Modelization of Photoacoustic Trace Gases Sensors

Bertrand Parvitte[1], Christophe Risser[1], Raphael Vallon[1], Virginie Zéninari[1]

[1]GSMA - Université de Reims, Reims, France

Abstract

Introduction: Photoacoustic detection is a technique that can be used to detect trace levels of gases using optical absorption and subsequent thermal perturbations of the gases. PA sensors generally use acoustic resonances to enhance the signal level and to improve the minimum detectable concentration. A cell design based on two identical cells connected by thin capillaries that use the Helmholtz resonance was developed. This design allows noise reduction by performing differential measurements between the two cells. (Figure 1) presents the design of the cell and the pressure wave amplitude associated with the Helmholtz resonance. As the technique has favorable detection characteristics when the system dimensions are scaled down, the realization of a micro-cell design would be of great interest to generalize the use of such sensors. In order to optimize the cost of development for such sensors, we must be able to accurately predict the response of the sensor. Use of COMSOL Multiphysics: We use the classical description where the acoustical response of the photoacoustic cell is obtained by writing the pressure wave as the expansion over the eigenmodes of the cell [1]. We use COMSOL Multiphysics to solve the Helmholtz equation in the Pressure Acoustics interface in order to obtain the eigenmodes, to normalize them and to calculate the thermal and viscosity losses [2]. We used LiveLink™ for MATLAB® to run the model from MATLAB® and take back the results for further calculations in MATLAB®. The Helmholtz resonance is highly dependent on losses in the capillaries, and pressure acoustics is not necessarily well adapted due to strong coupling between pressure and temperature variations. We realize a thermoacoustics frequency domain study using the Acoustics module of COMSOL to check that the results obtained using pressure acoustics were satisfying. Results: As a first step, the results of the simulations were compared to several measurements realized on a macroscopic cell (10 cm base dimension), excited with a CO2 laser. The measured resonant frequencies were found to be in good agreement with the eigenfrequencies. After normalization of the eigenmodes and of the exciting beam intensity, the calculated amplitude of the pressure wave was also found to be in good agreement with measurements. (Figure 2) presents a comparison between calculated pressure wave amplitude and measurements scaled by the microphone response. Conclusion: With these results we have demonstrated that the evaluation of a photoacoustic cell response can be accurately done using FEM simulation for resonance frequencies, quality factors and for the amplitude of the generated pressure wave. This will allow to accurately predicting the response of a photoacoustic sensor when varying its shape and its dimensions.

Reference

1. Yoh-Han Pao, Optoacoustic Spectroscopy and Detection, Academic Press (1977).
2. Bernd Baumann et al, Finite Element Calculation of Photoacoustic Signals, Applied Optics, 46, 1120-1125 (2007).

Figures used in the abstract

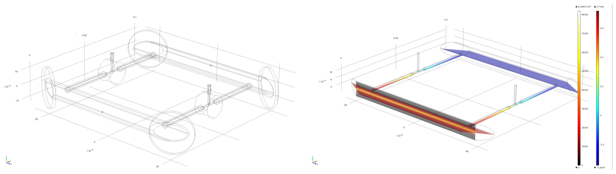

Figure 1: Scheme of the developed cell and illustration of the Helmholtz resonance mode.

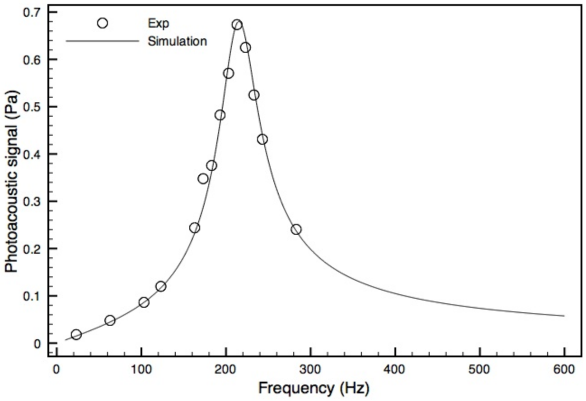

Figure 2: Comparison between experimental measurements (circles) and calculated pressure wave amplitudes.