D3

Investigation of quantum cascade laser developed to measure UF_6 enrichment

DLS LAB

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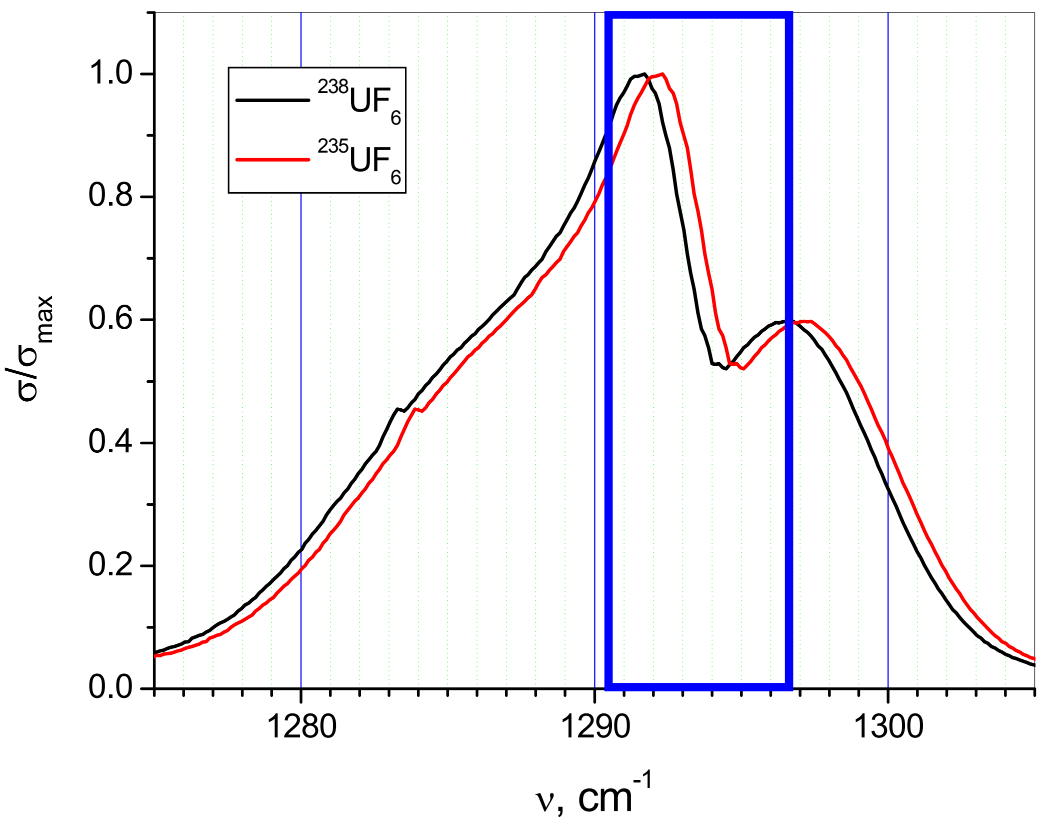
Introduction

UF_6 enrichment measurement is very important goal of IAEA safeguards. In frame of activity of IAEA working group for TDLS implementation in IAEA safeguards QCL development for UF_6 enrichment measurement was considered as very important step [1]. Thanks to IAEA German support program such QCL was developed and supplied to IAEA by Laser Components (Germany). IAEA requested GPI to investigate this QCL with respect to UF_6 enrichment measurement.

In present paper results of this investigation will be presented and will be compared with results obtained for other DL used for UF_6 enrichment measurement. Comparison of QCL results obtained with other DL types will be considered in D1.

[1] *G.Grigoriev, A.Lebrun, A.Mantz, L.Mechold, A.Nadezhdinskii, N. Peter – Stein, V.Ryzhikov, F.Tittel, M.Zendel, Status of the Tunable Diode Laser Spectroscopy Contribution to International Safeguards Verifications*, Abstracts of TDLS 2009, Zermatt, Switzerland, p.21.

