor which realize detecting diseases by breath sensing is desired for the home-based health care because of the population aging problem [1]. Optical breath sensor using waveguide CRDS (Cavity Ring-Down Spectroscopy) realizes hand-held sensor by integrating long optical path on waveguide. We have proposed optical amplifier assisted system using EDFA (Erbium-Doped Fiber Amplifier) to compensate the propagation loss of the sensing-waveguide [2]. One issue is the influence of EDFA gain fluctuation for the sensing light pulse. The gain fluctuation results in sensing inaccuracy. 4% CO_2 was not possible to be evaluated accurately with such that low sensing accuracy based on our calculation. (To make sure, human's exhaled breath contains 4% CO_2.). The value of the CO_2 volume is the reference for the other breath gases concentration measurement. If 4% CO_2 is not detectable, the other breath gases concentration detection is also not available. To improve the sensing accuracy, we have enhanced the detecting data points and took the average of data points' value. As a result, the range of sensing accuracy fluctuation is shorted from 48.2%~93.2% to 69.1%~83.8%. The lower limit sensing accuracy is 20.9% improved. We still need further discussion to realize accurate 4% CO_2 concentration detection.

2. Gas concentration measurement in CRDS

The experimental set-up of waveguide CRDS is shown in Fig. 1. The example sensing results of the system from PD are shown in Fig. 2. The light intensity decreases because of the loss in system. A light intensity criteria value is needed to estimate gas concentration. The cavity ring-down time [2] is the time the light intensity decreases from the original value to the criteria value. The gas concentration is estimated with the cavity ring-down time by using equation $\Delta\left(\frac{1}{\tau}\right)=\frac{1}{\tau_g}-\frac{1}{\tau}=\sigma nc$. In the equation, the cavity ring-down time of without and with gas is τ and τ_g, n is gas concentration, σ is absorption cross-section, c is light speed. Fluctuation in detecting light intensity results in inaccuracy of the cavity ring-down time; therefore; it results in inaccurate gas concentration estimation. The light intensity fluctuation shown in the Fig. 3 results in cavity ring-down time fluctuation. To evaluate the time fluctuation, we used the fitting curves shown in Fig. 4 (a). The lines in yellow and green (exponential curve) are the lower and upper limit line used to confirm the cavity ring-down time fluctuation. The cavity ring-down times of the yellow and the green line are estimated at 6.14 and 7.36 μs, respectively. The blue dots are the peak points of the sensing result. The red line is set as 1/e. The 1/e is the criteria value for cavity ring-down time estimation. The cavity ring-down time fluctuation is estimated at 1.22 μs, which indicates the sensing accuracy fluctuation between 48.2%~93.2% in 4% CO_2. The sensing accuracy fluctuation range is large. The 48.2% sensing accuracy is too low to detect 4% CO_2 based on our calculation. If 4% CO_2 is not detectable, the other breath gas concentration detection is also not available. The gas concentration sensing accuracy; therefore; need to be improved.

3. Experiment results and discussions

Sensing inaccuracy is caused by the light fluctuation. The light intensity fluctuation in the experiment result related to the light intensity and time. Light intensity is decided by the gain and loss in the experimental system. The main loss in this experiment is the propagation loss of the waveguide. The propagation loss of the waveguide is a constant. It will not change with time. We think; therefore; the reason of light intensity fluctuation is because of the EDFA gain fluctuation. The recovery time of the carrier in EDFA is μs-order [3]. The μs-order recovery time means the EDFA costs μs-order time to recover the gain to a new steady state level after providing gain to sensing light pulse [4]. In our experiment, the period of sensing light pulse injecting into the EDFA is 300 ns. 300 ns is shorter than the recovery time of the carrier in EDFA. EDFA provides insufficient gain to the sensing light pulse. The gain fluctuation results in the light intensity fluctuating. To improve the accuracy, we propose to enhance the data-acquisition number and take the average of light intensity value as each pulse peak. In Fig. 3, we take average of 5 fetch points value. The calculated average points are shown in Fig. 4 (b) (purple dots). The cavity ring-down times of the yellow and the green line are estimated at 5.75 and 6.57 μs, respectively. The cavity ring-down time fluctuation is estimated at 0.82 μs. The time fluctuation indicates the sensing accuracy fluctuation between 69.1% to 83.8%. The range of sensing accuracy fluctuation is shorted. The lower limit sensing accuracy is 20.9% improved. The improved accuracy is not enough to accurately detect 4% CO_2. We need ; therefore; further discussion to realize accurate 4% CO_2 concentration detection.

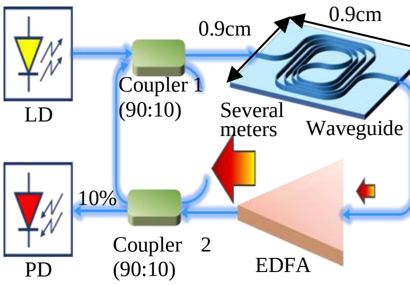

Fig. 1 Experiment system of amplifier assisted waveguide CRDS.

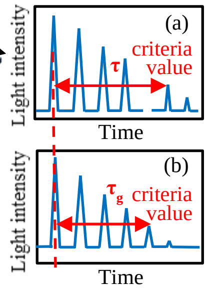

Fig. 2 Example sensing result (a)without gas (b)with gas

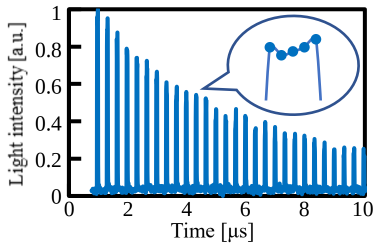

Fig. 3 Experiment result with light intensity fluctuation (5 fetch points for one pulse)

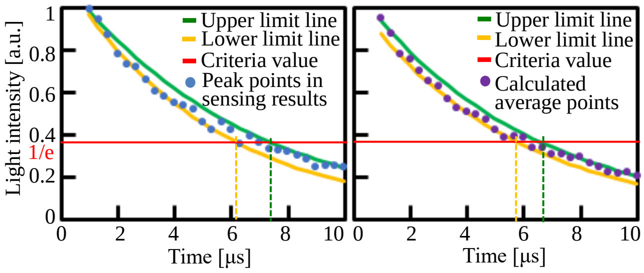

Fig. 4 Fitting curves of the sensing data (a) before average (b) after average

4. Conclusion

To improve the gas concentration sensing accuracy, we proposed to enhance the data-acquisition number and took the average light intensity value as each pulse peak. As a result, the range of sensing accuracy fluctuation is shorted from 48.2%~93.2% to 69.1%~83.8%. We still need further discussion to realize accurate 4% CO_2 concentration detection.

Acknowledgement

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Reference

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