Windowless photoacoustic cell for trace gas detection

Liu L(1,2,3)*, Huan H(1,2), Zhang L(1), Zhang X(1), Yin X(1), Shao X(1), Mandelis A(2)

(1) School of Physics and Optoelectronic Engineering, Xidian University, Xi'an 710071, China
(2) Center for Advanced Diffusion-Wave and Photoacoustic Technologies (CADIPT), Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, Ontario M5S 3G8, Canada
(3) CAS Key Laboratory of Spectral Imaging Technology, Xi'an 710119

*Corresponding author's email: Lixianliu@xidian.edu.cn

Photoacoustic Spectroscopy (PAS) technology is a widely recognized method for its excellent performance in trace gas detection and simplicity of the experimental setup [1,2]. The detectivity of the laser PAS configuration achieves down to ppm ~ ppb levels, thanks to high power and narrow band of laser sources and the high sensitivity of resonant cells. However, spurious signal generated by the resonator windows persists a challenge for the improvement of trace gas detection sensitivity. Unless incoherent noise [3], the noise originated by the window absorption is almost impossible to be removed by the classical filtering methods, e.g., amplitude and wavelength modulation. The closed photoacoustic resonators may be limited to particular applications due to the inlet and exhaust of the target gas. A windowless photoacoustic cell based on T-resonator [4] is presented in this paper for trace gas detection.

T-resonator depicted in Fig. 1(a) comprises resonance and absorption cylinders. The reason that T-resonator is appropriate for the windowless cell design lays in its resonant frequency is mainly determined by the resonance cylinder perpendicular to the light absorption path.

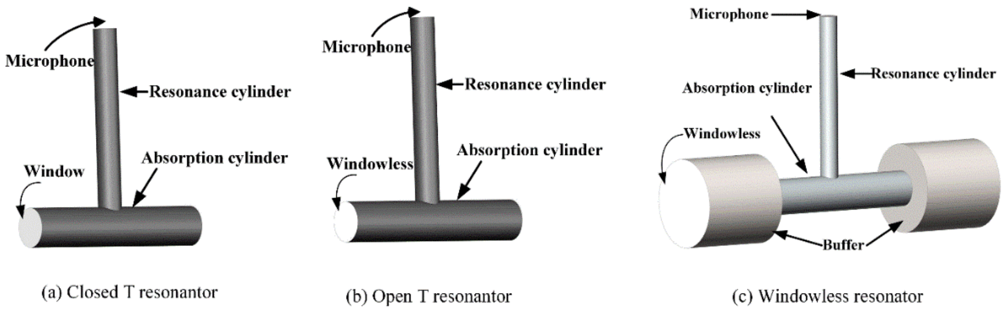

Fig. 1. T typed resonator models.

The proposed windowless cell is presented in Fig.1 (c) which consists of T-typed resonator and buffer cylinders. The penetration of the external acoustic noise is attenuated through the two buffer volumes at both ends of the absorption cylinder. The diameter and length of the buffers are selected in such a way the acoustic impendence of which is relatively high at the resonance frequency.

The three different T-type resonator models shown in Fig.1 were built with COMSOL Multiphysics 5.2. The geometry of absorption and resonance cylinders is identical for the three resonators and the lossy boundary conditions were adapted due to thermal and viscous losses at the resonator boundary. The finite element method (FEM) simulated amplitude response results are presented in Fig.2 which exhibits the good performance of the windowless resonator and the details are shown in Table 1. Although there is a large deviation of the resonance frequency of the three cells, the full width at half maximum (FWHM) of the windowless resonator is similar to the closed resonator, much better than the behavior of the open resonator. The windowless resonator with two buffers at both ends of the absorption cylinder has the capability for the noise suppression and can be used an open cell in the trace gas detection application.

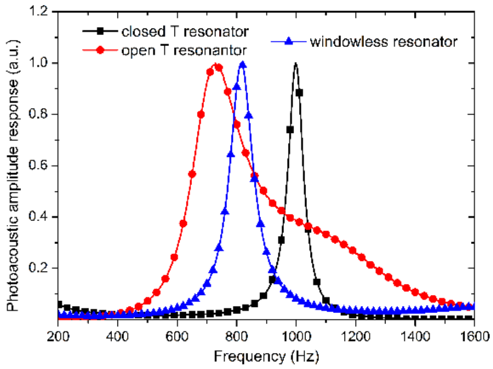

Fig. 2. The photoacoustic amplitude simulated response of three different resonators.

The FEM simulation results demonstrate that the windowless resonator comprising the T cell and buffer volume is an appropriate photoacoustic design for the elimination of the coherent spurious signal generated by the window absorption and the isolation of outside background noise. Thus, the windowless resonator is an effective open cell for trace gas detection.

Table 1. The simulation results of the three T typed resonators

Cell Type	Resonance frequency (Hz)	FWHM (Hz)
Closed resonator	998	28
Open resonator	728	105
Windowless resonator	816	34

Acknowledgements – The authors are grateful to the National Science Foundation of China (Grant No. 62175194, 62105252, 61805187 and 61801358). This work was also supported by “the Fundamental Research Funds for the Central Universities” (Grant No. JB20190412 and XJS190505).

References

[1] Z. Yu, J. Assif, G. Magoon, P. Kebabian, W. Brown, W. Rundgren, J. Peck, R. Miake-Lye, D. Liscinsky, B. True, Aerosol Science and Technology 51:12 (2017) 1438. doi: 10.1080/02786826.2017.1363866.

[2] L. Liu, A. Mandelis, H. Huan, K.H. Michaelian, Optics Letters 42 (7), 1424 (2017). doi: 10.1364/OL.42.001424.

[3] L. Liu, A. Mandelis, H. Huan, A. Melnikov, Applied Physics B 122:268 (2016). doi: 10.1007/s00340-016-6545-2.

[4] L. Liu, A. Mandelis, H. Huan, K.H. Michaelian, A. Melnikov, Vibrational Spectroscopy 87: 94 (2016). doi: 10.1016/j.vibspec.2016.09.013.