Below 10^{-7} Absorption Sensitivity Limited by Diode Laser Quantum Noise

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Abstract

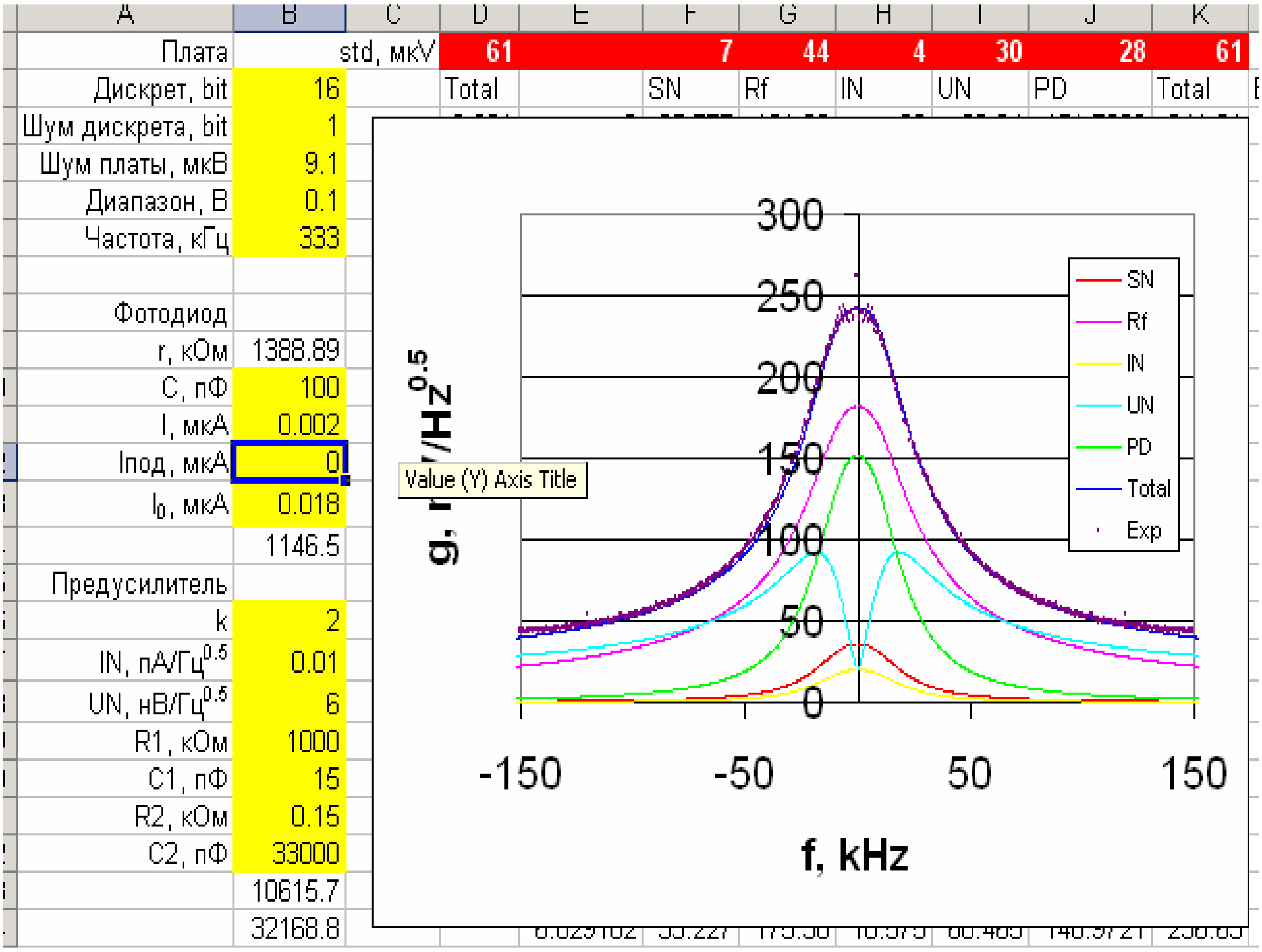
In this paper results of experiment when fundamental limit of TDLS sensitivity was achieved will be presented. Origin of this limitation is related to DL quantum noise. To achieve this sensitivity software was developed to control main mechanism of sensitivity limitation. Following problems were solved to achieve sensitivity fundamental limit:

1. Optimization of photo-detector system
2. No cross-talking in detector system and DL excitation current
3. Temperature stabilization at $3\ 10^{-5}$ K level
4. Diode laser quantum noise limited operation
5. No interference above 10^{-6}
6. Flicker noise reduction
7. No mode competition noise

Незнание законов физики никого не освобождает от необходимости следования им.