UF_6 spectra

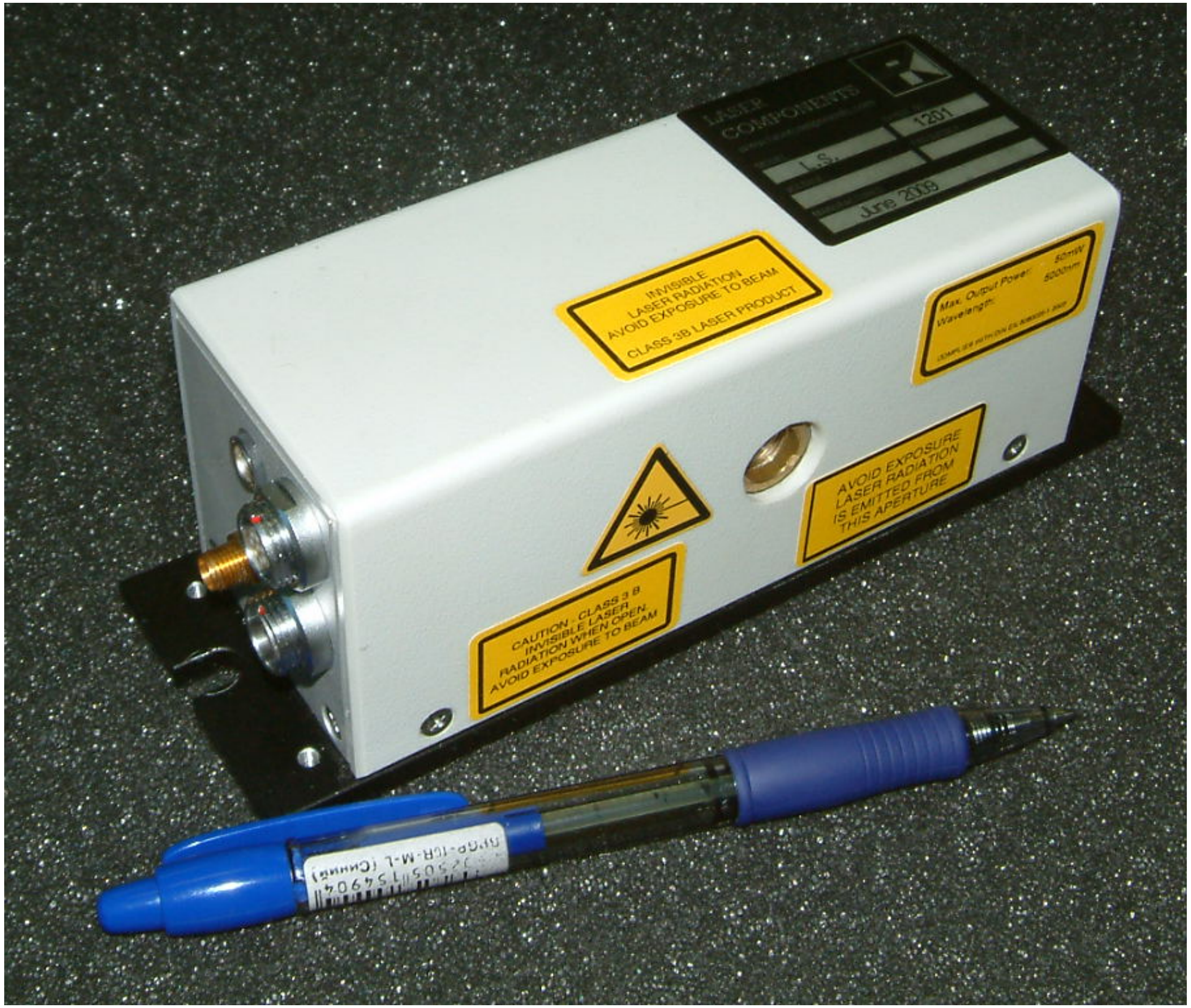


$^{235}UF_6$ and $^{238}UF_6$ cross section [2] spectra obtained using FTS. DL spectra demonstrate fine structure on right part of Q-branch.

Blue rectangular shows requirement of DL frequency tuning to measure UF_6 enrichment.

[2] A.Berezin, S.Malyugin, A.Nadezhdinskii, D.Namestnikov, Ya.Ponurovskii, D.Stavrovskii, Yu.Shapovalov, I.Vyazov, V.Zaslavskii, Yu.Selivanov, N.Gorshunov, G.Grigoriev, Sh.Nabiev, UF6 enrichment measurements using TDLS techniques, Spectrochimica Acta, A 66, 796– 802 (2007)

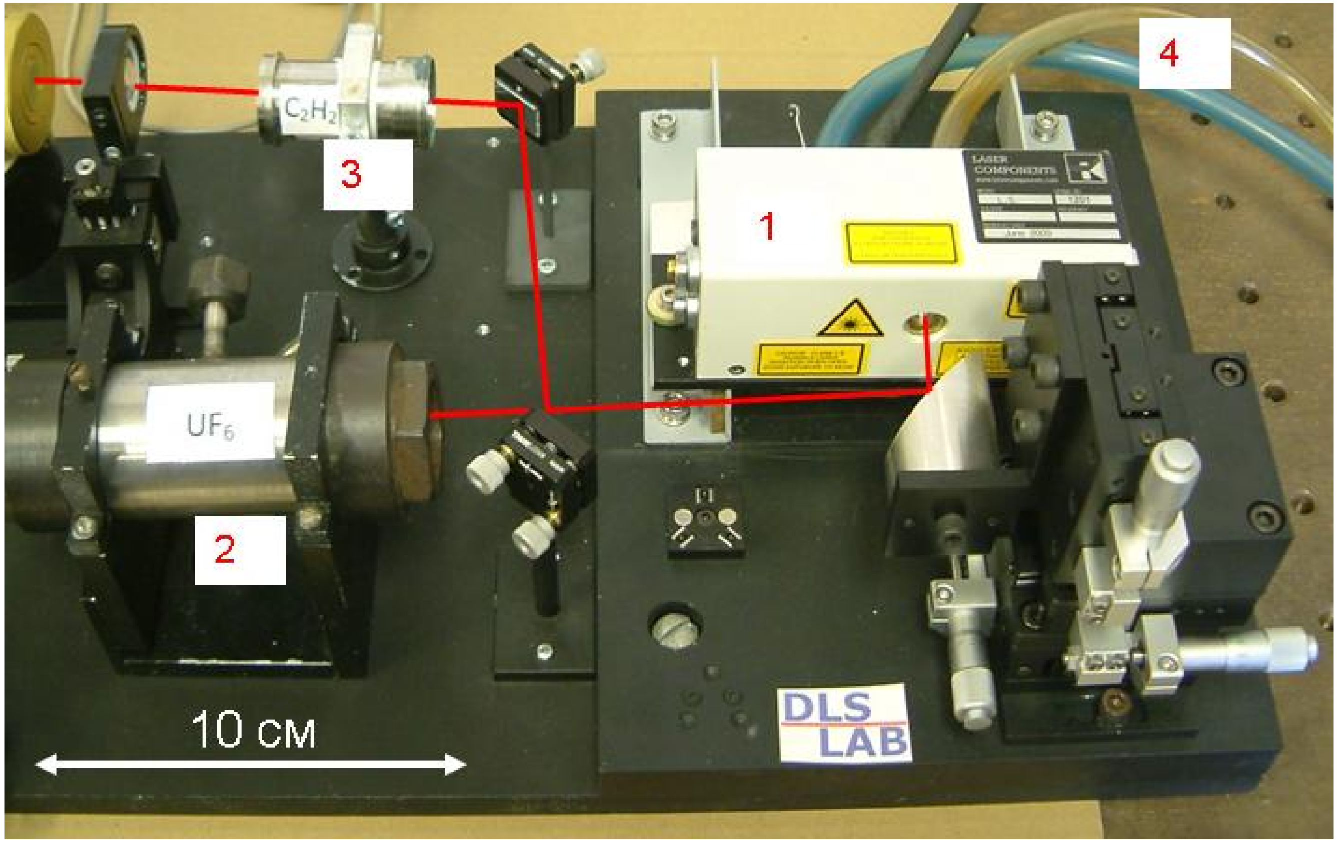
QCL module development



Thanks to IAEA German support program QCL module was developed and supplied to IAEA by Laser Components (Germany).

View of QCL module developed.

