



REPORT

on

Gas absorption and VCSEL emission spectra study

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SUMMARY

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Gas absorption and VCSEL emission spectra study

The report is based on the study of gas absorption spectra measurement in the IR range and the study of VCSEL emission spectra ($\lambda=1312\text{nm}$) measured at high resolutions using the Bruker IFS 120 and 125 spectrometer (figure 1).



Fig. 1 Bruker IFS 120 spectrometer

1. High resolution measurements of gas absorption spectra (H_2O , CH_4 , CO_2 , HF and NH_3)

It was proposed to study the absorption spectra of several gases in the IR range in order to determine the possibility of VCSEL usage in gas sensing. High resolution measurements of the absorption spectra of H_2O , CH_4 , CO_2 and NH_3 were made. The obtained results presented in figure 3 – 5 is the wave number range that presents an interest for VCSEL gas detection purposes ($\lambda=1300\text{nm}$ up to $\lambda=1350\text{nm}$).

All the measurements were done using a spectrometer and a mounted setup for gas absorption measurements shown in figure 2.

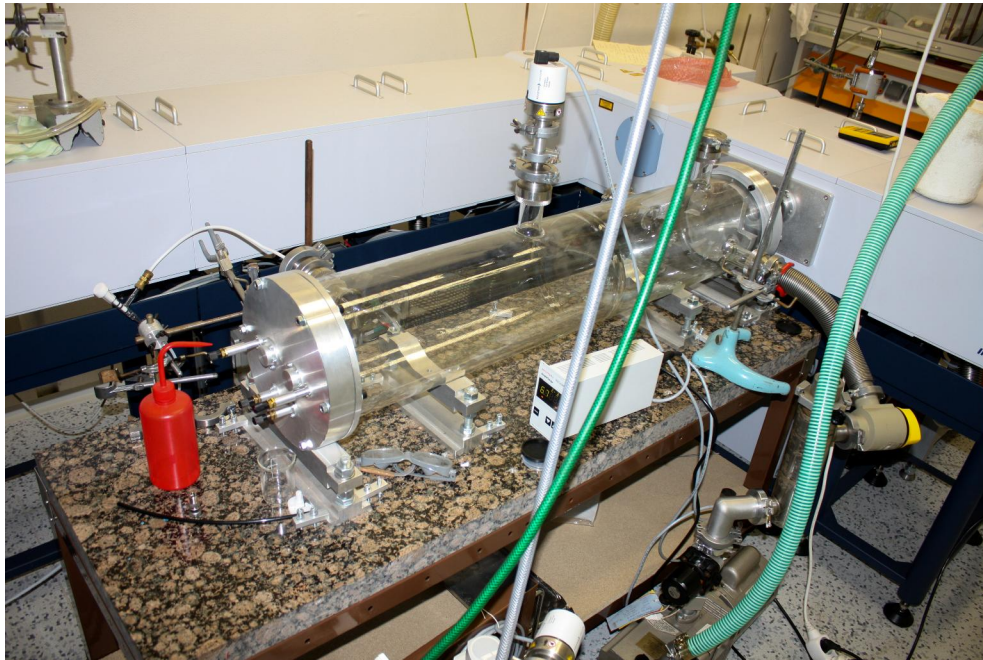


Fig. 2 Bruker IFS 125 spectrometer and mounted setup for gas absorption spectra measurements

As it was observed, the absorption spectra measured for CO₂ does not present any absorption lines and, evidently, does not present any interest for the research in the mentioned wavelength region.

Water absorption spectra

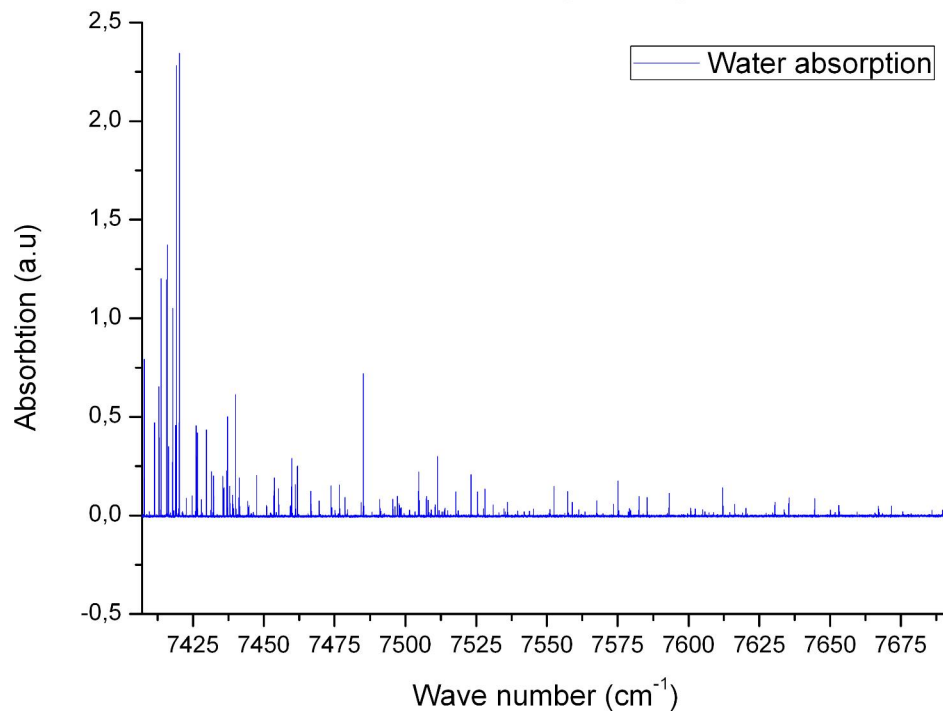


Fig. 3 H₂O absorption spectra in the wavelength range (1300-1350nm)

