Jaunu čukstošās galerijas modu mikrorezonatoru izstrāde optisko frekvenču standartu un biosensoru pielietojumiem, un to raksturošana ar femtosekunžu optisko frekvenču ķemmi

Projekta 9. atskaite par paveikto periodā

01.03.2019.- 31.05.2019.

I. Brice
A. Atvars
R. Viter.
J. Alnis

NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020

EIROPAS SAVIENĪBA
Eiropas Reģionālās attīstības fonds

IEGULDĪJUMS TAVĀ NĀKOTNĒ

ERAF projekts Nr. 1.1.1.1/16/A/259

Par projektu

- **Projekta nosaukums:** Jaunu čukstošās galerijas modu mikrorezonatoru izstrāde optisko frekvenču standartu un biosensoru pielietojumiem, un to raksturošana ar femtosekunžu optisko frekvenču ķemmi.
- **Projekta numurs:** 1.1.1.1/16/A/259
- **Projekta mērķis:** jaunu zināšanu-zinātības iegūšana CGM rezonatoru izstrādē, stabilizēšanā un modelēšanā, un rezonatoru izmantošanā biomolekulu detektēšanai, tādējādi atbalstot Latvijas Viedās specializācijas mērķu sasniegšanu, zinātnes un tehnoloģiju cilvēkkapitāla attīstību un jaunu zināšanu radīšanu tautsaimniecības konkurētspējas uzlabošanai.

- **Projekta vadītājs:** J. Alnis
- **Projekta administratīvais vadītājs:** I. Brice
- Projektu realizē LU ASI kvantu optikas laboratorija

- **Plānotie projekta galvenie rezultāti:** 4 publikācijas, 3 zinātību apraksts, 1 licences līgums.
- Paredzēti 9 konferenču apmeklējumi un 6 zinātniskās vizītes
- **Projekta īstenošanas laiks:** 01.03.2017. - 29.02.2020.

Darbinieki

- Vadošie pētnieki
  - J. Alnis
  - A. Atvars
  - R. Viter
- Zinātniskie asistenti
  - I. Brice
- Laboranti
  - K. Grundšteins
  - K. Draguns

Kvantu optikas laboratorijas kopbilde 2019. gada februāris.

Projekta budžets

Projekta kopējās izmaksas: 648 252,61 EUR, to skaitā ERAF finansējums (85%) - 551 014,72 EUR.

- Izdevumi MP1 – 33 108.93 EUR
- Izdevumi MP2 – 46 967.37 EUR
- Izdevumi MP3 –
  - pieprasīti 50 218.34 EUR
  - apstiprināti 50 168.34 EUR
- Izdevumi MP4 – 19 164.77 EUR
- Izdevumu MP5 - 38 392.16 EUR
- Izdevumu MP6 - 84 367.70 EUR
- Izdevumi MP7 - 78 512.16 EUR
- Izdevumi MP8 - 34 725.76 EUR
- Izdevumi MP9 - 50 197.04 EUR
- Izdevumi MP10 - 78 897.21 EUR
  - Periods 01.01.2019.-31.05.2019.

Iepirkumi

- Comsol datorprogrammas iepirkums (izpildīts).

- Materiālu iegādes iepirkums 1 (izpildīts).

- Instrumentu nomas iepirkums (izpildīts).

- Materiālu iegādes iepirkums 2 (procesā):

- biokīmisko materiālu iegāde 2 (procesā)

- dažādi materiāli izpētes stendu izveidei (optika, mehānika, elektronika, materiāli u.tml.) 2 (izpildīts)

Sasniegtie rezultāti

Nr.	Rādītāja nosaukums	Plānotā vērtība	Sasniegtā vērtība	Mērvienība	Komentārs
2.	Zinātnisko rakstu skaits, kuru izstrādei un publicēšanai sniegts atbalsts projekta ietvaros	5	2	Zinātnisko rakstu skaits	1 publicēts 1 iesniegts
2.1.	Žurnālos vai konferenču rakstu krājumos, kuru citēšanas indekss sasniedz vismaz 50 procentus no nozares vidējā citēšanas indeksa	4	1	Zinātnisko rakstu skaits	1 iesniegts
3.1.	Jauna produkta vai tehnoloģijas prototips	3	0	Prototipu skaits	Tiek rakstīta tehniskā specifikācija
4.	Tehnoloģiju tiesības	3	0	Skaits	
5.	Intelektuālā īpašuma licences līgumi	1	0	Skaits	
6.	Privātās investīcijas, kas papildina valsts atbalstu inovācijām vai pētniecības un izstrādes projektiem	32412.63	**31 701.74**	EUR	
8.	Citi pētījuma specifikai atbilstoši projekta rezultāti (t.sk. dati), kas papildina rezultātu rādītājos Nr. 2., 3.1., 4., 5. minētos rezultātus	41	30	Skaits	