Optimization of photo-detector system

Each diode laser and particular application needs optimization of photodiode and preamplifier in use.



Example of photodiode and preamplifier optimization. Different noise mechanisms are considered and compared with experimentally measured noise spectrum

Absence of cross-talking

Cross-talking usually is the main sensitivity limiting mechanism. Special software was develop to control in real time quality of detection (FFT ADC) and diode laser excitation current (FFT DAC) systems.

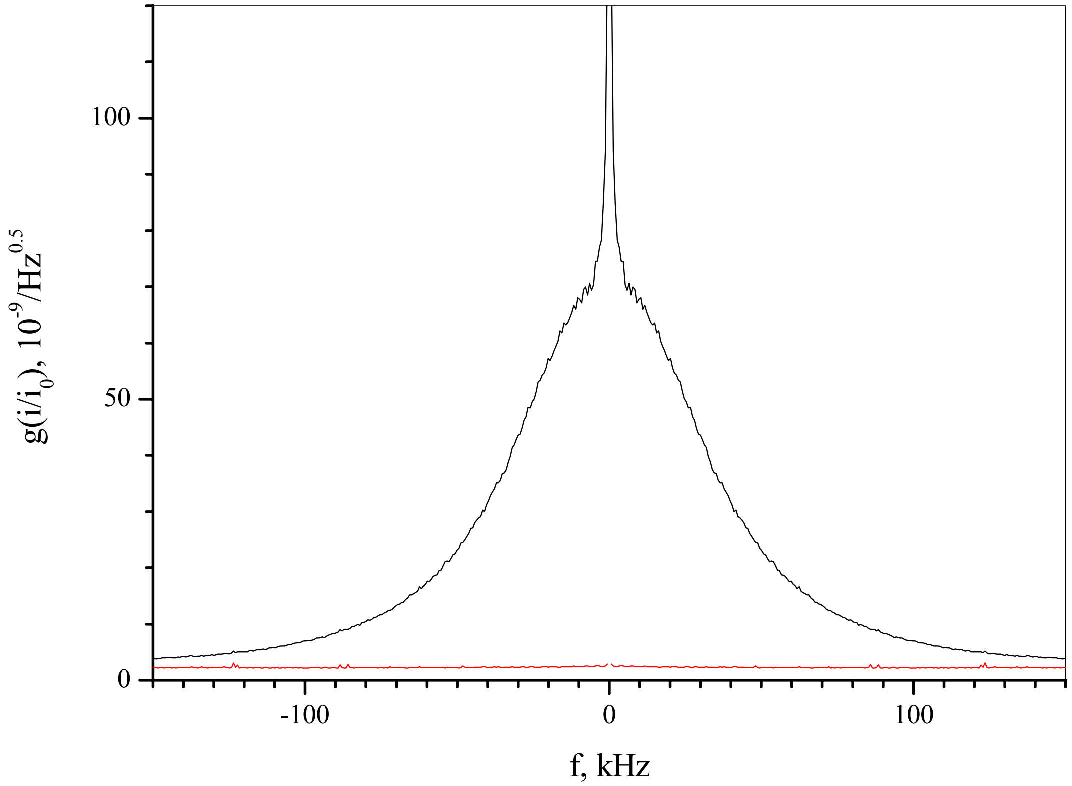
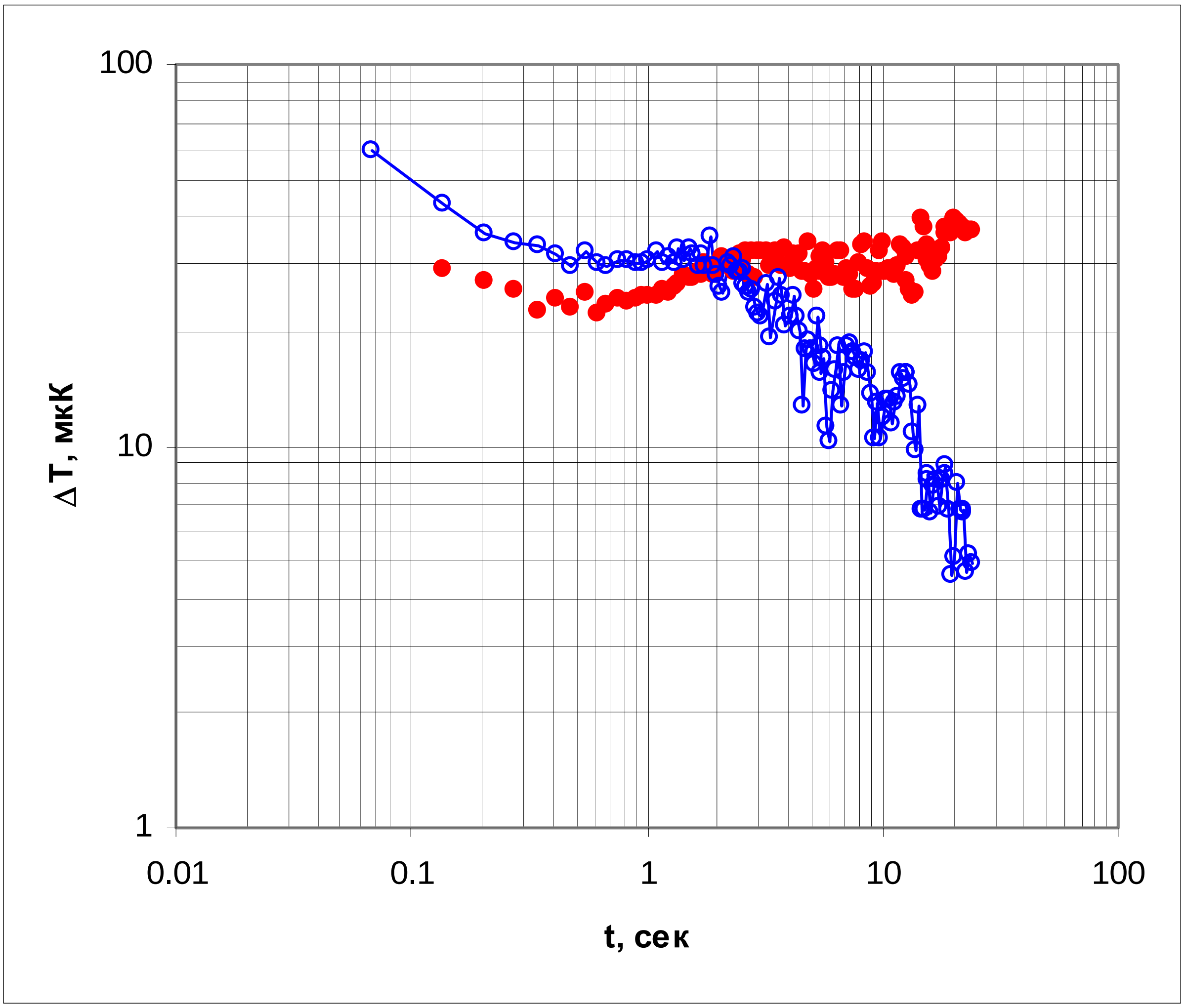