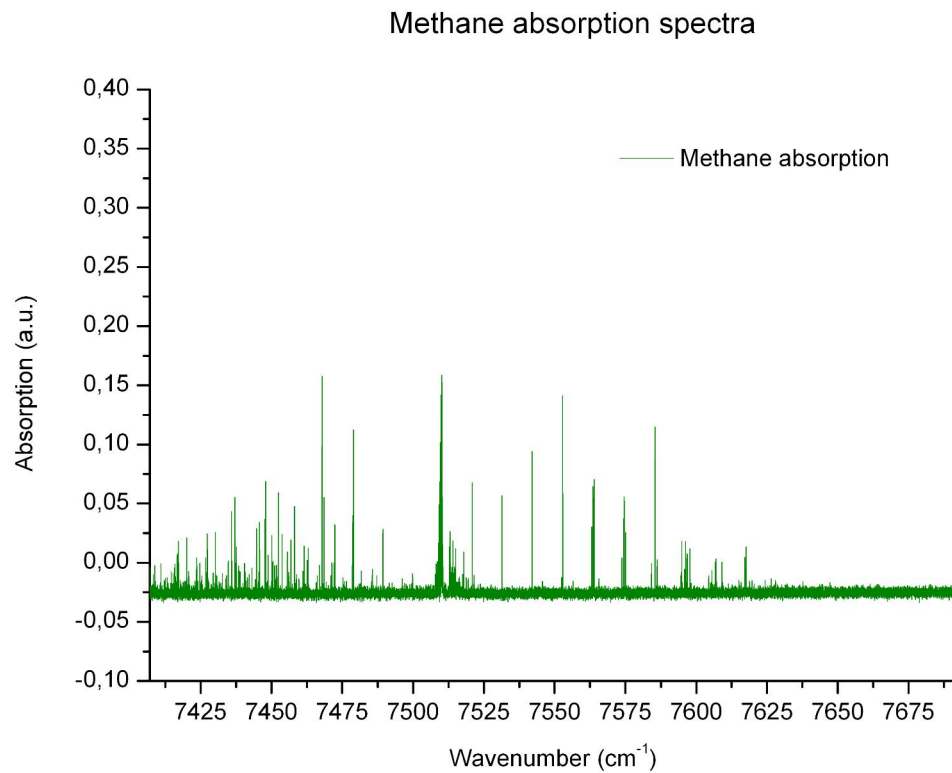


Fig. 4 CH₄ absorption spectra in the wavelength range (1300-1350nm)

This is why the spectra for CO₂ is not presented. It is evident from figure 3-5 that these gases present a promiscuous interest for VCSEL gas detection purposes. The H₂O, CH₄, and NH₃, and also HF absorption spectra show multiple absorption lines that can be used for calibrating the VCSEL in order to determine a detection method of these gases.

The usage of VCSEL lasers in gas detection in the wavelength region 1300-1350nm shows to be satisfactory.

Ammonia absorption spectra

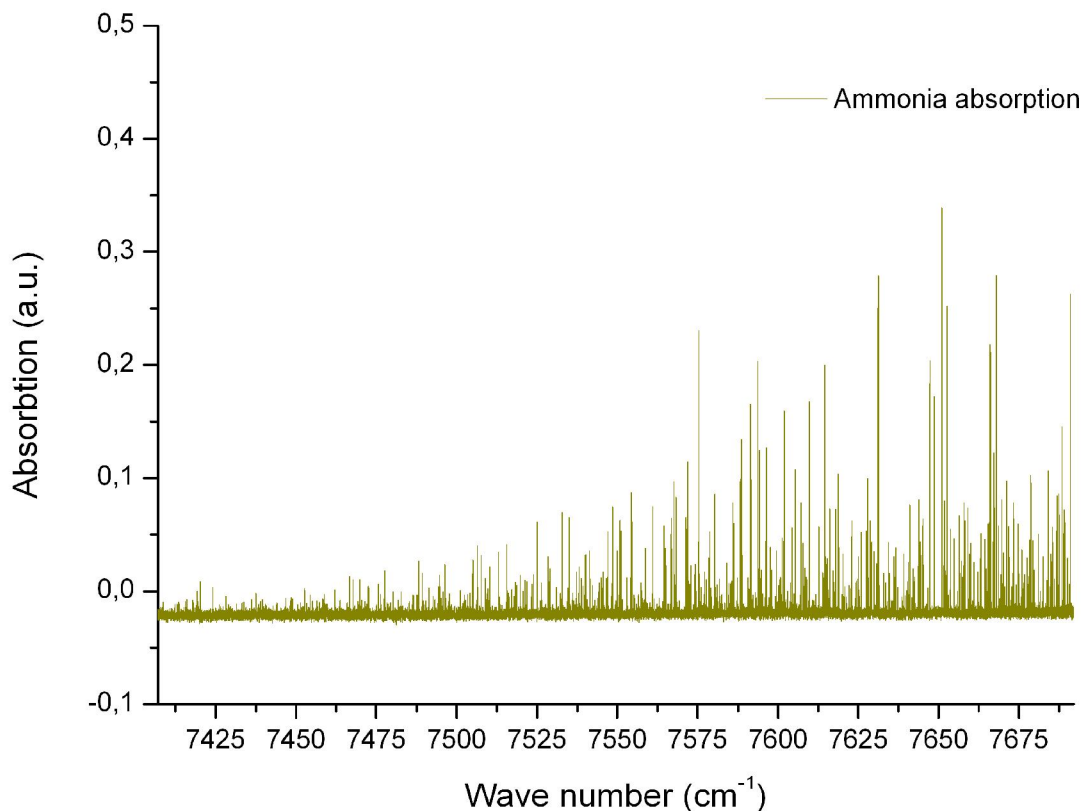
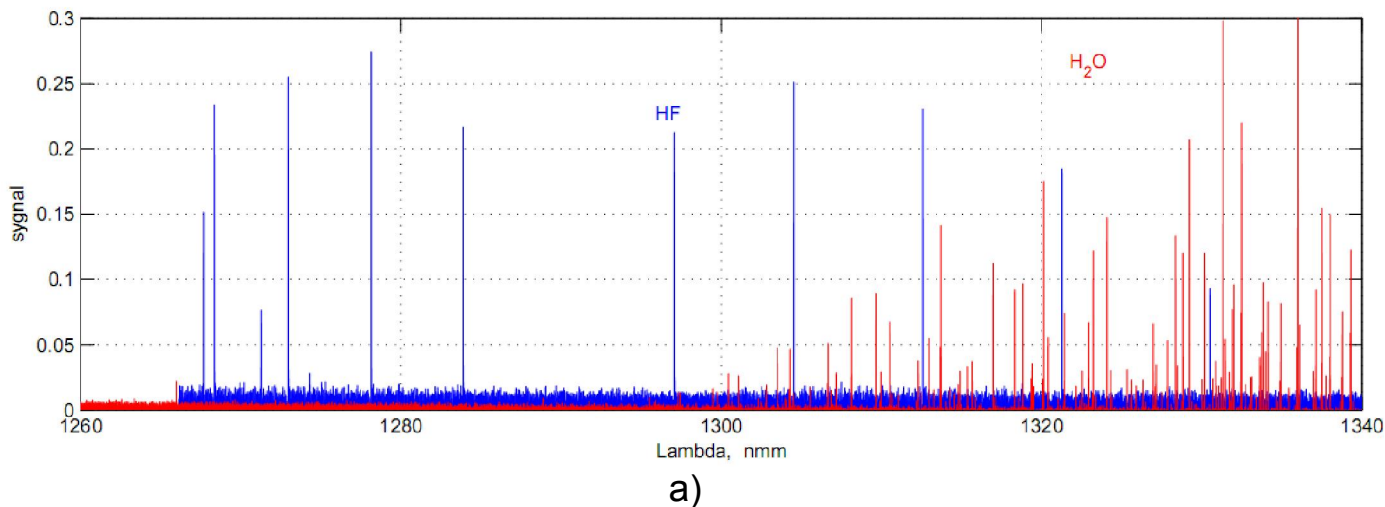