Konferenes/vizītes

R. Viter devās vizītē uz Gdaņskas Universitāti Polijā

- ar 1550 nm gaismas avotu dažādās vidēs ar dažādiem refrakcijas rādītājiem tika testēti ČGMR
    - pārklāti ar Au nanodaļiņām
    - pārklāti ar PANI
- ar 785nm ierosmes avotu tika mērīta arī virsmas pastiprināta Raman spektroskopija
- Jauni ČGMR pārklāšanai ar N-dopētām nanodaļiņām

Konferenes/vizītes

J. Alnis piedalījās konferencē par atsevišķu molekulu detektēšanu **Single molecule sensors and nanosystems** (S3IC) 3.-5. Apr. 2019.
https://premc.org/conferences/s3ic2019/

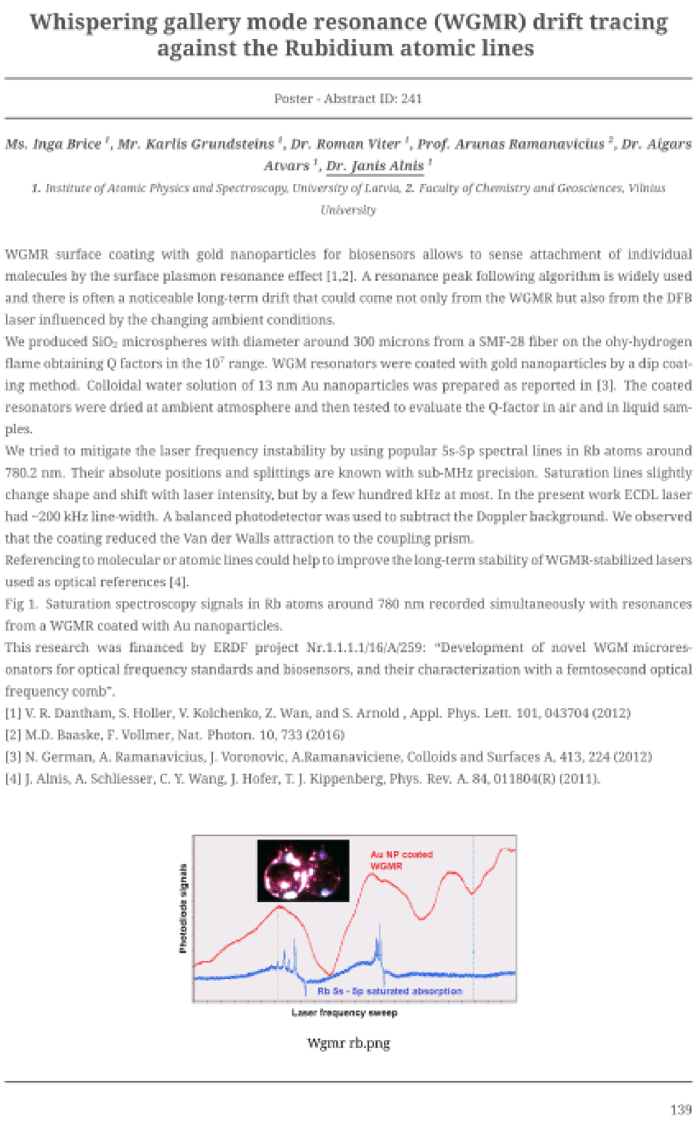
Konferencē ap 100 dalībnieki.

Starpbrīžos izstādē varēja uzzināt par jaunākajiem lāzeriem.

Organizators Prof. Frank Volmer ir eksperts par ČGM mikrorezonatoriem.

Abstrakts un plakāts no konferences

Single molecule sensors and nano-systems



Whispering gallery mode resonance (WGMR) drift tracing against the Rubidium atomic lines

Poster - Abstract ID: 241

Ms. Inga Brice [1], Mr. Karlis Grundsteins [1], Dr. Roman Viter [1], Prof. Arunas Ramanavicius [2], Dr. Aigars Atvars [1], Dr. Janis Alnis [1]

1. Institute of Atomic Physics and Spectroscopy, University of Latvia, 2. Faculty of Chemistry and Geosciences, Vilnius University

WGMR surface coating with gold nanoparticles for biosensors allows to sense attachment of individual molecules by the surface plasmon resonance effect [1,2]. A resonance peak following algorithm is widely used and there is often a noticeable long-term drift that could come not only from the WGMR but also from the DFB laser influenced by the changing ambient conditions.

We produced SiO_2 microspheres with diameter around 300 microns from a SMF-28 fiber on the ohy-hydrogen flame obtaining Q factors in the 10^7 range. WGM resonators were coated with gold nanoparticles by a dip coating method. Colloidal water solution of 13 nm Au nanoparticles was prepared as reported in [3]. The coated resonators were dried at ambient atmosphere and then tested to evaluate the Q-factor in air and in liquid samples.