Figure shows example of these programs operation.
Photo-current **i** noise spectra with laser on (black) and off (red) are presented.
i0 corresponds to photocurrent value for excitation current equal double of its threshold value,
Central narrow peak is due to diode laser flicker noise.

Practical absence of cross-talking both in photo-detection and diode laser excitation current systems can be observed.

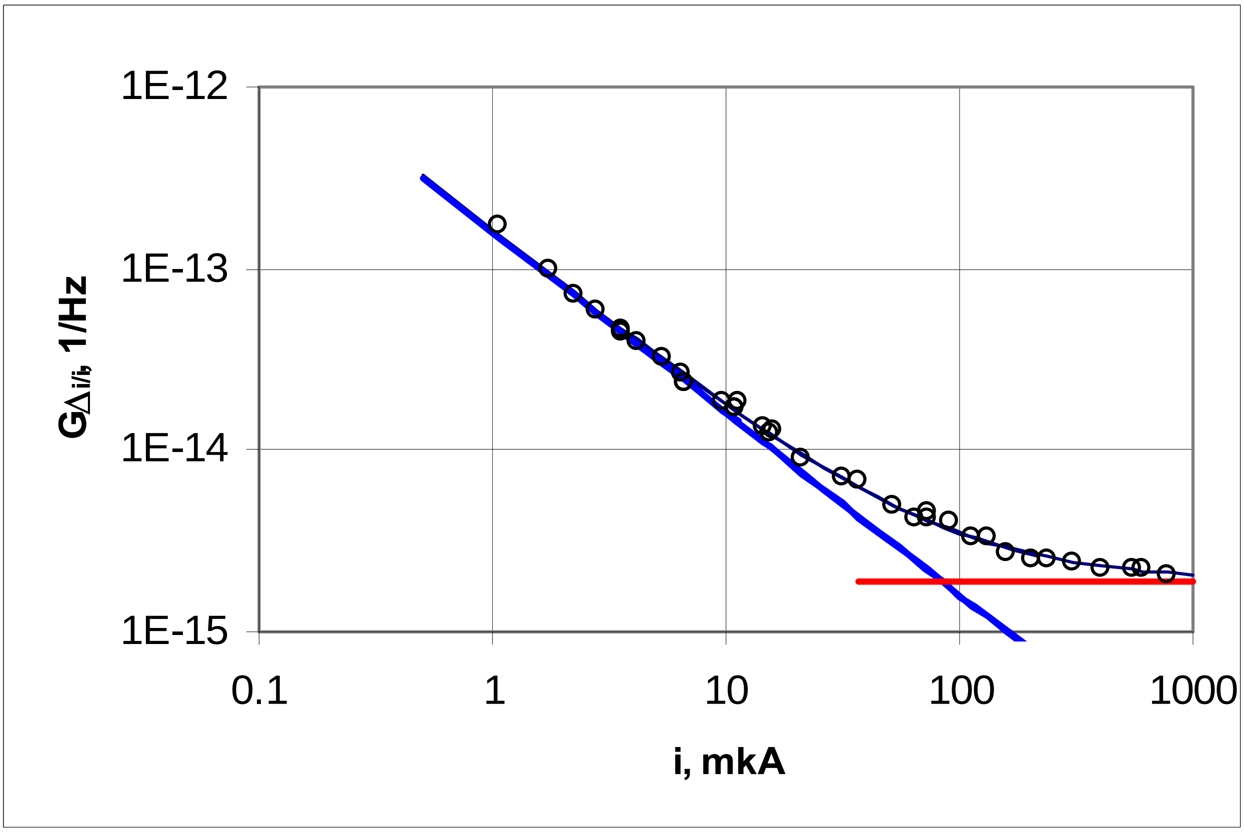
Temperature stabilization at 3 10^{-5} K level

To achieve the fundamental sensitivity fundamental limit in TDLS, DL frequency stability plays important role.



Allan plot of temperature instability measured by termistor (blue open cycles) and with help of reference spectral line (red solid cycles) as function of averaging time t. Diode laser temperature stability at 0.03 mK level was achieved (see separate poster).
To control this option special software (temperature stabilization) was developed

Diode laser quantum noise limited operation



Quantum noise limited operation of diode laser based system.