Fig. 5 NH₃ absorption spectra in the wavelength range (1300-1350nm)

Figure 6 shows the superposition of HF and H₂O absorption spectra. As it is evident from figure 6, *b*, *c*, *d*, *e* there are 4 regions consisted of water and HF absorption lines that can be used for calibration (water lines) and detection of HF.



a)

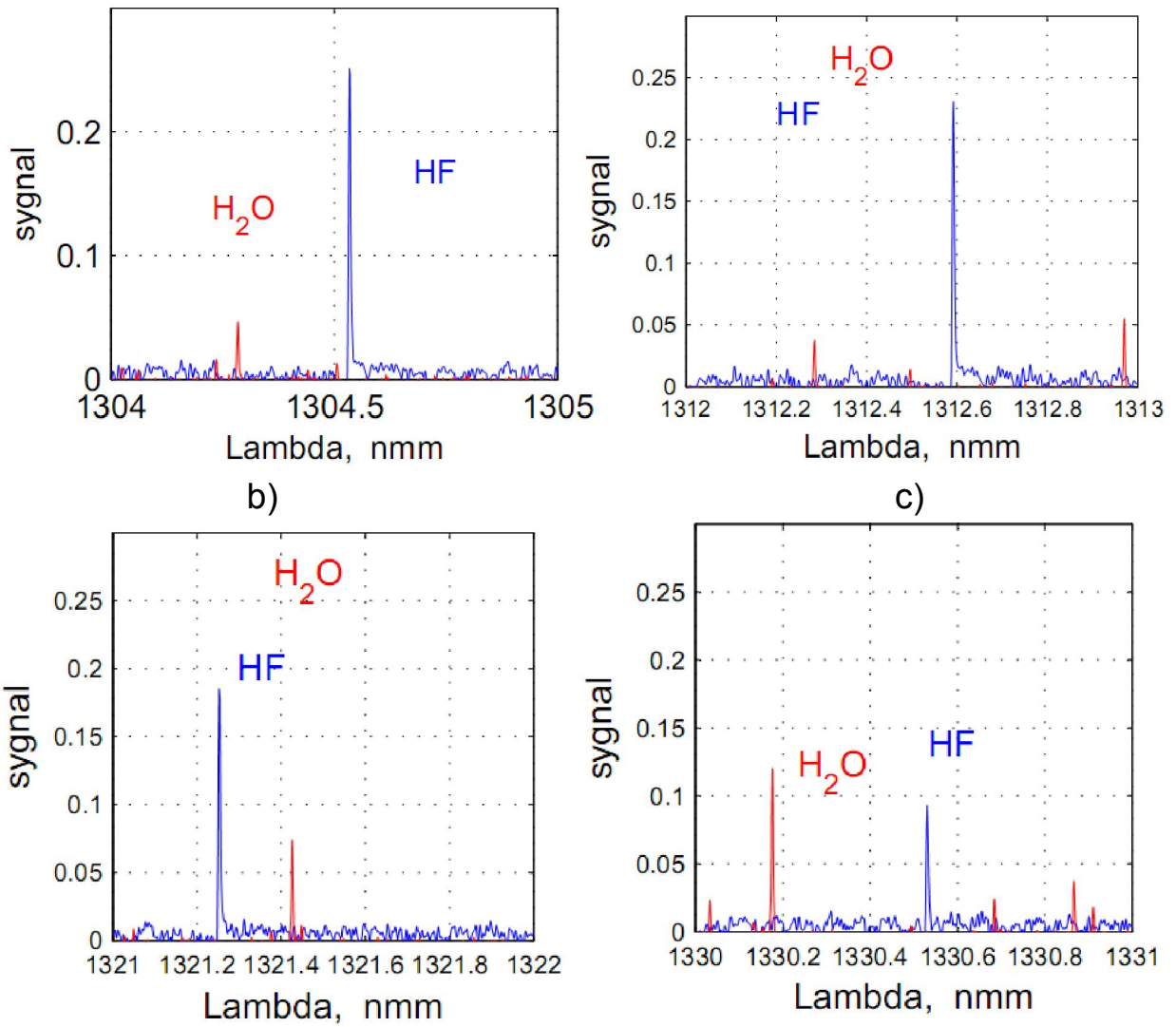
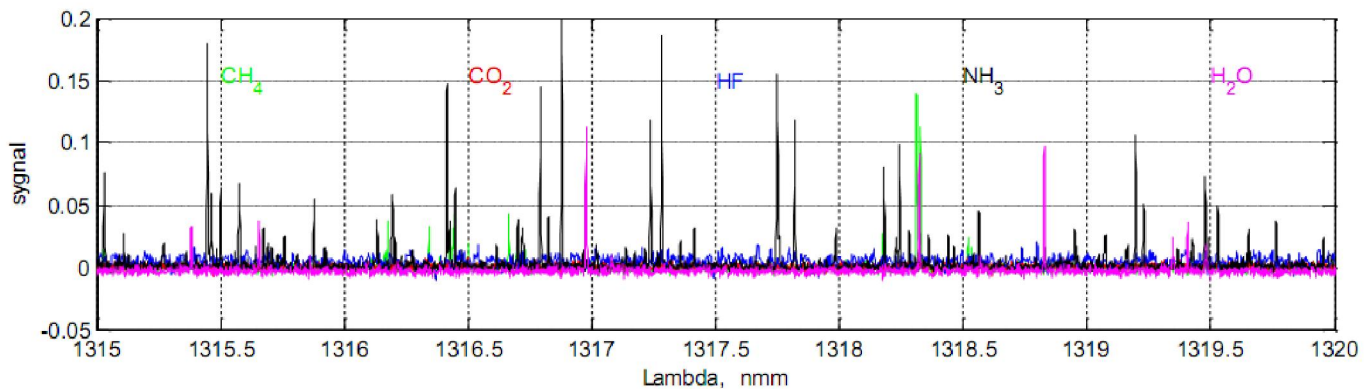
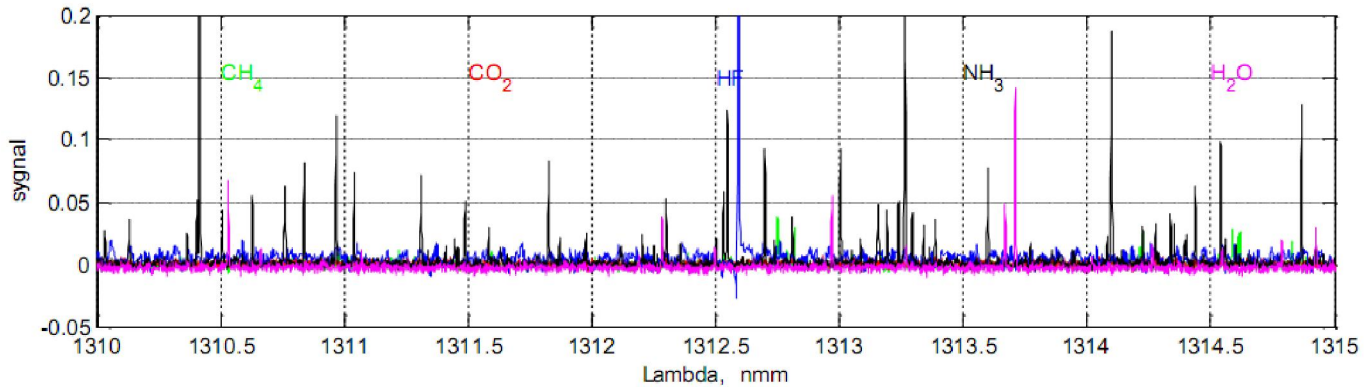
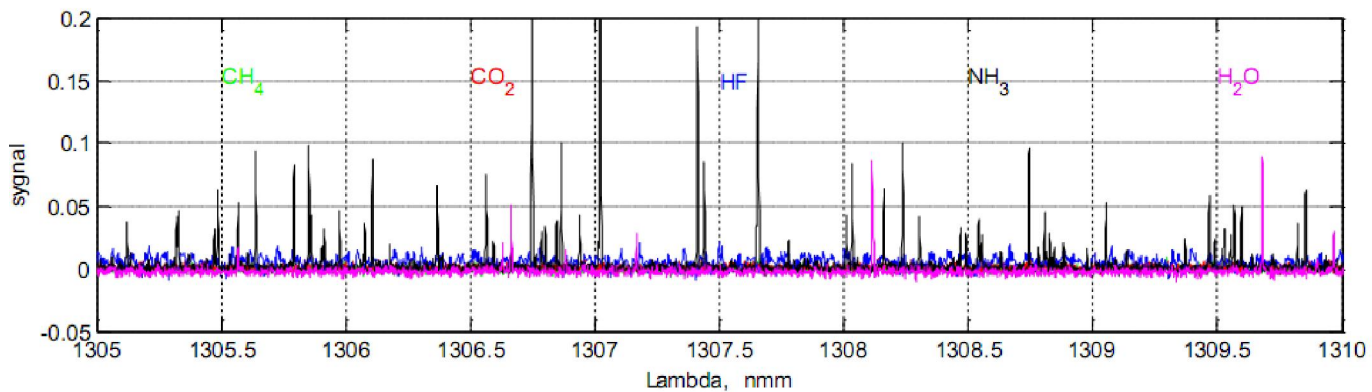