We tried to mitigate the laser frequency instability by using popular 5s-5p spectral lines in Rb atoms around 780.2 nm. Their absolute positions and splittings are known with sub-MHz precision. Saturation lines slightly change shape and shift with laser intensity, but by a few hundred kHz at most. In the present work ECDL laser had ~200 kHz line-width. A balanced photodetector was used to subtract the Doppler background. We observed that the coating reduced the Van der Walls attraction to the coupling prism.

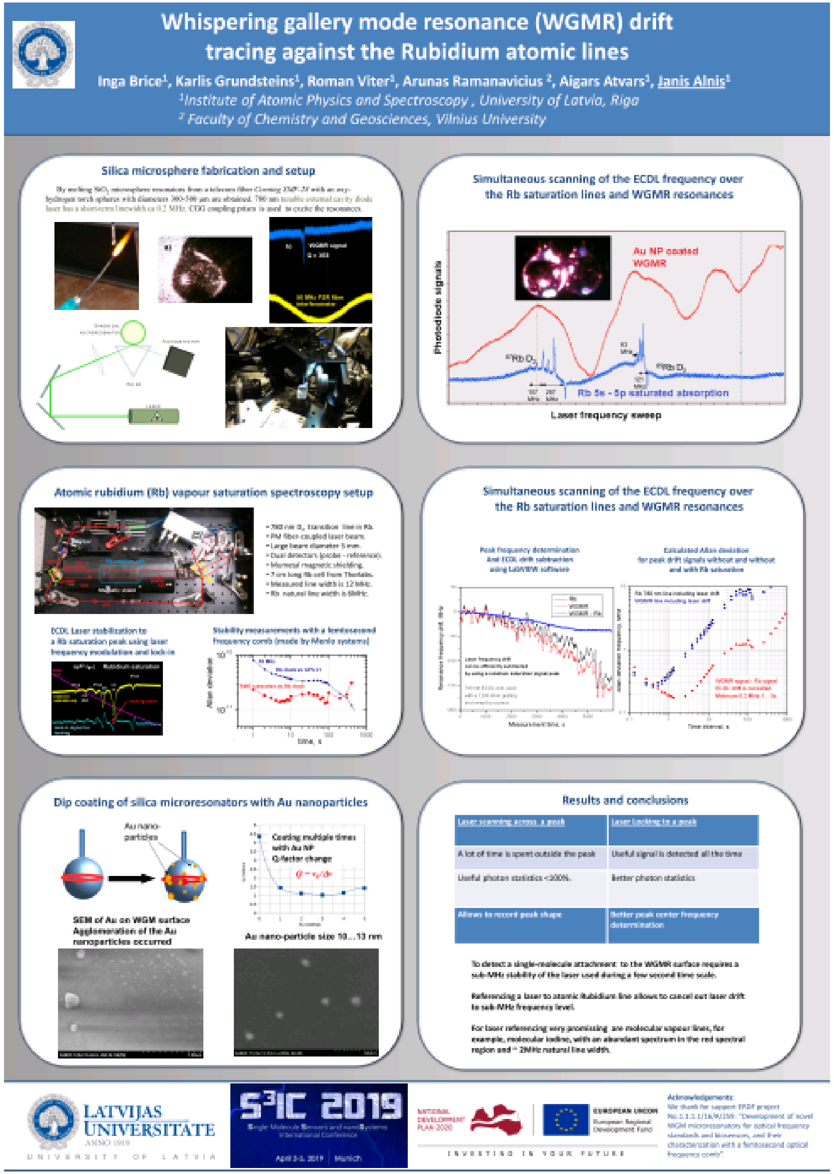
Referencing to molecular or atomic lines could help to improve the long-term stability of WGMR-stabilized lasers used as optical references [4].

Fig 1. Saturation spectroscopy signals in Rb atoms around 780 nm recorded simultaneously with resonances from a WGMR coated with Au nanoparticles.

This research was financed by ERDF project Nr.1.1.1.1/16/A/259: "Development of novel WGM microresonators for optical frequency standards and biosensors, and their characterization with a femtosecond optical frequency comb".

