L9 – laser detection of trace gases in air

Version “remote”

Experiment, signals and data elaboration

Real L9 experiment, that is usually performed in the Laboratory for Advanced, consists in determination about NO_2 content in atmosphere using Cavity Ring-Down Spectroscopy (CRDS). The experimental scheme is shown in Fig. 1.

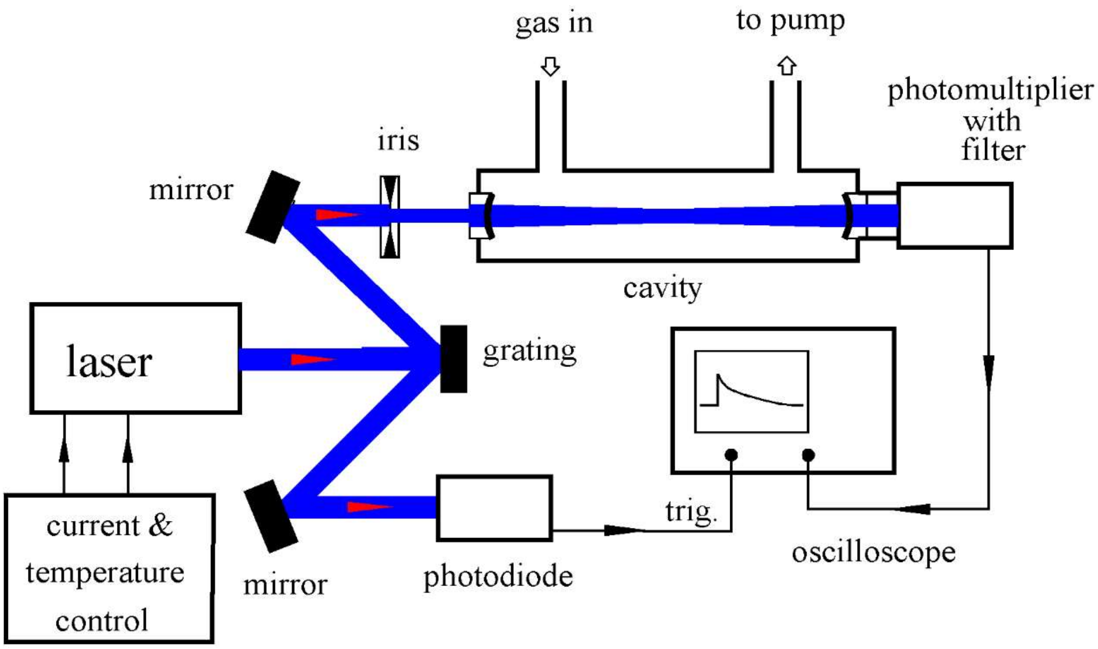


Fig. 1. The experimental scheme.

Semiconductor laser working at 411 nm is a light source. It emits pulses of about 6 ns duration time at full width of half maximum (FWHM) which are repeated with a frequency of 10 kHz. A diffraction grating working in first order (+1) together with an iris diaphragm are used for elimination of background broadband emission from the laser. This radiation (generated due to residual spontaneous emission) might be a source of interferences. The radiation deflected by the grating in -1 order of diffraction is detected by a photodiode. It is used for synchronization of signal acquisition system with the laser pulses.

Each laser pulse directed to the optical resonator of 0,5 m in length excites its main mode. The resonator consists of mirrors of very high reflectivity. The air sample is contained inside. Light detector – a photomultiplier (protected by interference filter that is resonant with the laser wavelength) is used to determine the resonator quality factor. Such parameter decreases with the losses coefficient (i.e. the absorption) increase. For instance the photon lifetime in the cavity can be determined as a Q-factor measure. A comparison of photon lifetime in empty cavity (τ_0) and the lifetime registered in presence of investigated gas (τ) provides opportunity to determine absorption coefficient of the sample:

$$\alpha(\lambda) = \frac{1}{c}\left(\frac{1}{\tau} - \frac{1}{\tau_0}\right), \tag{1}$$

where c denotes the light speed. Since the absorption coefficient $\alpha = N\sigma$ (where σ is the absorption cross section), as a consequence the absorber concentration (N) can be found. The sensitivity of CRDS systems is practically about ~4 ÷ 5 orders of magnitude better than that one of a single pass spectrometry.

Usual concentration of NO_2 in atmosphere is of the order of several tens of ppb. It can be generated due natural mechanisms as well as due to the electric discharges and thermal processes. These methods were applied in our experiment and consecutive signals – shown in Table 1 - were registered.