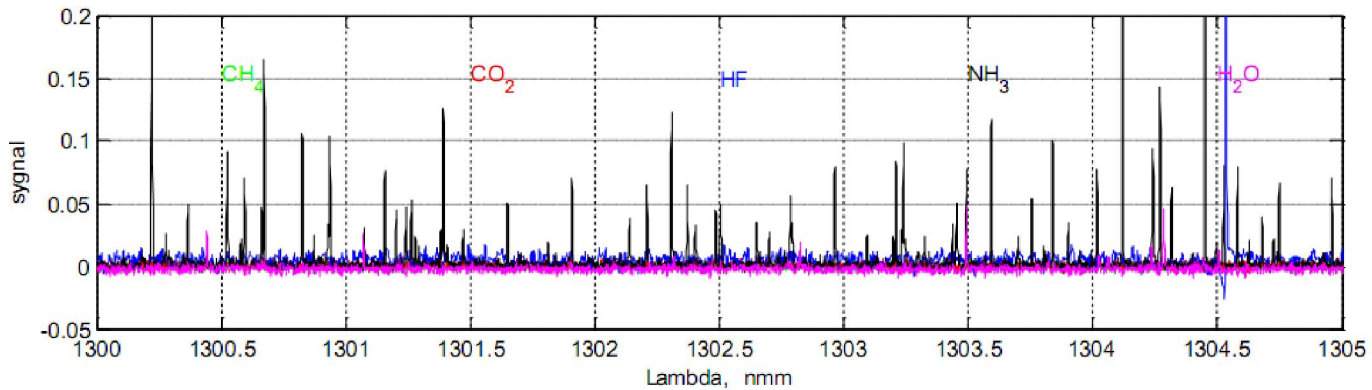


Fig. 6 Superposition of H₂O and HF absorption lines in the range $\lambda=1260\text{nm} - 1340\text{nm}$ and 4 region for calibration purposes - b, c, d, e.

Figure 7 shows a superposition of the absorption spectra of all studied gases (H₂O, CH₄, NH₃, HF, CO₂) for a more essential understanding of absorption spectra lines that could be used in gas sensing. The presence of a wide amount of absorption lines for NH₃ is evident from figure 7.