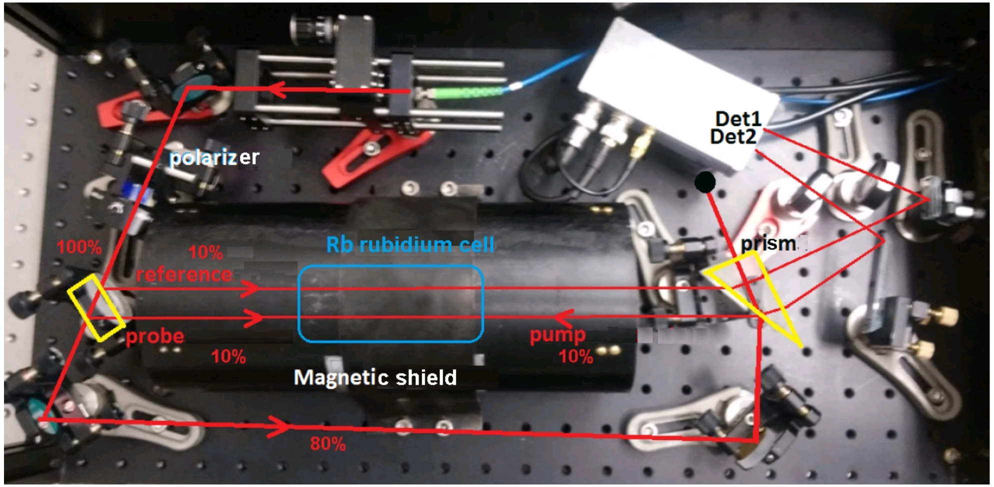
[1] V. R. Dantham, S. Holler, V. Kolchenko, Z. Wan, and S. Arnold , Appl. Phys. Lett. 101, 043704 (2012)
[2] M.D. Baaske, F. Vollmer, Nat. Photon. 10, 733 (2016)
[3] N. German, A. Ramanavicius, J. Voronovic, A.Ramanaviciene, Colloids and Surfaces A, 413, 224 (2012)
[4] J. Alnis, A. Schliesser, C. Y. Wang, J. Hofer, T. J. Kippenberg, Phys. Rev. A. 84, 011804(R) (2011).

Wgmr rb.png



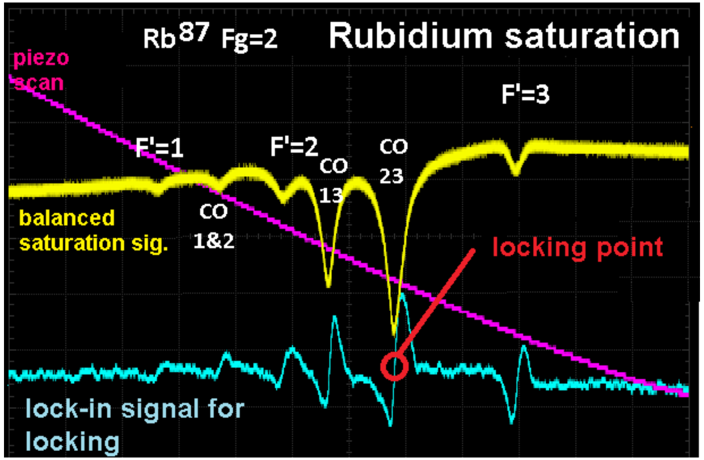
ČGMR rezonatora līniju referencēšana pret rubīdija atomu pāreju, lai atbrīvotos no lāzera frekvences nestabilitātēm.

Atomic rubidium (Rb) vapour saturation spectroscopy at LU ASI

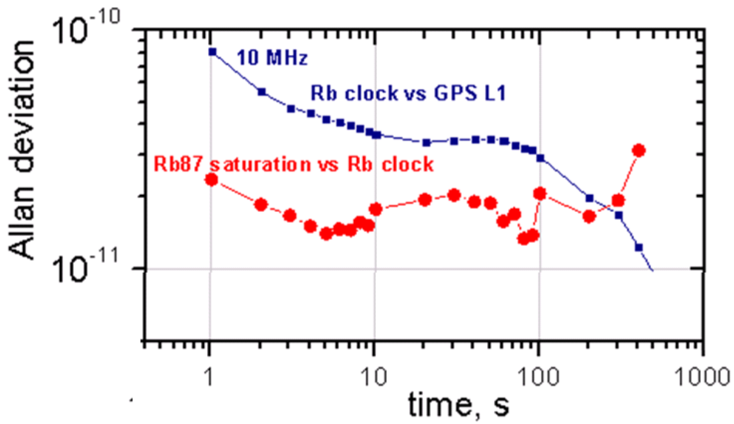


- 780 nm D_2 transition line in Rb
- PM fiber-coupled laser beam
- Large beam diameter 5 mm.
- Dual detectors (probe - reference)
- Mumetal magnetic shielding
- 7 cm long Rb cell from Thorlabs
- Measured linewidth 12 MHz
- Rb natural linewidth 6MHz