Experimental set up

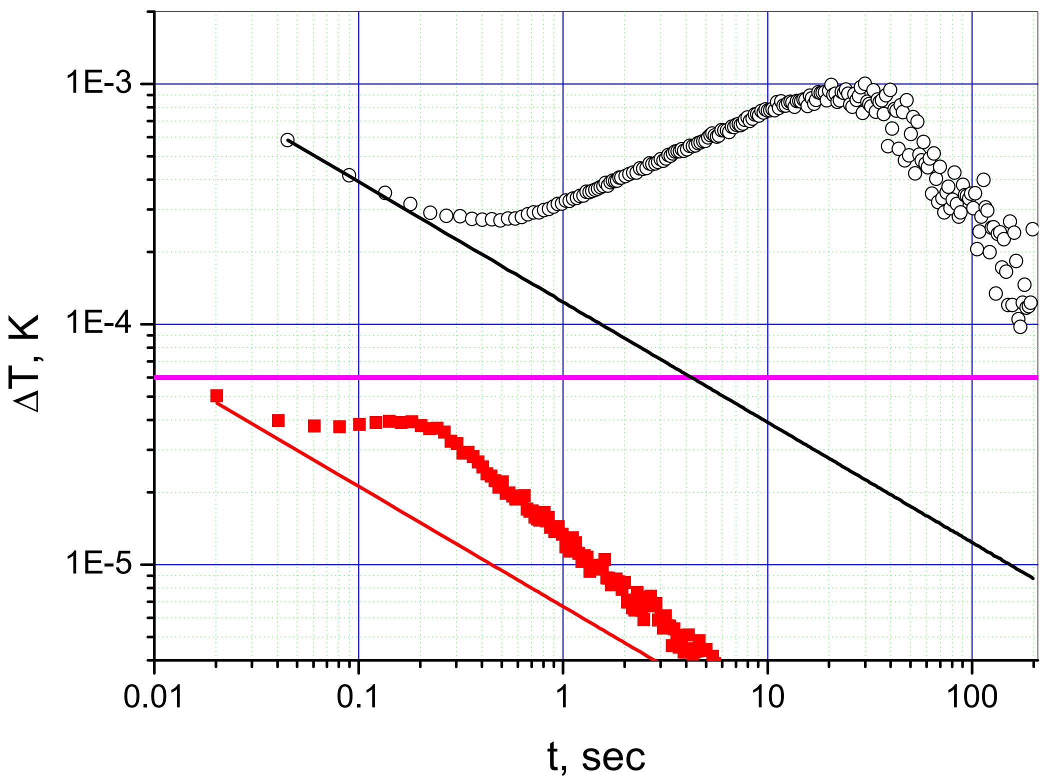


QCL module developed (1) was installed in experimental set up to investigate QCL parameters and to measure UF_6 enrichment.

QCL radiation (red) was divided into two beams, passed gas cells (2, 3), and was directed to two PD of analytical and reference channels. QCL module water cooling (4) was used.

Temperature stabilization

Quality of temperature stabilization is very important for high accurate measurements in TDLS. Test of QCL module demonstrated very band performance: very slow and huge temperature instability (black circles).

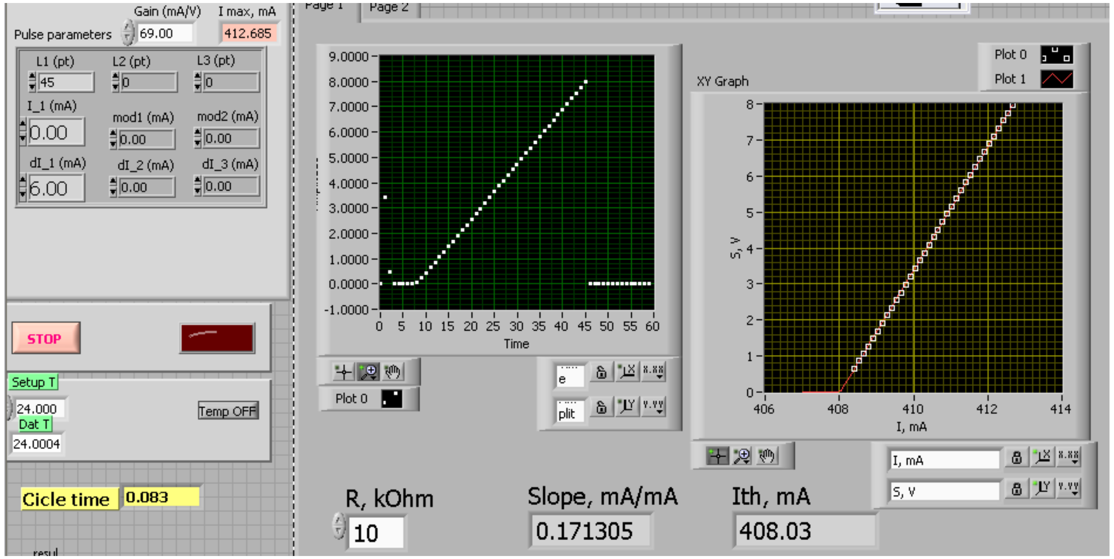


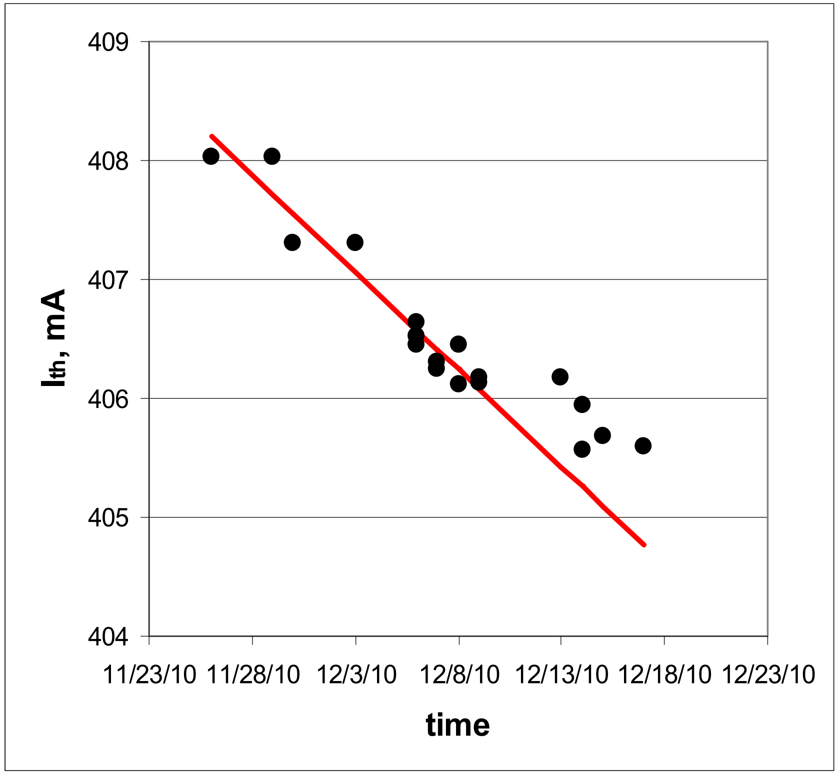
Temperature stability as function of averaging time.

After total module redesign temperature stabilization performance was significantly improved (red squares). Magenta horizontal line was calculated based on IAEA requirements for UF_6 enrichment measurements.

“QCL test” software

Interface of “QCL test” software.
For given DL temperature (24 °C in present case) 2 parameters are determined: threshold current (I_{th}) and quantum efficiency – number of photoelectrons per one electron of excitation current (slope).

