Photoacoustic Modeling Using Amplitude Mode Expansion Method in a Multi-scale T-cell Resonator

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Abstract

The photoacoustic (PA) effect consisting of the generation of an acoustic signal based on the absorption of light has already demonstrated its potential for various spectroscopic applications for both gaseous and solid samples. The signal produced during photoacoustic spectroscopy (PAS) measurement is, however, usually weak and needs to be amplified. This is achieved by using a photoacoustic cell resonator where acoustic resonances are utilized to significantly boost the signal. Therefore, a PA resonator has a significant role in PAS measurement set-ups. When designing or optimizing a new PA resonator, numerical methods are generally used to simulate the photoacoustic signal generation. In this paper, the amplitude mode expansion (AME) method is presented as a quick and accurate simulation tool. The method is used to simulate the photoacoustic signal in a multi-scale T-cell resonator over a wide frequency range. The resonator consists of three interconnected cylinders of varying lengths and diameters. A small absorption cylinder is longitudinally connected to a bigger cavity cylinder. A resonance cylinder is perpendicularly mounted on the cavity cylinder, thus forming a T-like structure. The AME method is based on eigenmode expansion and introduction of losses by quality factors. It is executed using a MATLAB® code which accesses the Pressure Acoustics, Frequency Domain COMSOL Multiphysics® interface using the COMSOL Server™ to calculate the eigenmodes. The AME simulation results are compared and analyzed against the results from the viscothermal method which was done using the Thermoviscous Acoustics, Frequency Domain COMSOL Multiphysics® interface. Reasonably good agreement is obtained between the two methods. However, small frequency shifts in the resonances of the AME method are noted. The shifts are attributed to the location of the dominant mode within the T-cell. The viscothermal method is considered the most accurate method for simulating the photoacoustic signal in small resonators. However, it is computationally very demanding. The AME method provides a much faster simulation alternative. This is particularly useful in the design and optimization of photoacoustic resonators where numerical methods are preferred over experimental measurements due to their speed and low cost.

Figures used in the abstract

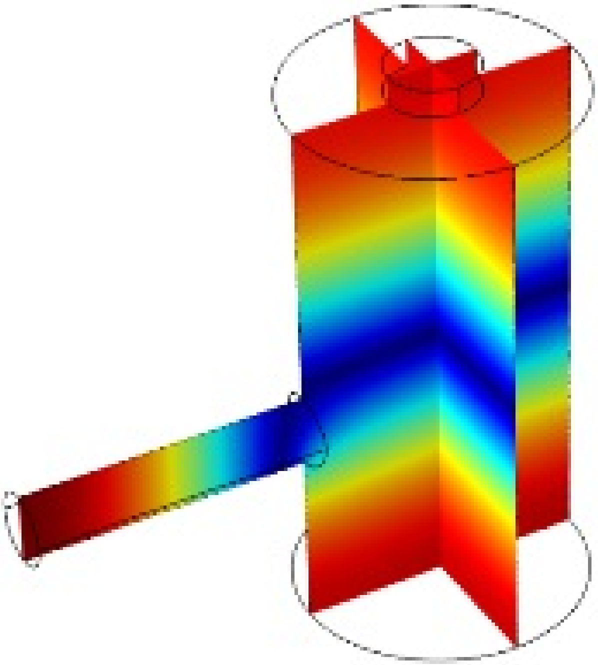

Figure 1: Acoustic pressure mode inside the T-cell at 11,200 Hz. The resonance at this frequency is due to strong longitudinal modes supported by the resonator.