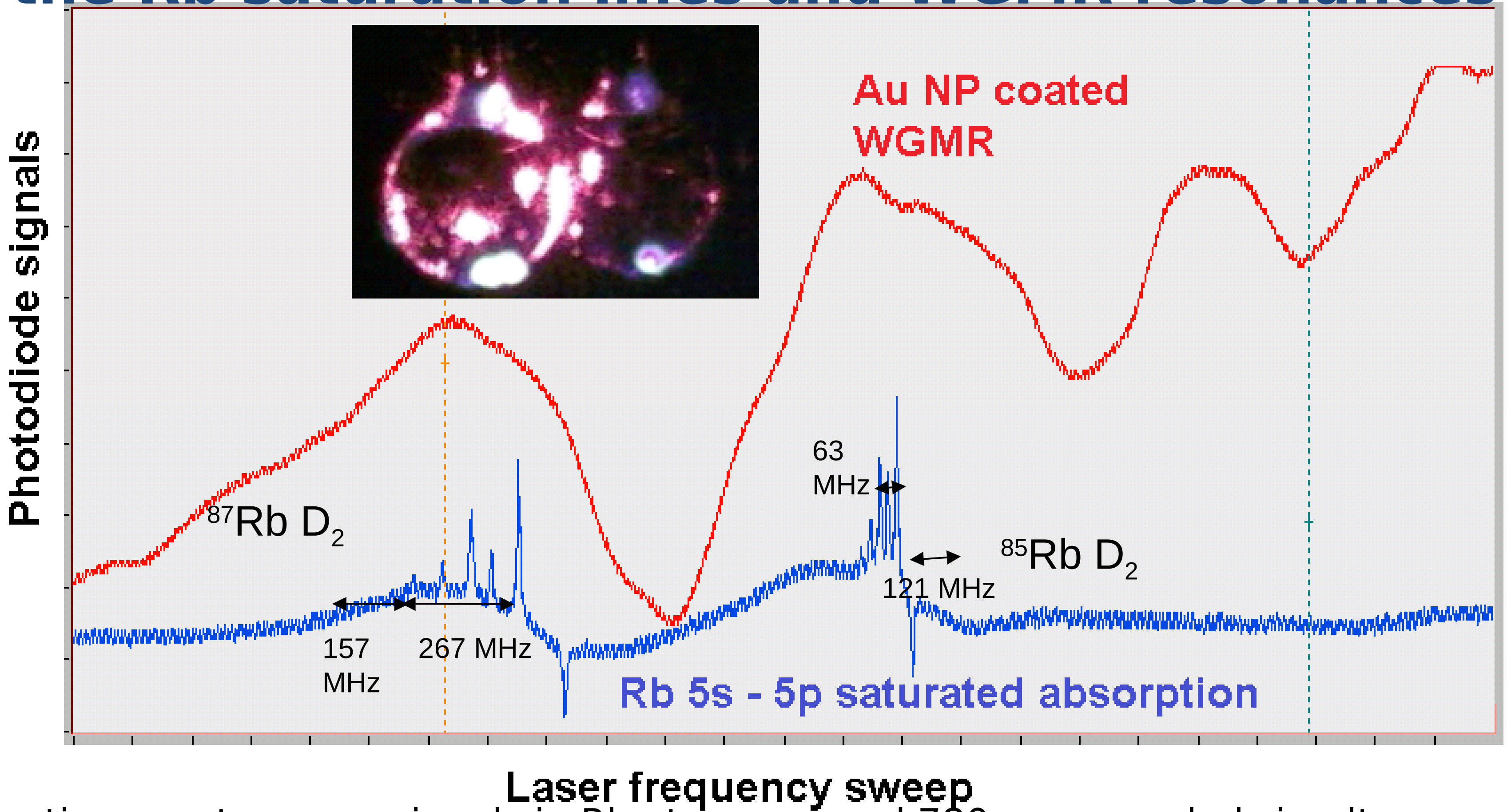
ECDL Laser stabilization to a Rb saturation peak with a lock-in



Stability measurements with a femtosecond frequency comb (made by *Menlo systems*)



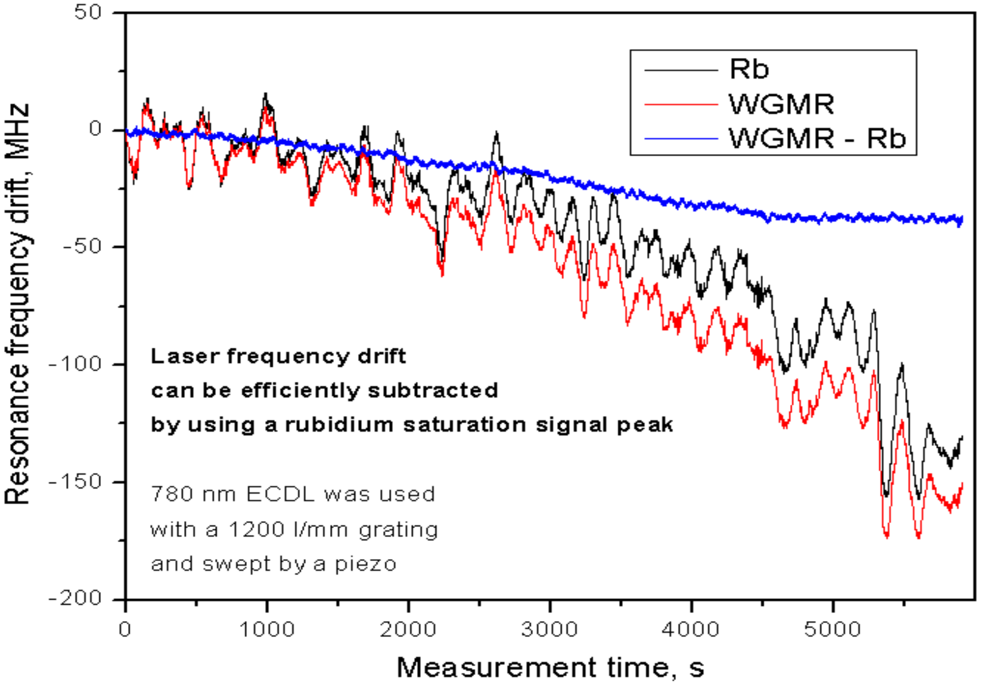
Simultaneous scanning of the ECDL frequency over the Rb saturation lines and WGMR resonances