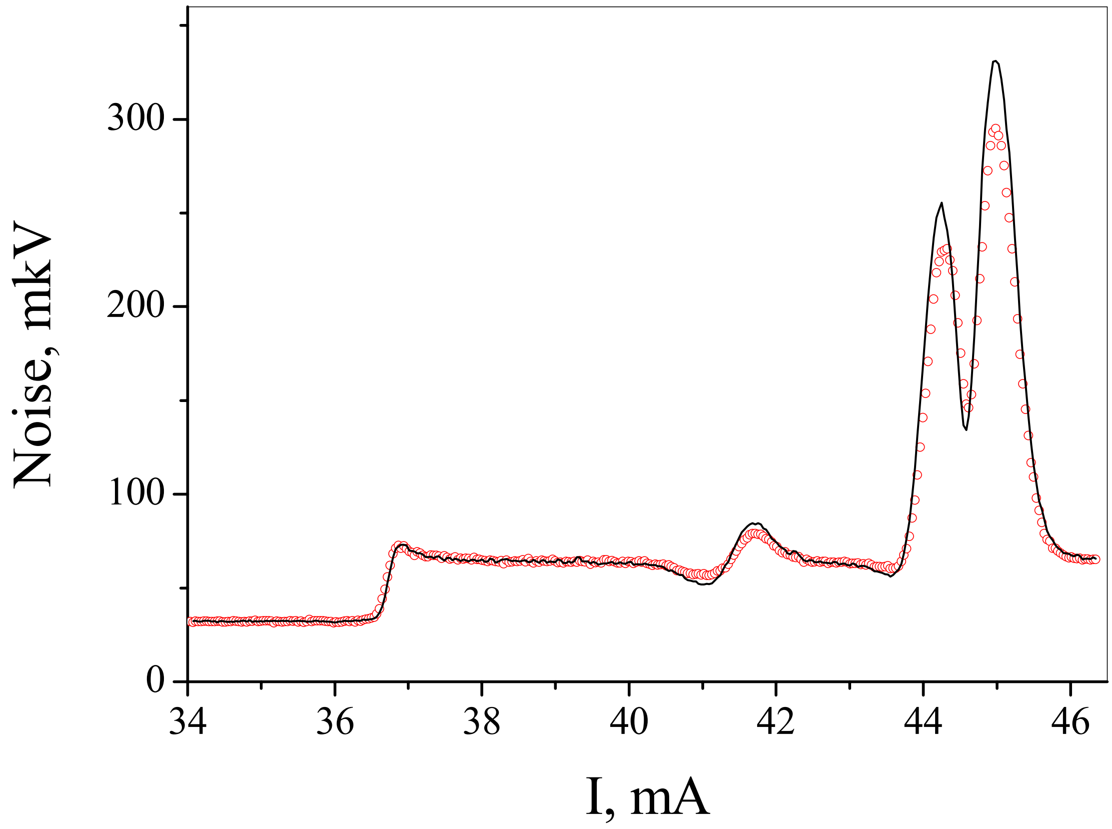
Blue line represents shot noise due to photo-current quantum nature (see separate poster).

Red line corresponds to diode laser quantum noise (see separate poster)

Diode laser quantum noise dominates for photo-current values above 100 mkA