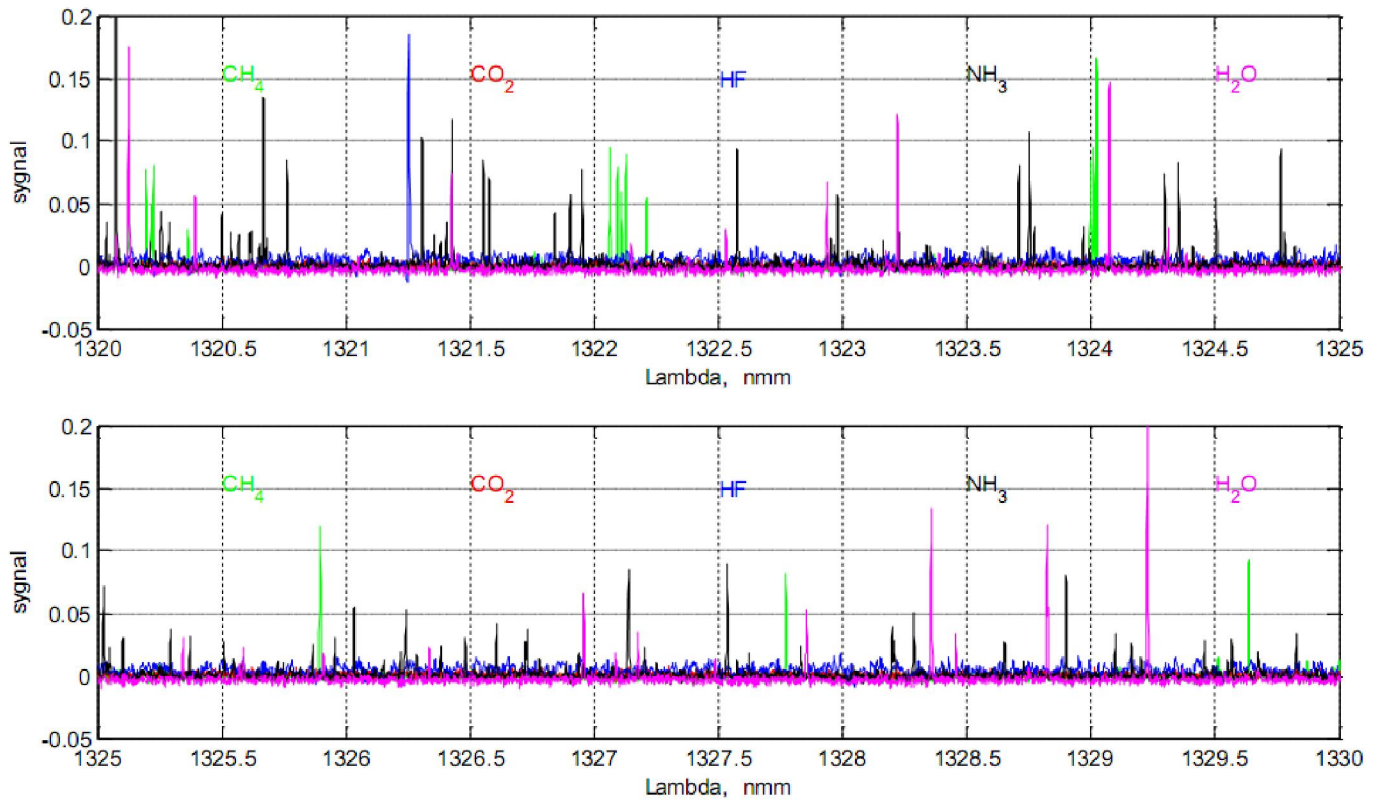


Fig. 7 Superposition of the absorption spectra of all studied gases (H₂O, CH₄, NH₃, HF, CO₂) in the wavelength region ($\lambda=1300\text{nm} - 1330\text{nm}$)

Table 1 shows the pressure values used for measuring the absorption spectra of the above mentioned gases.

Table 1 Gas pressure used for absorption spectra measurements

| Gas | Pressure (Torr) |
|------------------|-----------------|
| H ₂ O | 4 |
| NH ₃ | 3.7 |
| CH ₄ | 3.9 |
| CO ₂ | 2 |

2. High resolution measurements of VCSEL emission spectra (no temperature stabilization)

High resolution measurements of the emission spectra of VCSEL (u36_137-18 sample, $\lambda=1312\text{nm}$) had been carried out using the Bruker IFS 120 spectrometer (Fourier Transform Spectrometry, fig. 1) and a mounted measurement setup (fig. 8) with no temperature stabilization of the VCSEL laser.

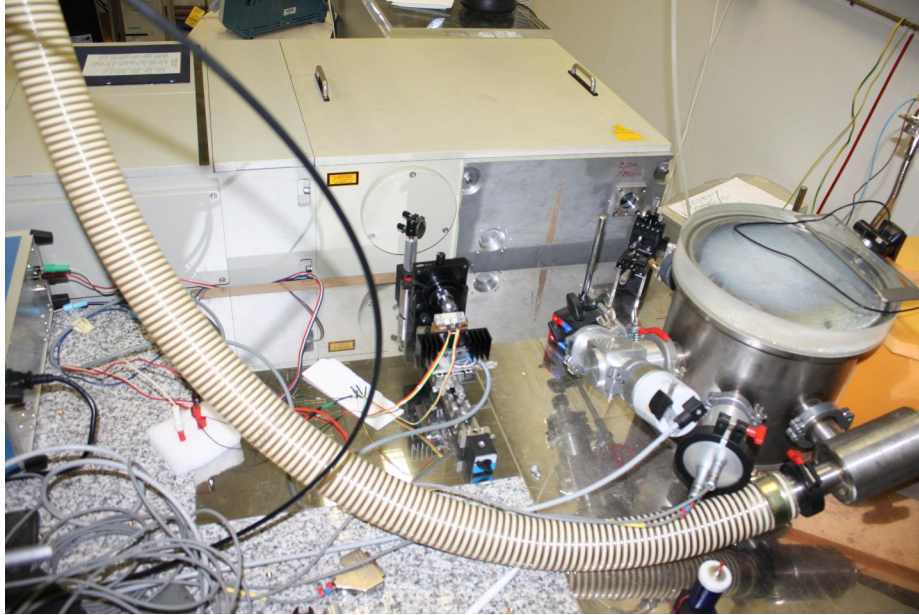


Fig. 8 Bruker IFS 120 and the setup used for high resolution emission spectra measurements.