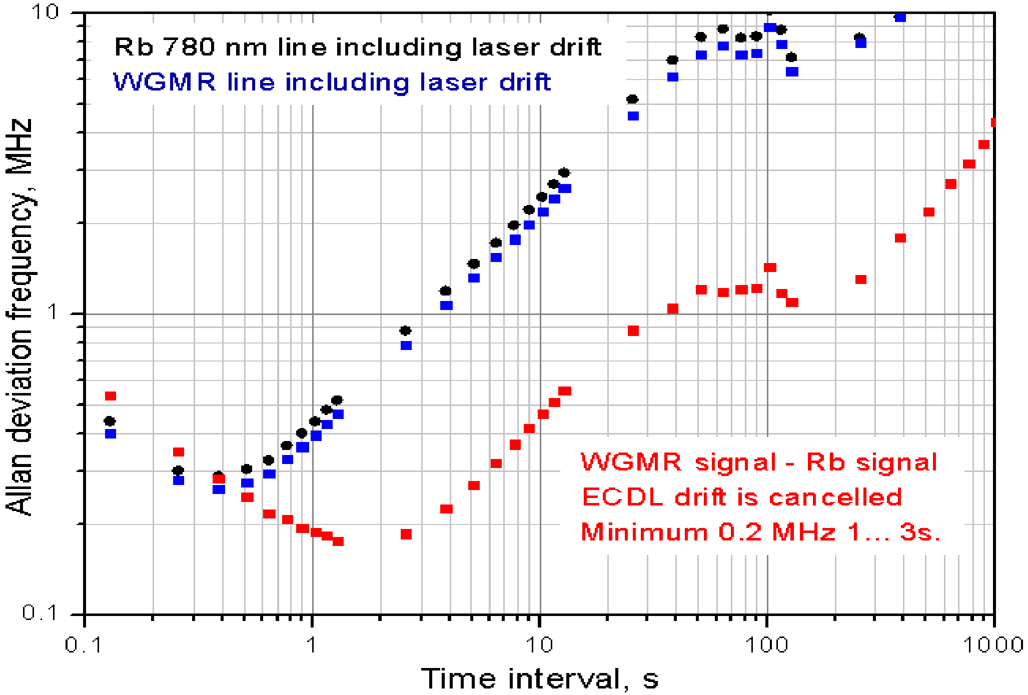
Saturation spectroscopy signals in Rb atoms around 780 nm recorded simultaneously with resonances from a WGMR coated with Au nanoparticles.

Stability of the simultaneous scanning of the ECDL frequency over the Rb saturation lines and WGMR resonances

Peak frequency determination and ECDL drift subtraction using LabVIEW software



Calculated Allan deviation for peak drift signals without and with Rb saturation



Results and conclusions of the method involving Rb lines

Laser scanning across a peak	Laser Locking to a peak
A lot of time is spent outside the peak	Useful signal is detected all the time
Useful photon collection is only during the peak crossing	Better photon statistics
Allows to record peak shape	**Better peak center frequency determination**

Referencing a laser to an atomic or molecular line allows to cancel out laser drift to sub-MHz frequency level.

Single-molecule attachment detection to the surface of WGMR requires a sub-MHz stability of the laser used during a few second time scale.

More promising than Rb are molecular lines, for example, molecular Iodine lines being abundant in the red spectral region.