Table 1. Signals registered in the experiment at various conditions.

Situation	**Sample preparation**	**files**
Pure nitrogen	Nitrogen evaporated from liquid phase	*nitrogen.xlsx*
Air	Air collected from laboratory before the experiment	*air1.xlsx*
Spark 1	NO_2 – air mixture generated due to long spark discharge in air	*spark1.xlsx*
Spark 2	NO_2 – air mixture generated due to short spark discharge in air	*spark2.xlsx*
Crone 1	NO_2 – air mixture generated due to weak crone discharge in air	*crone1.xlsx*
Crone 2	NO_2 – air mixture generated due to medium crone discharge in air	*crone2.xlsx*
Crone 3	NO_2 – air mixture generated due to strong crone discharge in air	*crone3.xlsx*
Air	Air collected from laboratory at the end of the experiment	*air2.xlsx*

The files (as well as the cross section file *NO2.txt*) are supplied together with this description.

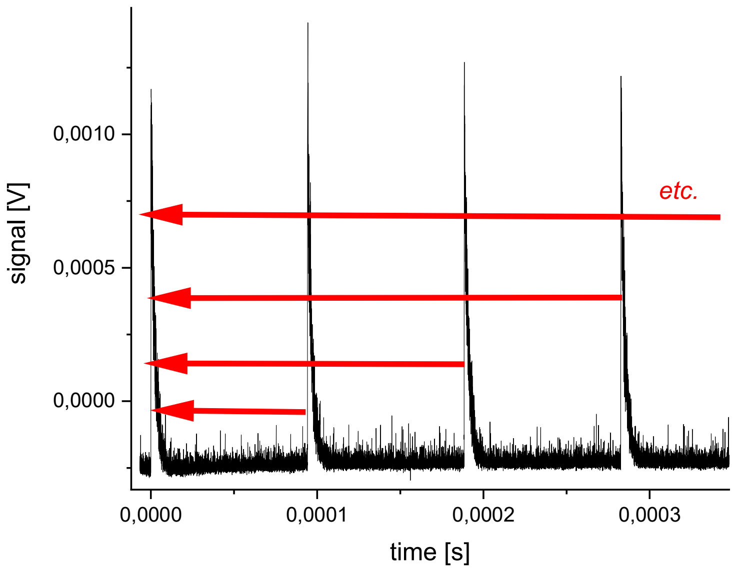
The data file structure and column descriptions are given in the tables below:

	1	**2**	**3**	**4**	**5**	**6**
	Sample	**T**	**ch1**	**ch2**	**mean**	**inverted**
0	-331	-6,62E-06	0,000801	0,0002975	0,000164	-0,00016367
1	-330	-6,60E-06	0,000801	0,0005949	0,000193	-0,00019323

	1	2	3	4	5	6
Excel row number	Sample number	Time respect to trigger pulse [s]	Reference signal from the photodiode [V]	Photomultiplier signal after the last trigger [V]	Photomultiplier signal after 5 min. averaging [V]	Inverted photomultiplier signal after 5 min. averaging [V]

Laser pulses from the photodiode are shown in col. 3. About 25 – 30 pulses are registered in one oscilloscope record. Single photons are registered (short, large negative pulses) from the cavity by the photomultiplier (col.4). After averaging of these signals over 5 min (about $3 \cdot 10^6$ pulses – col. 5) a decay of the radiation intensity is seen. In col. 6 the inverted photomultiplier signal is stored.

As it was mentioned above each record from the col. 5 or 6 consists of approximately 25 exponential pulses. Individual pulses are strongly affected by noises and fluctuations. Student should consecutively shift and average the pulses in order to achieve the form of one record - a single exponent. In this way the signal to noise coefficient will be improved by the factor of $\sim\sqrt{25} = 5$. The record of the photodiode pulses (that is synchronous with the photomultiplier registration) should be used for precise determination of the start moment of each individual exponent. The method of signal conversion is shown in Fig. 2. Student should prepare his own software for data elaboration in any language. The code should be included as an appendix to final report. Ilustrated description of the software operation should be included to the report.



One expects that during the elaboration the NO_2 concentration for each situation described in Tab. 1 will be determined. The data should be presented in absolute concentration unites ([cm^{-3}]) and in mixing ratio units in respect to normal atmospheric conditions ([ppb]). The *nitrogen.xlsx* registration is assumed as the reference file, that is useful for τ_0 determination since the nitrogen evaporated from the liquid phase contains a lowest amount of NO_2 molecules. A discussion of the results is expected.

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