Figure 9 shows the emission spectra measured at high resolution with no temperature stabilization of VCSEL laser. The measurements were made beginning with one hour of continuous operating of the laser assuming that 1 hour of continuous operating will assure an approximate stabilization of the laser temperature and the environment around it. The measurements were made after a certain amount of time (60 min, 120 min, 180 min, 228 min, 271 min, 298 min).

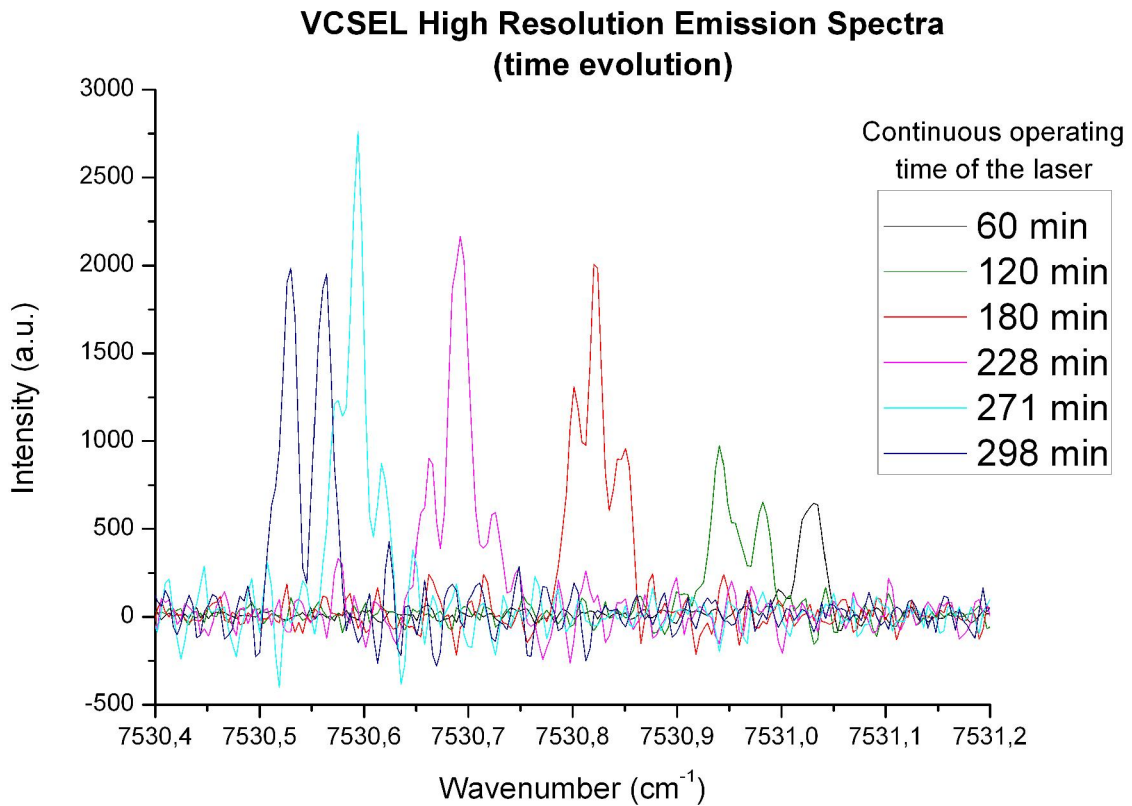


Fig. 9 High resolution measurements of VCSEL emission spectra (5 measurements made in after different time of continuous operating of VCSEL laser)

It is evident from figure 9 that a temperature stabilization of VCSEL laser is crucial for high resolution measurement purposes and that the emission power of the laser increases in time. This could be also a consequence of temperature change of the laser environment.

The stabilization of laser temperature or the constructive stabilization of laser emission line can serve as a conclusion for high resolution measurements and for developing gas sensing devices based on VCSEL laser in the IR range.

3. Time-resolved high resolution measurements of VCSEL emission

The emission spectra of VCSEL laser was measured using a time-resolved high resolution setup as it is shown in figure 10, in order to determine the emitted line width of VCSEL laser. The emission spectrum is presented in figure 11.

The line width emitted by the VCSEL laser shows to be a quite narrow and satisfactory if considering gas sensing usage purposes. Figure 12 shows the same emission spectra at a higher scale in order to determine the line width more precise.



Fig. 10 Measurement setup used for time-resolved high resolution measurements of VCSEL emission spectra

All the data was acquired using no temperature stabilization. During repeated measurements it was observed that the emission spectrum of VCSEL is not stable and it does not show a single mode emission.