Diode laser quantum noise limited operation (software)

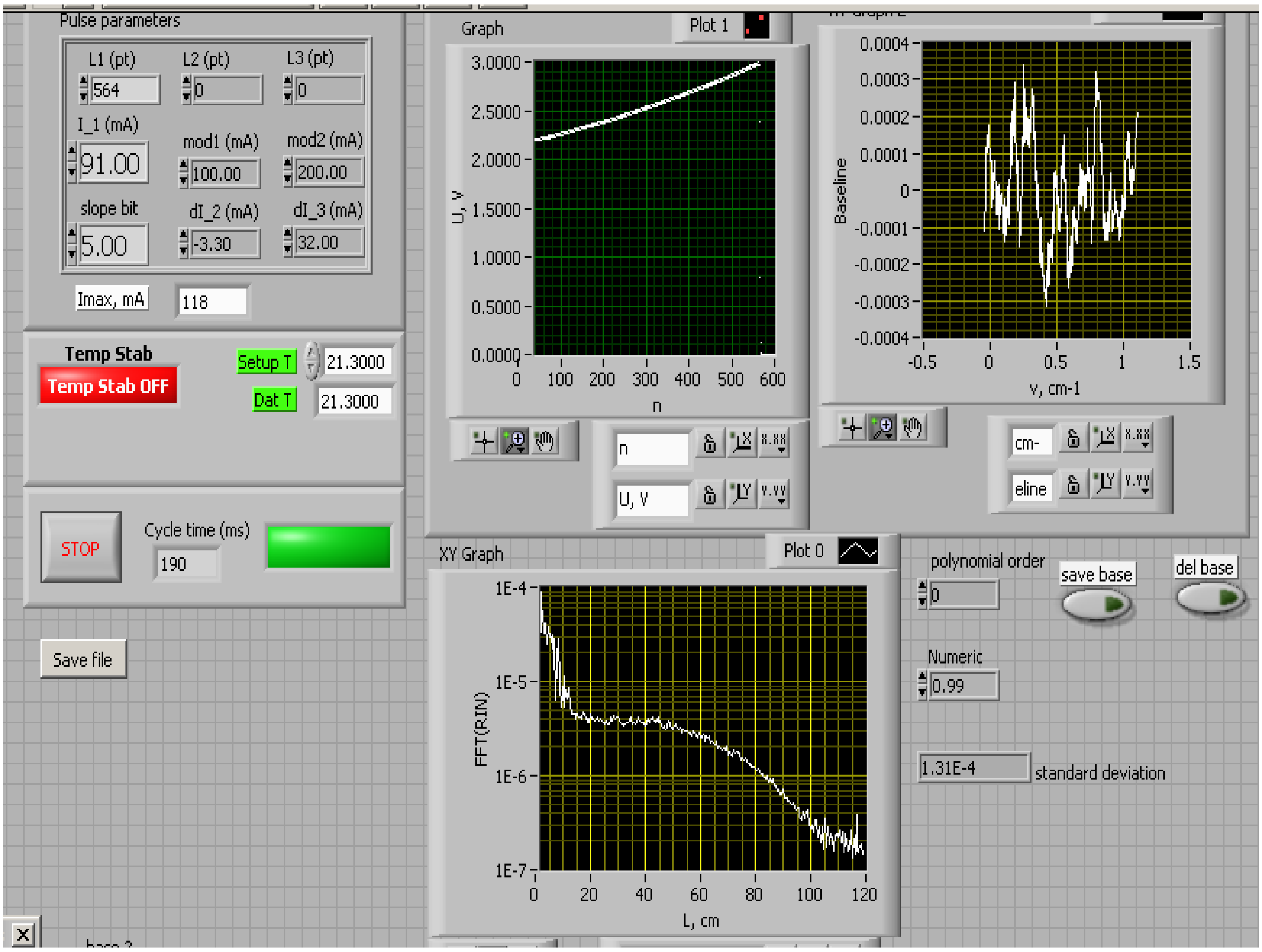
To control above mentioned option special software was developed (DL Noise) to compare experimentally measured noise with its predicted value (black curve) (see separate poster)