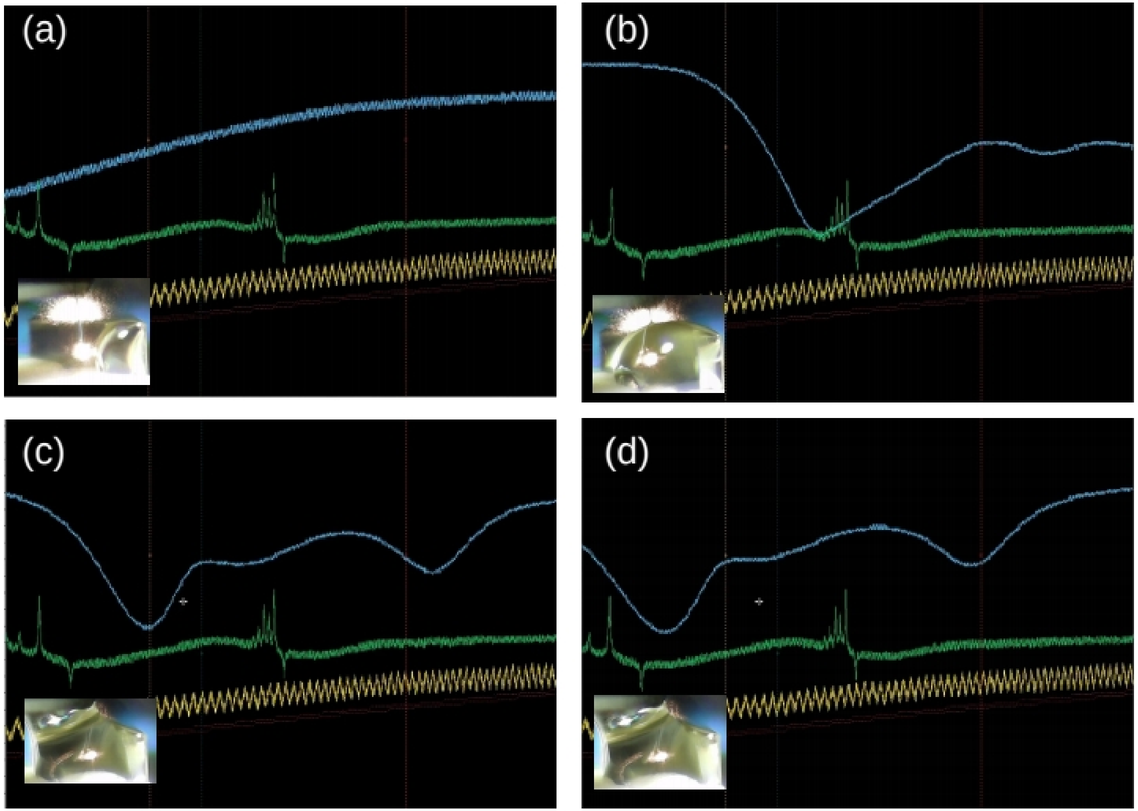
Activities

-Developed new setup for electrospray pyrolysis deposition.