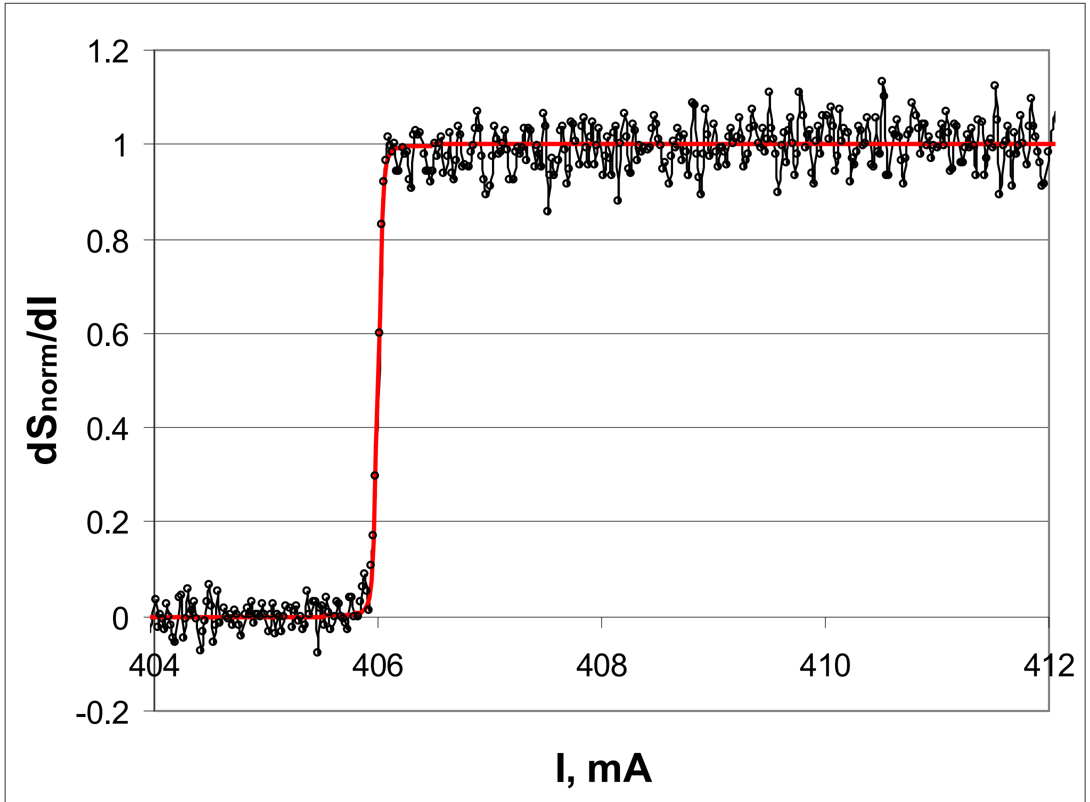




Quantum efficiency measured for QCL (17.1 %) is significantly higher MIR DL (0.1 %) and is close to NIR DL (20 %) ones subject of quantum cascades in use.

Threshold current time dependence was observed during QCL tests. From this dependence QCL life time was estimated to be 5 years.

QCL parameters



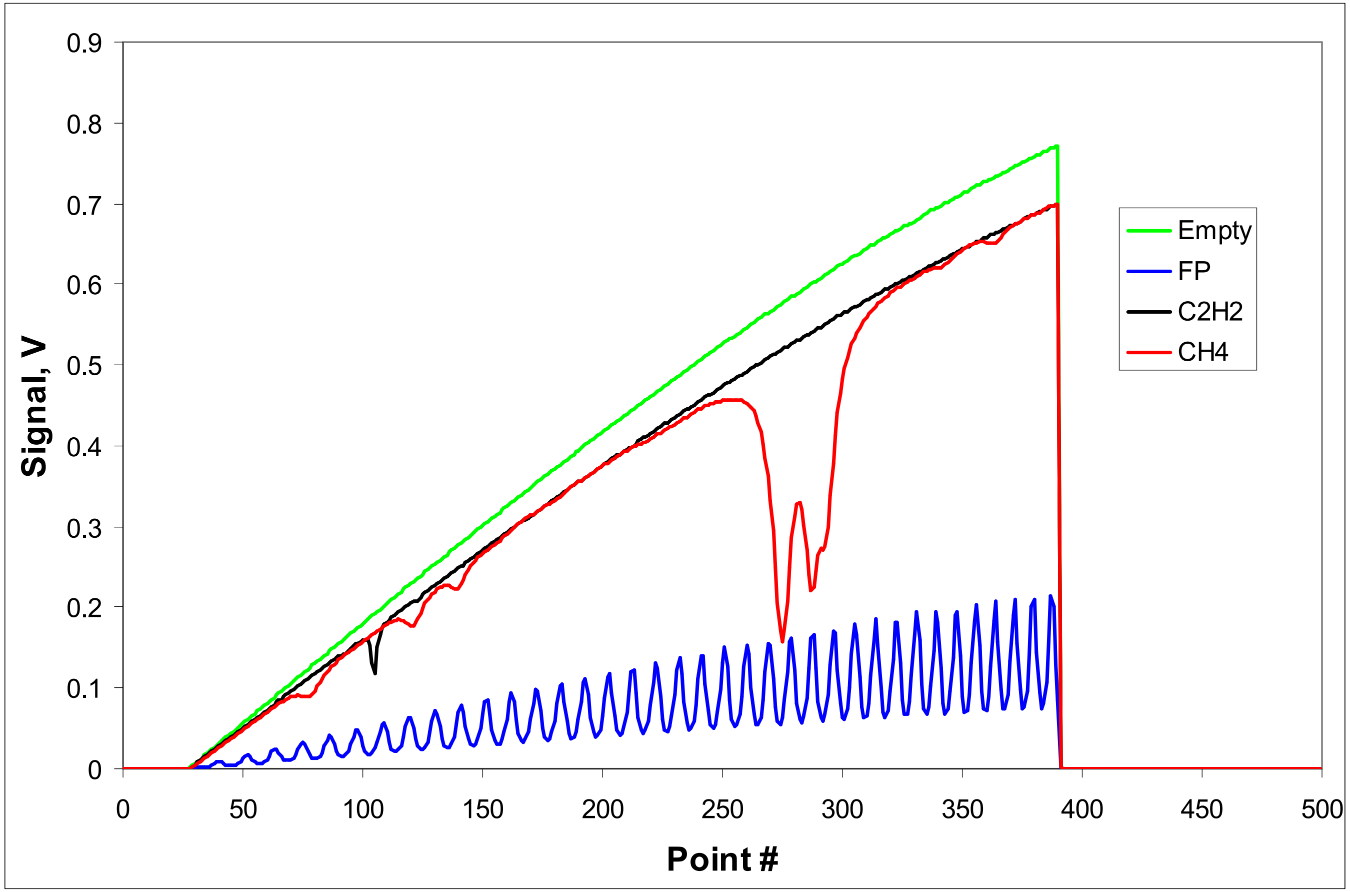
Derivative of normalized signal as function of excitation current.