On this picture both diode laser intensity and frequency quantum noise can be observed

No interference above 10^{-6}

To control interference presence special software was developed (baseline&interference) (see separate poster) to determine in real time origins of interference or feedback to remove their influence.



Interface of baseline&interference software

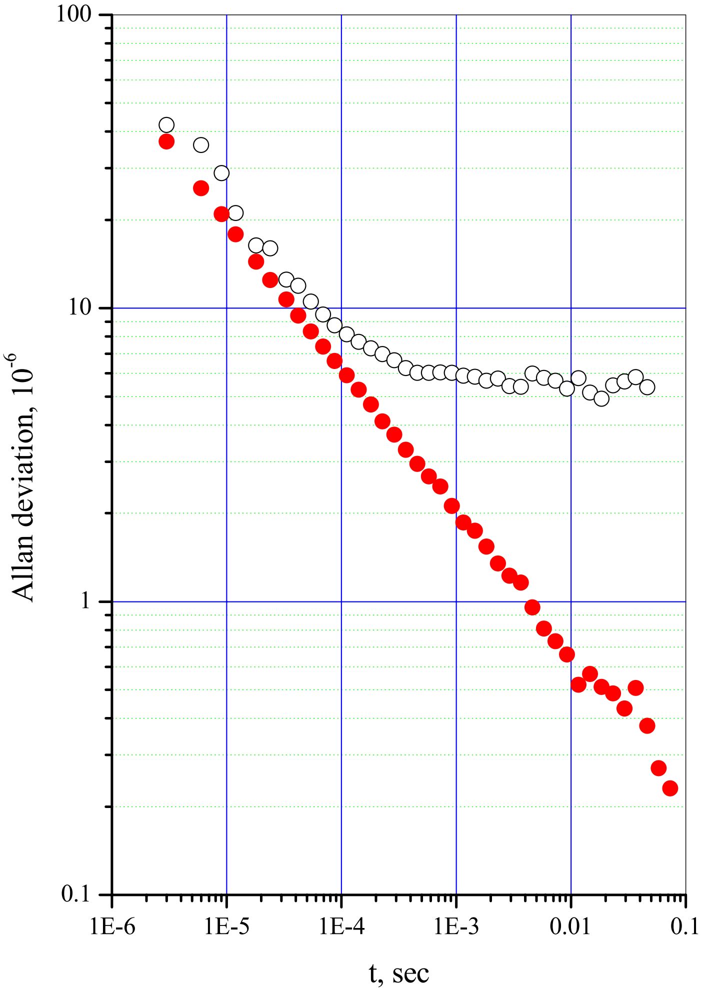
No interference above 10^{-6}

Flicker noise reduction

Diode laser Flicker noise plays important role in TDLS sensitivity limitation. Frequently this noise type limits sensitivity.

Physical origin of this noise is related to fluctuations of excitation current density in diode laser active area.

When noise origin is known, its suppression is straightforward.