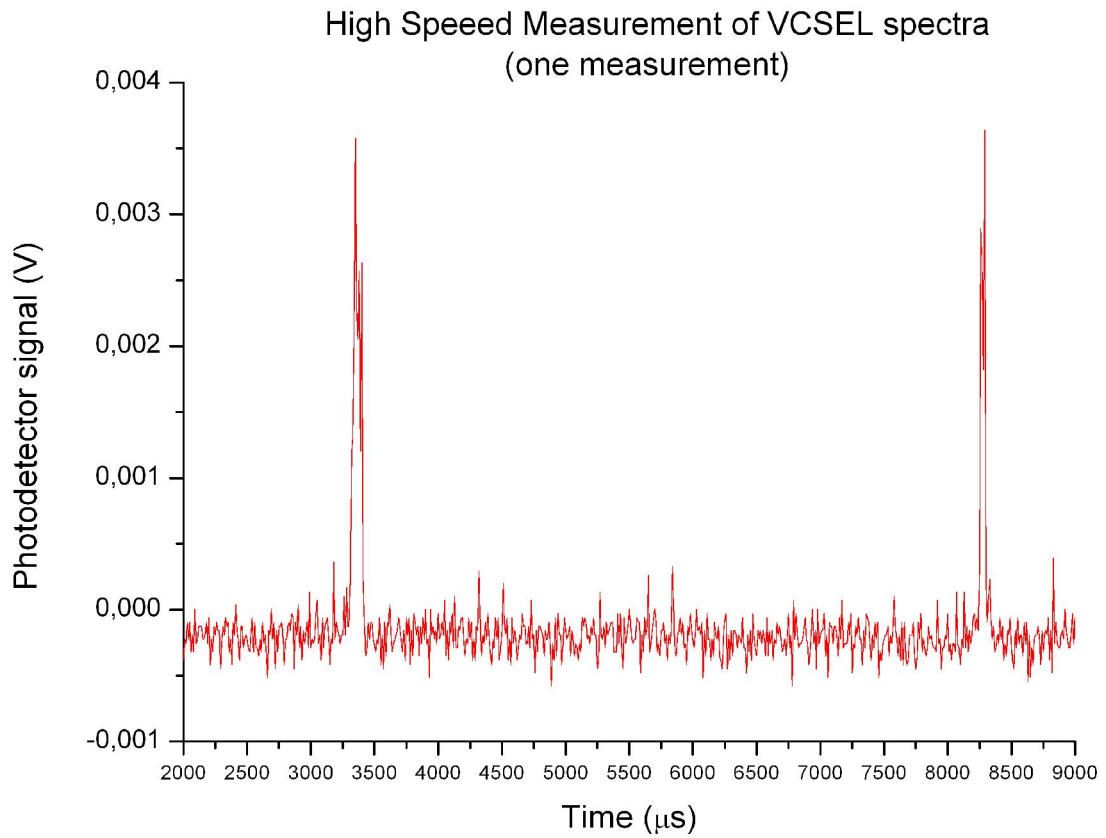


Fig. 11 Time-resolved high resolution measurement of VCSEL emission spectra

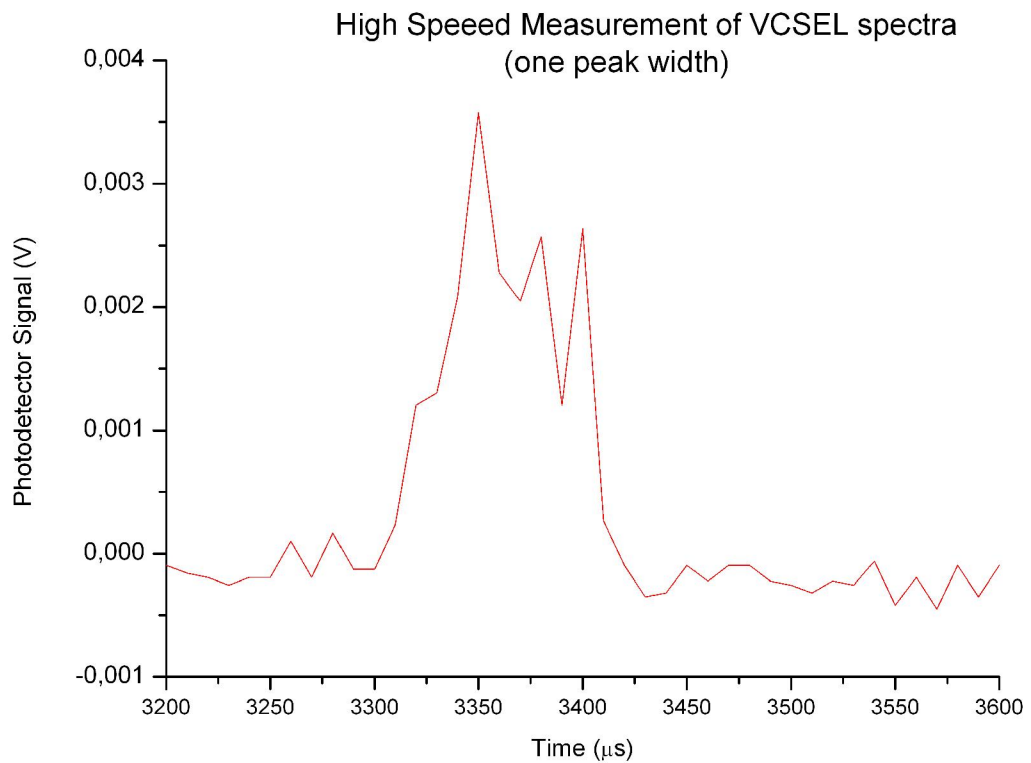


Fig. 12 Time-resolved high resolution measurement of VCSEL emission spectra (zoomed time scale)

The position of the emitted mode varies essentially during repeated measurements, which provides again the conclusion of temperature stabilization necessity. This variation is shown in figure 13.

Moreover, during repeated measurements it was observed that the VCSEL laser is very sensible to the optical feedback of the mounted setup used. The optical path between the laser and the photodetector, the setup mirrors and the internal mirrors of the photodetector influence considerably the operation of the VCSEL laser, working as an external optical resonator and imposing the generation and amplification of several modes in the obtained spectra that correspond to the external resonator.

If shortening the distance (i.e. the optical path) between the photodetector and laser it was observed that the number of amplified modes decreased. Different laser modes and external resonator modes were being amplified at different time values (fig. 13).