Normalized signal is determined by two parameters: threshold current - I_{th} and photons number at threshold - $N_p(I_{th})$ (see B1).

$$S_{norm} = \frac{1}{2}\left[I - I_{th}\right] + \sqrt{\frac{1}{4}\left[I - I_{th}\right]^2 + \frac{I_{th} I}{N_p\left(I_{th}\right)^2}}$$

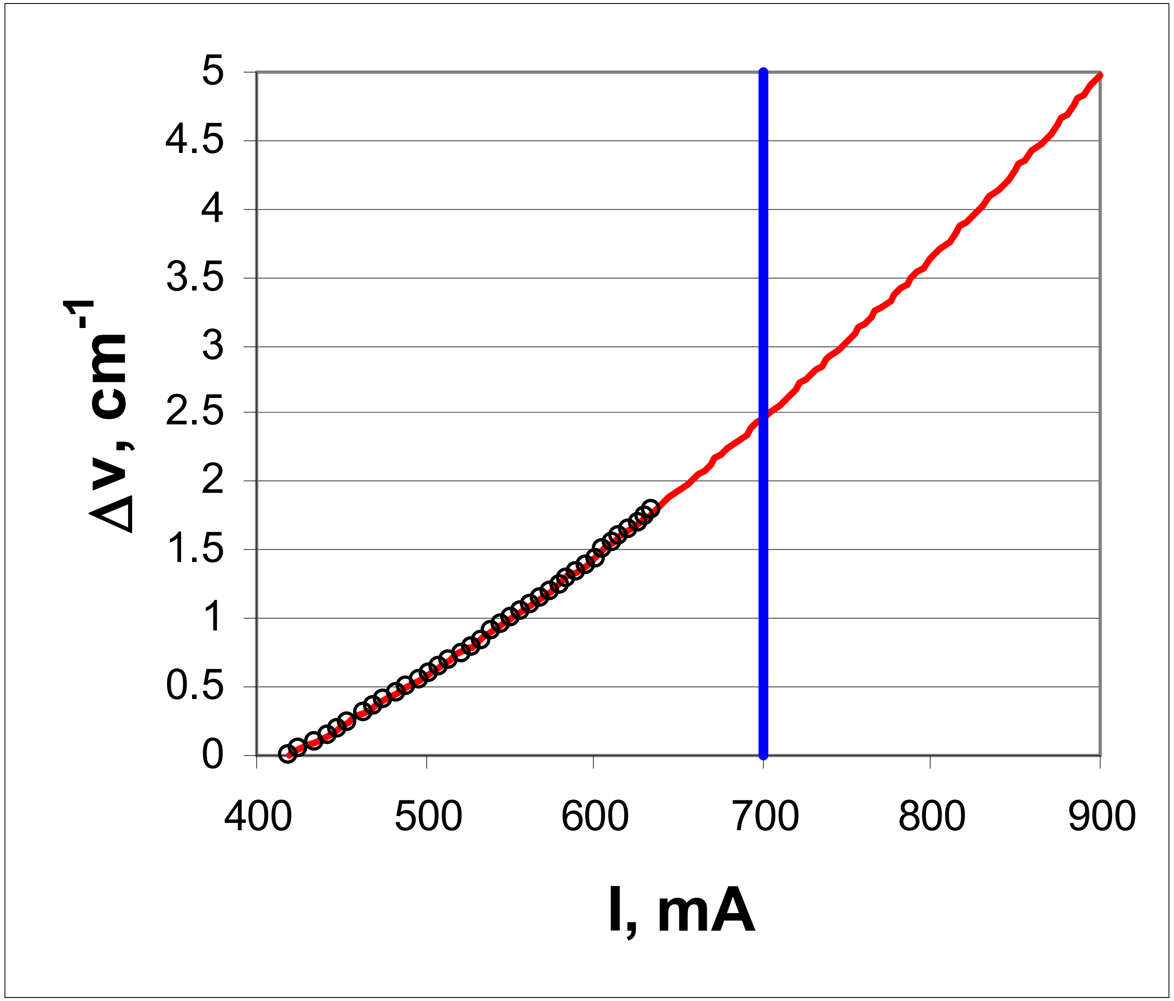
Red curve is normalized signal dependence with following parameters: I_{th} = 406.0 mA, $N_p(I_{th})$ = 26000. The last value is 30 times higher with respect to MIR DL (see D1) and explains QCL operation at room temperature.

QCL frequency tuning calibration



To determine QCL frequency tuning calibration 4 signals of reference channel were recorded:
Green – nothing in reference channel.
Blue – FP etalon.
Black – cell with C_2H_2.
Red – cell with CH_4.

QCL frequency current tuning



QCL frequency current tuning was measured using FP etalon spectrum (black circles).

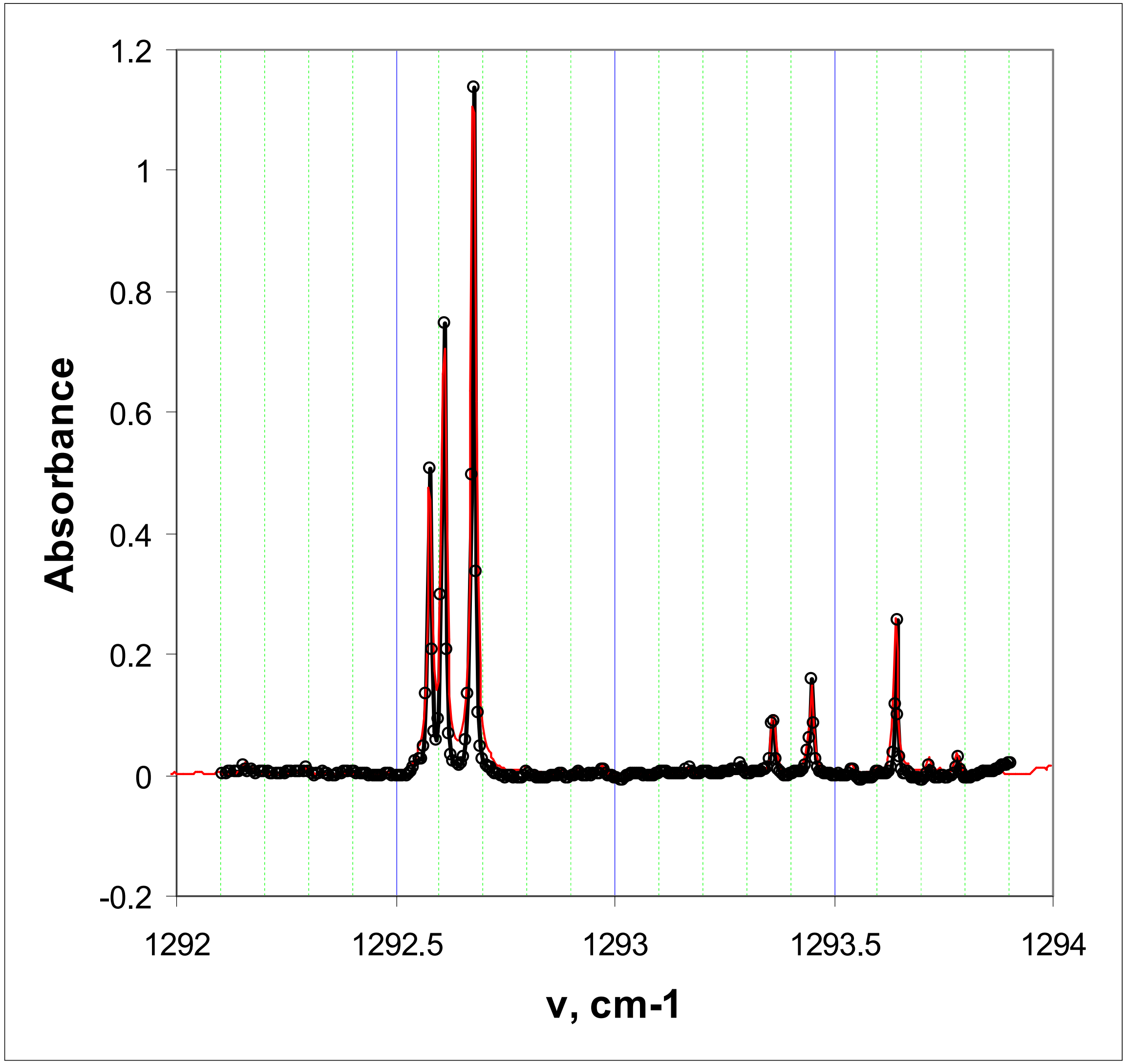
It is proportional to excitation current heat dissipation (red curve).