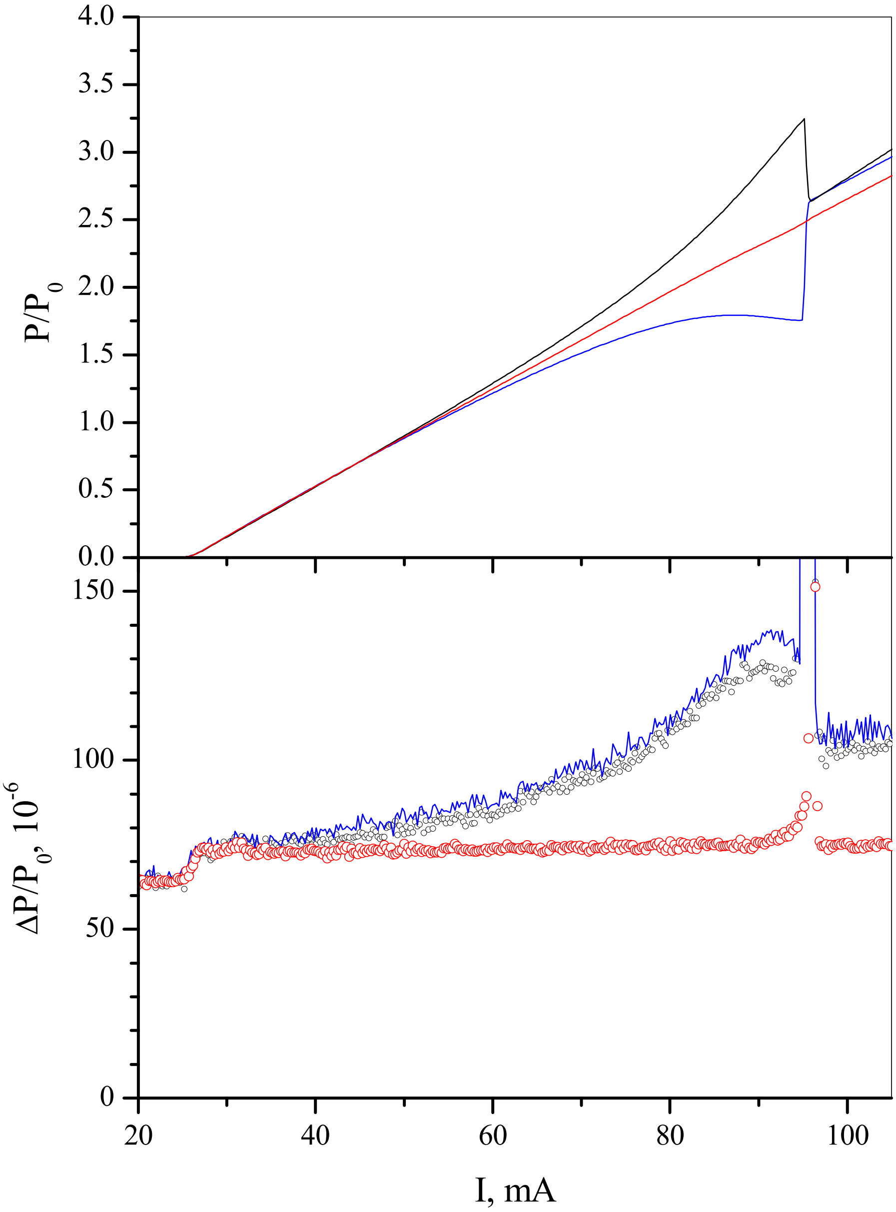


Special software was developed to control diode laser flicker noise suppression.

Diode laser relative intensity noise for tradition operation mode (black open cycles) and the operation mode taking into account its nature (red solid cycles).