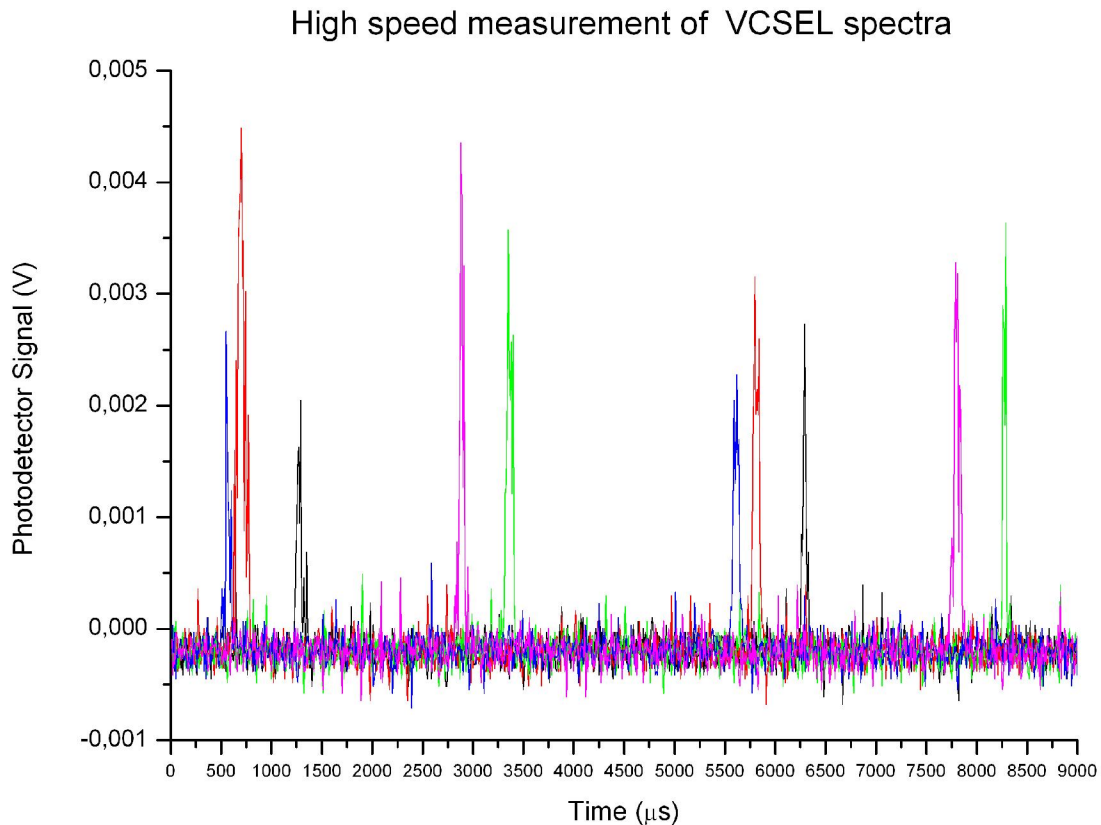


Fig. 13 Superposition of time-resolved high resolution measurement of VCSEL emission spectra (5 measurements)

Another conclusion that has been made is that as the distance of the optical path changes the amplification of one or another mode can be influenced. Figure 14 shows the superposition of several measurements made while changing the position of the mirror used in the setup (a slight arbitrary change of small values, about 0.1 mm or even smaller).

We suppose that the influence of the optical feedback could be decreased if using an optical isolator and an optical polarizer between the photodetector and the VCSEL laser in order to exclude the inverse reflection that influences the VCSEL laser emission. Of course, better result will be achieved in case of temperature stabilization of VCSEL laser.

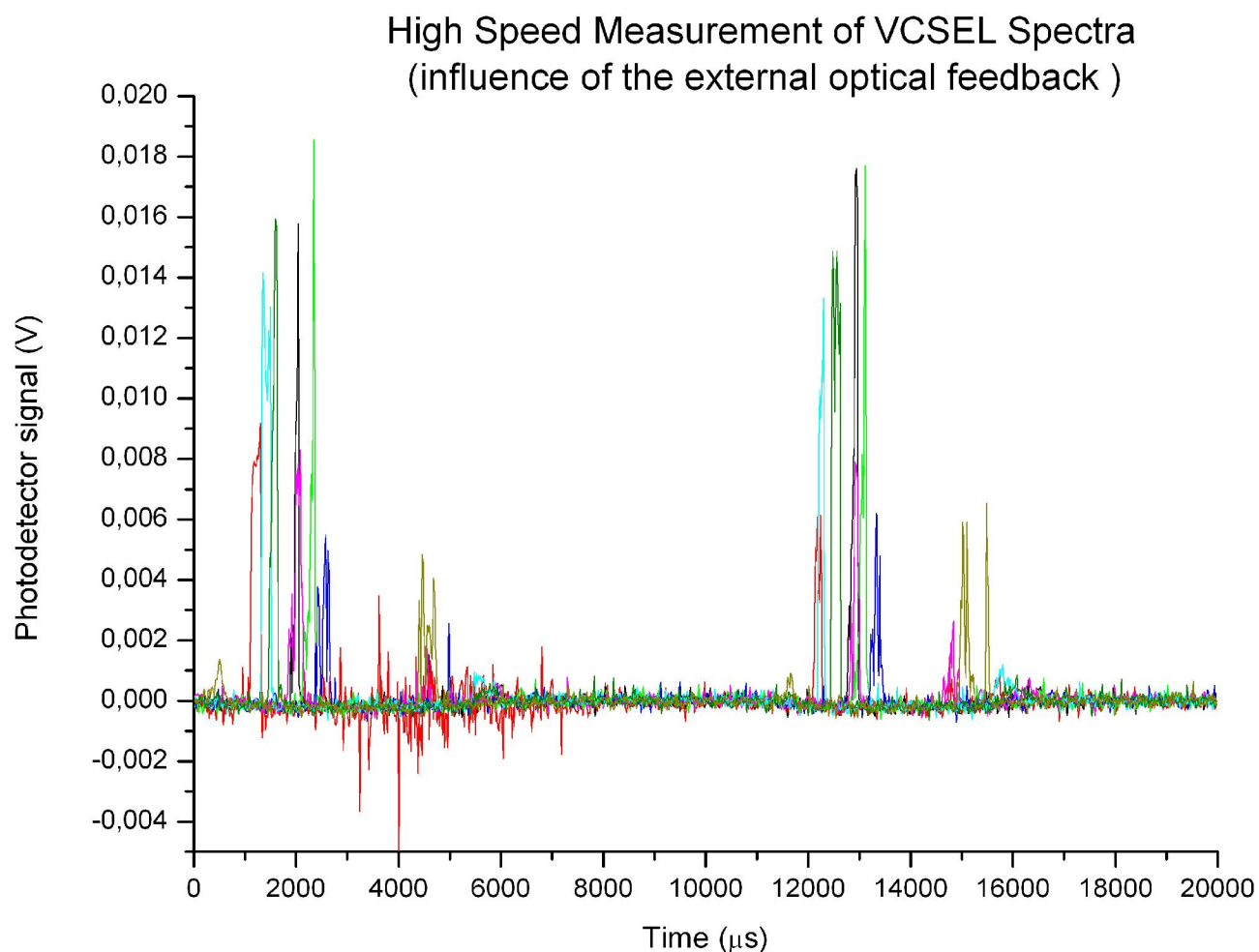


Fig. 14 Superposition of time-resolved high resolution measurement of VCSEL emission spectra for arbitrary values of the optical path (slight change of the optical path value)

Conclusions

The obtained high resolution absorption spectra of H₂O, CH₄, NH₃, HF gases in the interested IR range ($\lambda=1300\text{nm}$ up to 1350nm) shows promising results in developing gas sensing devices if using the water absorption lines for calibration.

The line width of the laser line emitted by VCSEL is satisfactory and quite narrow for using it for gas sensing purposes. The main condition that has to be assured is the amplified wavelength position of VCSEL (constructive or by temperature stabilization) and the single mode operation of VCSEL. Temperature stabilization is a crucial factor in high resolution measurements of VCSEL emission spectra.

The optical feedback is influencing essentially the operation of VCSEL. The value of the external optical path influences the amplification of different modes that correspond to the external resonator created by the optical setup and to the VCSEL laser.

Acknowledgement

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