For maximum excitation current declared by supplier 700 mA (blue vertical line) current tuning is 2.5 cm^{-1}.

For 900 mA current tuning can achieve 5 cm^{-1}.

The last is question of QCL life time.

QCL spectral range identification



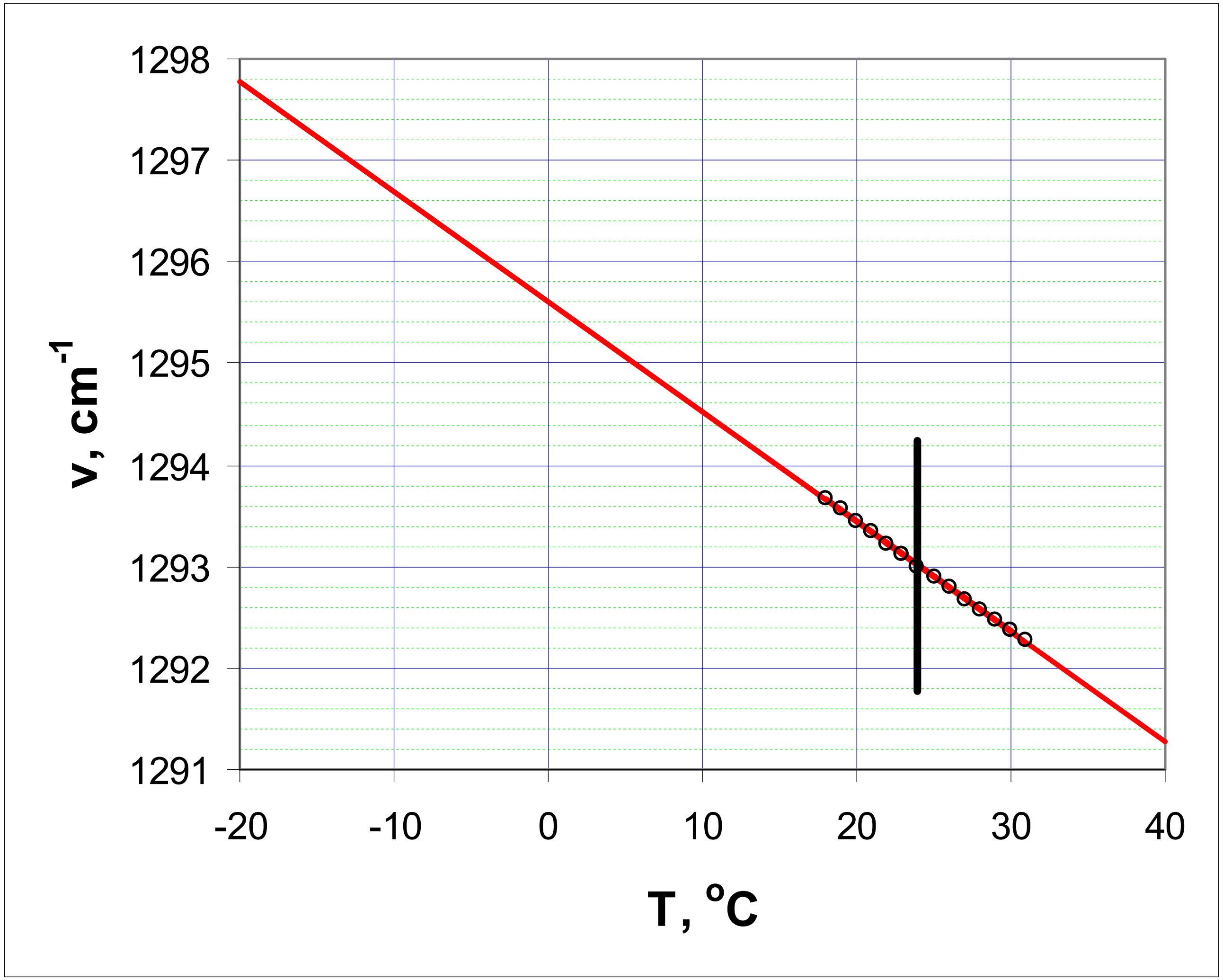
Black circles – recorded absorbance when cell with low pressure CH_4 was installed in reference channel.

Red curve - absorbance modeling using HITRAN 2008 spectral data base [3].

Conclusion: UF_6 spectral range of interest is covering by present QCL.