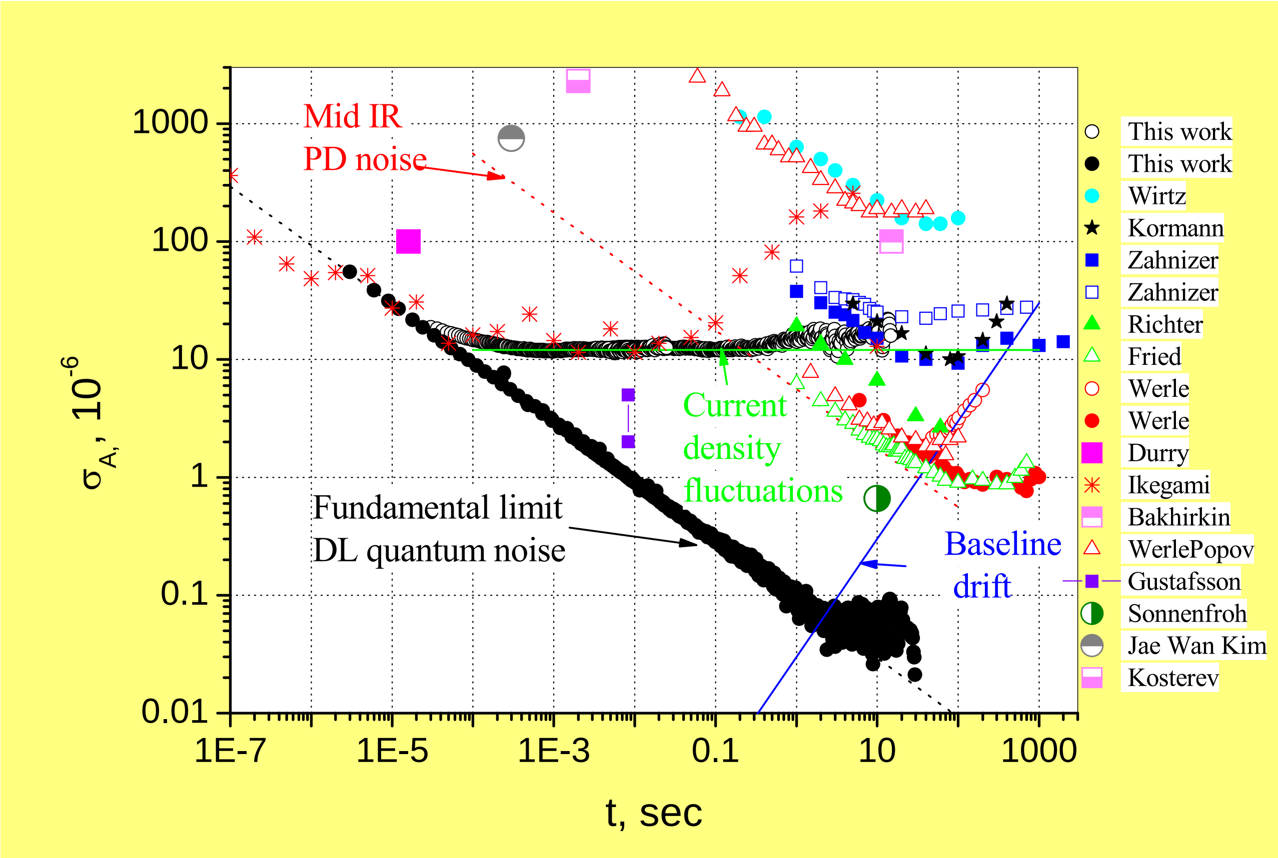
No diode laser mode competition noise

Diode laser mode competition noise depends of particular laser prosperities



Example of diode laser mode competition noise suppression

6 10^{-8} Absorption Sensitivity



Allan plots of absorption sensitivity (minimum detectable absorption, noise equivalent absorption) as function of averaging time t.

Comparison of the best known to author results achieved.

If physical nature of main sensitivity limiting mechanisms is known, their influence can be suppressed.

For optimized photo-detector system, electronics, and optics, as well as generation #3 of TDLS operation mode (see separate paper) fundamental limit of TDLS sensitivity (diode laser quantum noise) can be achieved.

Conclusion

Fundamental limit due to diode laser quantum noise was achieved: below 10^{-7} for averaging time above 1 sec (best presented in this poster result is equal $6\ 10^{-8}$ for 5 sec averaging time). This limit is determined by diode laser fundamental property and doesn't depend on electronics or optical characteristics of the system under consideration.

Frequently (in photo-acoustic and ring-down spectroscopy) minimum detectable absorption coefficient is considered. This parameter is equal to $6*10^{-12}\ cm^{-1}$ for our system (Chernin multi-pass cell in use: 0.5 m, 200 passes) and it is comparable with the best known results obtained in Stark spectroscopy.

Next sensitivity parameter widely used in literature is minimum detectable molecular concentration. For example, for HF molecule above mentioned sensitivity corresponds to minimum detectable concentration 0.8 ppt.