Advanced photo-acoustic gas analyzer

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Abstract
The gas analyzer based on optical parametric oscillators and laser photoacoustic spectroscopy is demonstrated in this paper. Optical parametric oscillator was pumped by compact nanosecond 1.053 μm Nd:YLF laser.

Key words: laser photo-acoustic spectroscopy, optical parametric oscillator, trace gas detection,
The monolithic PPLN OPO cavity consists of two high-reflectivity mirrors at the signal wave. The output mirror is transparent at the pump and idler wavelengths; the input mirror has a high transmission coefficient at the pump wavelength. The step motor moves crystal in relation to pumping beam.

From Fig. 1 one can also see that the idler beam tunability of 2–4.3 µm was achieved with PPLN crystal (the signal wavelength was tunable between 1.394 and 2.224 µm, respectively).

![Figure 1. PPLN OPO tuning curve (idler wave).](image)

Use of chalcogenide crystals as a nonlinear medium for OPO allows the range from 2 µm to 18 µm to be overlapped. The advantages of these crystals are following: their relatively high thermal conductivity, large bandgap and, as a result, low two-photon absorption and low group velocities mismatching [9]. Optical parametric oscillator based on chalcogenide crystals allows covering wide spectral range from 2 to 11 µm.

The advantages of OPO combined with photoacoustic detector are:

- wide spectral range;
- OPO power in several times higher than diode laser power;
- response linearity of the device for variation of measured concentrations for 6 orders;
- real-time response at ppb level.

AgGaS$_2$ (AGS) crystal has high nonlinear optical coefficient and high optical transmission from 0.5–12.0 µm, which makes it realistic to generate infrared parametric radiation. The monolithic AGS OPO cavity (Fig. 2) consists of two high-reflectivity mirrors at the signal wave. The output mirror is transparent at the pump and idler wavelengths; the input mirror has a high transmission coefficient at the pump wavelength. The designed monolithic block allows correcting the cavity length by means of changing the distance between two cylindric holders in the flanges. The step motor moves crystal in relation to pumping beam. The crystal in Figure 2 goes up to 4.2–11 µm. It depends on orientation of the crystal.

![Figure 2. The OPO monolithic cavity OPO based on AGS crystal.](image)

From Fig. 3 one can also see that an idler beam tunability of 4.2–10.6 µm was achieved with AGS crystal (the signal wavelength was tunable between 1.169 and 1.405 µm, respectively).

![Figure 3. AGS OPO tuning curve (idler wave)](image)

**Laser photo-acoustic spectral study**

For excitation of photo-acoustic spectra we used the nanosecond mid-IR OPO described in previous part. More often in PA devices are used sinusoidally modulated radiation and resonant cells. In the pulsed photoacoustics, the system is illuminated with a laser pulse rather than with periodic modulation. In our experiments we used the photoacoustic resonant cell.

Absorption spectra of different gaseous mixture were studied with use of tandem OPO-PAD. Below these absorption spectra are presented. You can see absorption spectra of experimental gaseous mixture CH$_4$ (black line) in Fig. 4.

There are absorption spectra of different gaseous mixture present here (CH$_4$, C$_2$H$_6$, C$_2$H$_8$, C$_3$H$_8$, atmosphere outside and inside) in range from 2.35 to 3 µm (see Fig. 5).
Absorption spectra of different gaseous mixture are presented here (CH₄, C₃H₈, C₂H₆, C₂H₄, atmosphere outdoors and indoors) in the range from 3.30 to 3.6 μm (see Fig. 6).

Fig. 4. Absorption spectra: absorption spectrum of experimental gaseous mixture CH₄ (black line), absorption spectrum of CH₄, HITRAN (red line), absorption spectrum of H₂O, HITRAN (blue line).

Fig. 5. Absorption spectra: absorption spectra of experimental gaseous mixture CH₄, C₃H₈, C₂H₆, C₂H₄ and absorption spectra of atmosphere outside and inside in the range from 2.35 to 3 μm.

Fig. 6. Absorption spectra: absorption spectra of experimental gaseous mixture CH₄, C₃H₈, C₂H₆, C₂H₄ and absorption spectra of atmosphere outside and inside in the range 3.30 to 3.6 μm.

Absorption spectra of human’s breath (black line) and human’s breath after smoking (red line) in the range from 2.3 to 3 μm are presented in Fig. 7.

Fig. 7. Absorption spectra: absorption spectrum of human’s breath (black line) and absorption spectrum of human’s breath after smoking (red line).

Conclusion
This work shows perspectives of using photoacoustic spectroscopy in medical and scientific practice. Compact analytical systems for different applications can be developed with use of this approach.

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References