[3] http://www.cfa.harvard.edu/hitran/

QCL frequency tuning



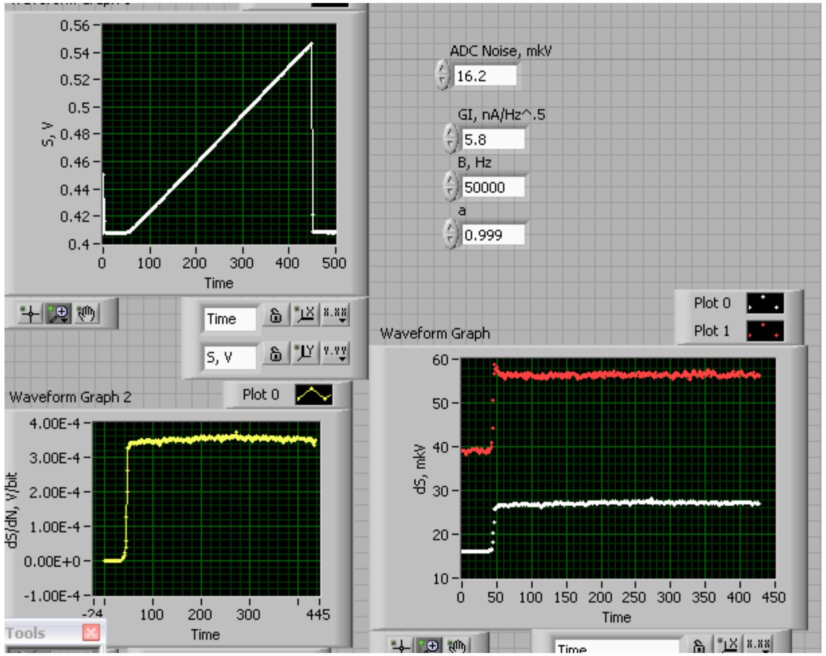
Using identified spectral lines temperature QCL frequency tuning calibration was performed.
Vertical black line corresponds to QCL current tuning for given temperature (see slide #10).

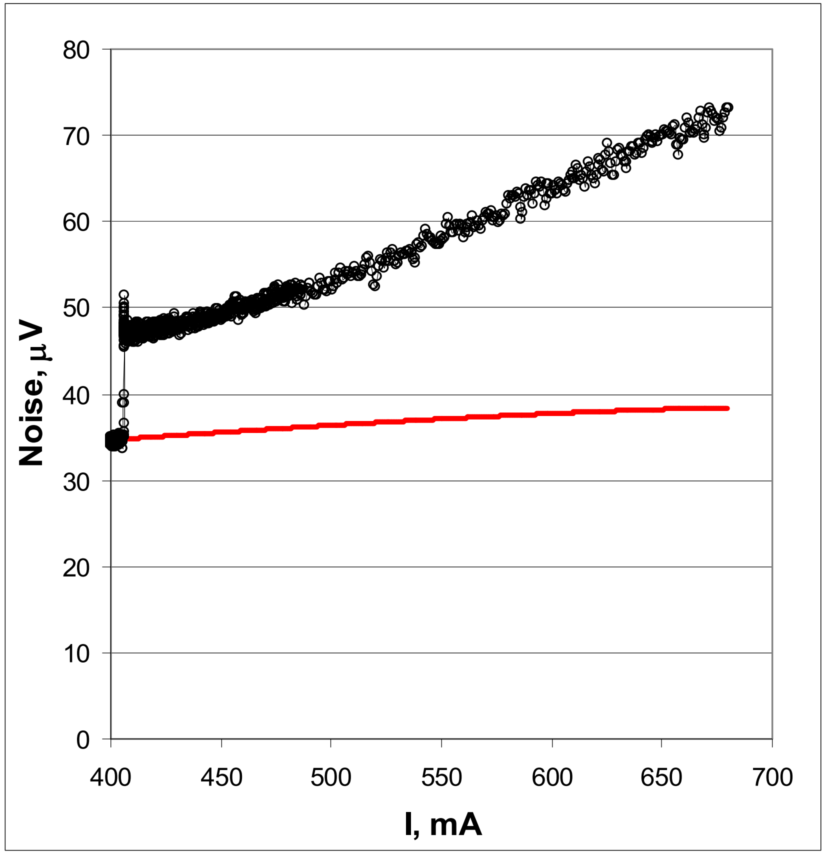
Conclusion: DFB QCL provides possibility of both current and temperature continuous frequency tuning for UF_6 enrichment measurement (see slide 3). QCL current tuning range increase is required.

QCL noise

Interface of “QCL Noise” software.

This software was developed to investigate signal and its noise near threshold.





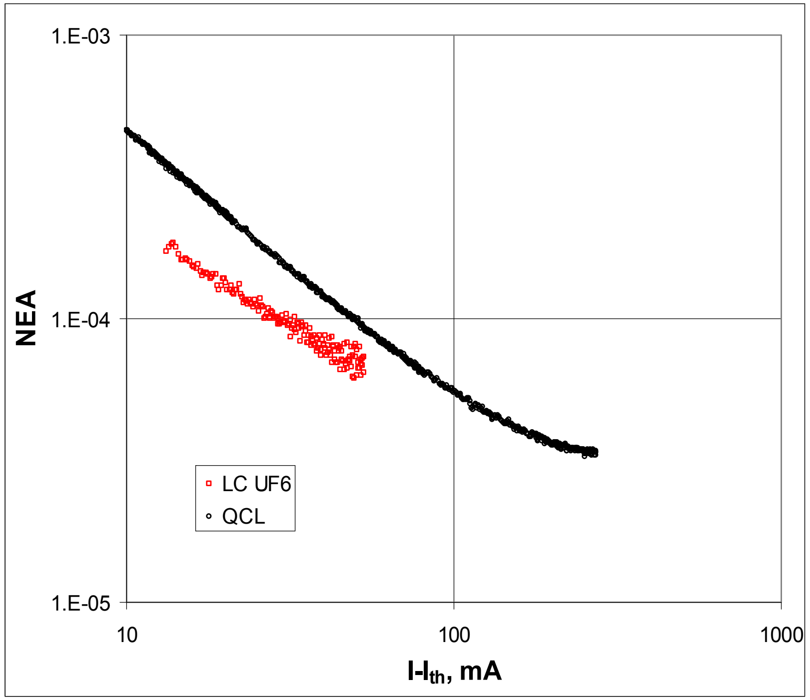
QCL signal noise as function of excitation current. Signal varied from 0 at threshold up to 5 V for 680 mA.

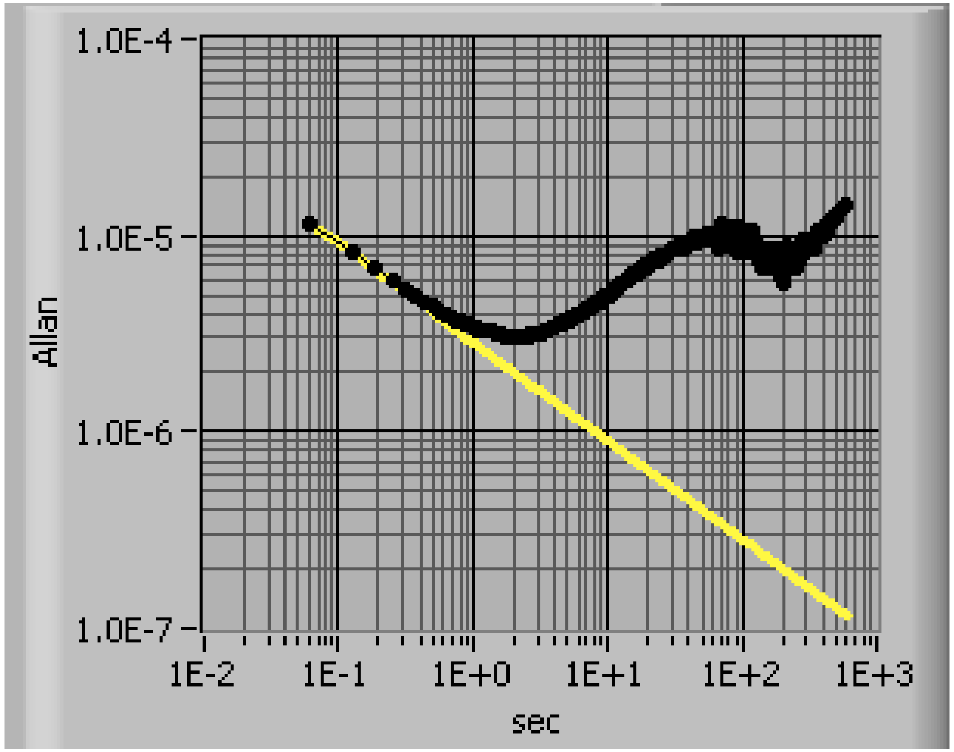
Usually TDLS in MIR spectral range is limited by PD noise (red). It was found that excitation current shot noise dominates for QCL (see B1, D1 for details).

QCL NEA

Noise Equivalent Absorbance - NEA (relative photocurrent noise) is measure of TDLS detectivity.

NEA as function of excitation current value above threshold for single measurement. For MIR DL (red) NEA is limited by PD noise. For QCL (black) additional noise can be observed.



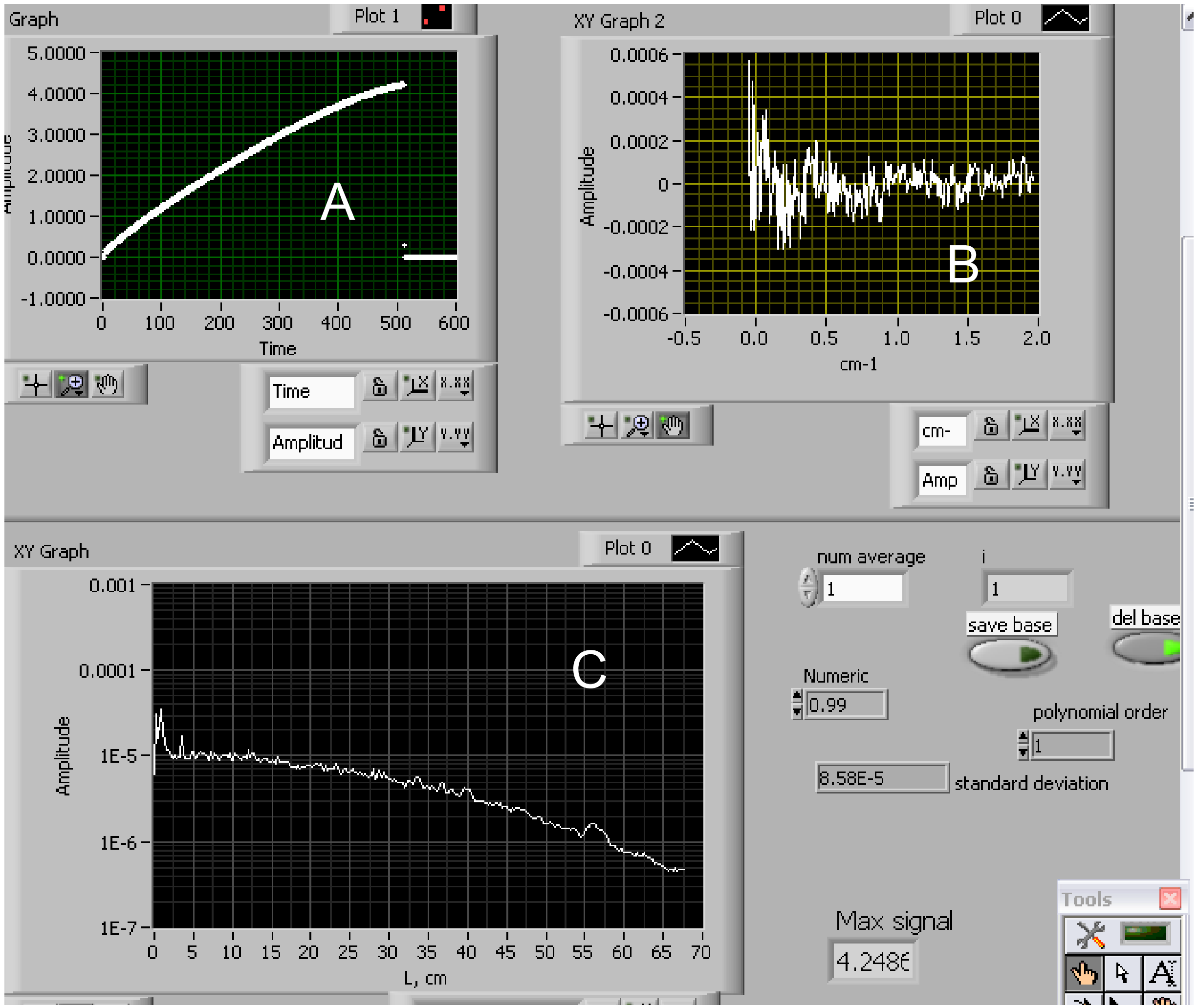


“QCL Allan” software interface.

NEA as function of averaging time.

NEA = 3 10^{-6} can be achieved for 2 sec averaging time. Then drift can be observed.

QCL Baseline



Interface of “QCL Baseline” software.
A – Signal; B – Baseline;
C – Baseline FFT.
Smoothed curve in graph C is due to signal noise. Some peaks can be observed for different distances – L to be compared with set up configuration. Two peaks (56 and 3.5 cm) can be attributed to interference of scatted light. There are no surfaces at distance 0.5 – 1.5 cm. Possible explanation – standing wave determined by DFB interaction with QCL facets.

Conclusions: better alignment is needed to suppress interference; QCL frequency cycles stabilization has to be used.

Conclusion

QCL developed to measure UF_6 enrichment was tested.
Test software set was developed to investigate QCL parameters.
QCL module was redesign to achieve satisfactory temperature stabilization performance.
QCL quantum efficiency and threshold were measured. From threshold time dependence QCL life time was estimated – 5 years.
QCL photons number at threshold was determined $N_p(I_{th}) = 26000$ being orders of magnitude larger with respect to other DL types.
QCL frequency temperature and current tuning was calibrated. It is good enough for UF_6 enrichment measurements.
QCL noise was investigated. Excitation current shot noise is dominant one for QCL.
NEA = 3 10^{-6} was achieved for 2 sec averaging time close to IAEA requirements.
QCL Baseline was investigated. New Baseline type was observed. Approach of it suppression was proposed.