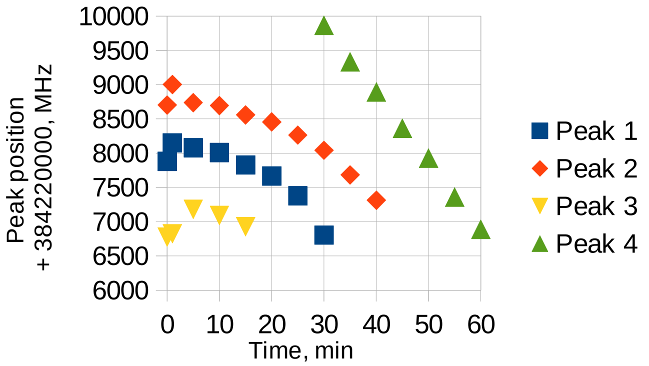
-New set of samples of ZnO on WGMR

-Analysis of Au-WGMR sensor response to glucose

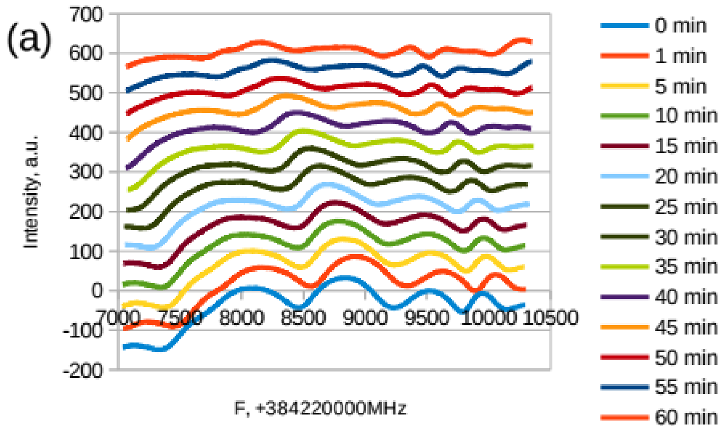
Glucose sensor

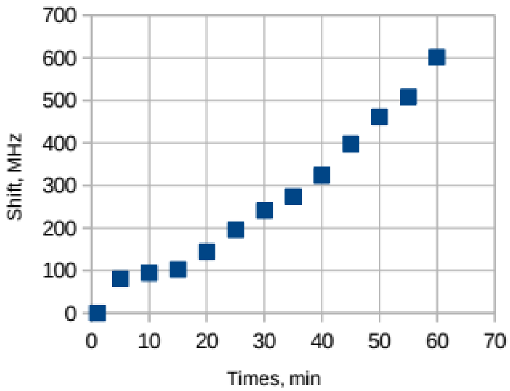


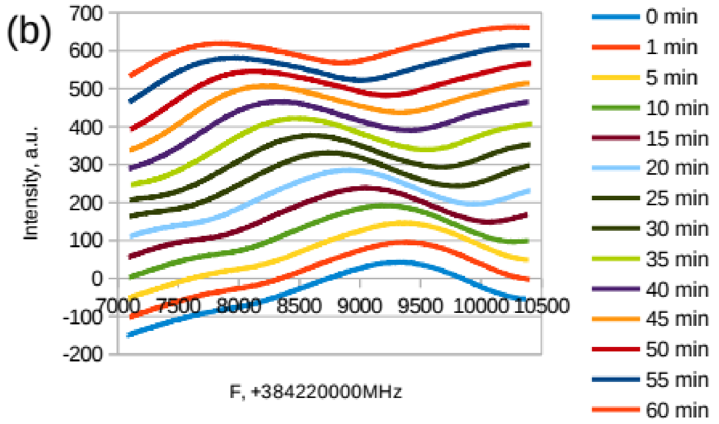
Yellow signal is interference fringes, green - Rb saturation spectroscopy and blue is the WGM resonance specter (a) in air and no resonance dips can be seen, (b) WGM in buffer solution with resonance dips, (c) and (d) in glucose solution where resonances drift in time to the left.

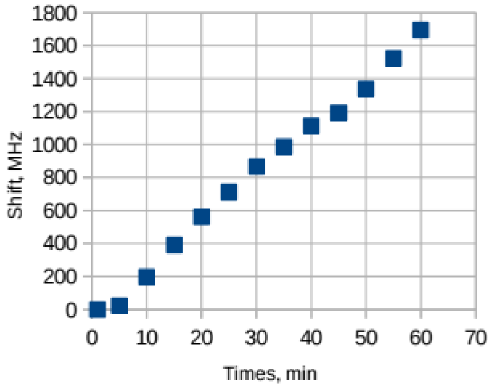


Au nanoparticles VS PANI glucose sensor





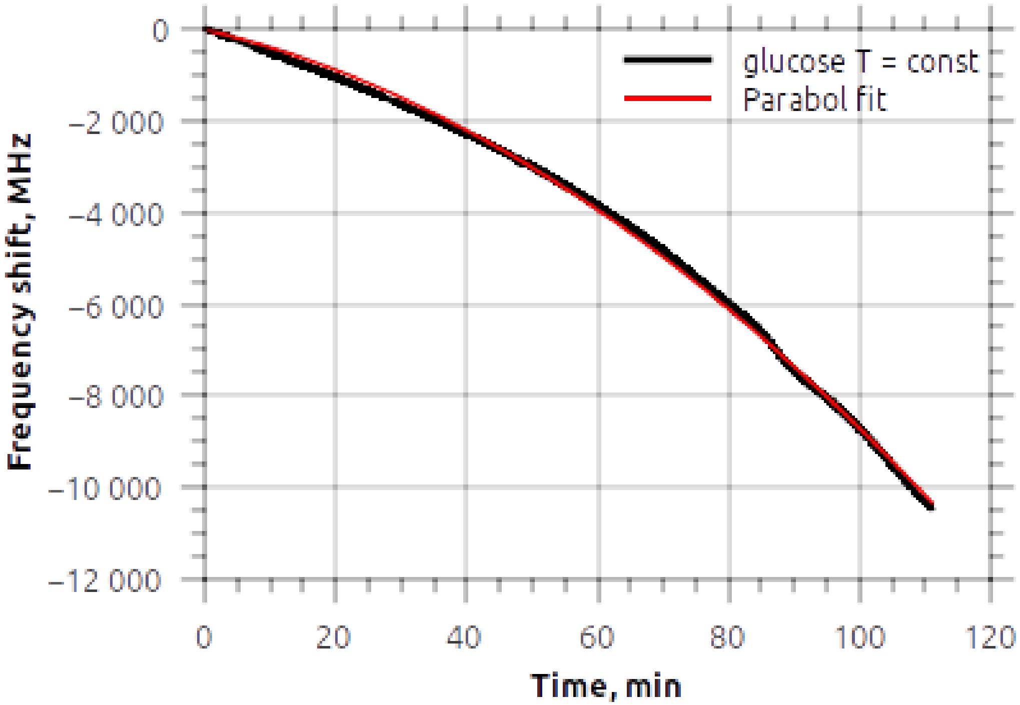




Microsphere WGMR in same concentration glucose solution (a) Au nanoparticle gluose sensor WGM resonance shift, (b) PANI gluose sensor WGM resonance shift.

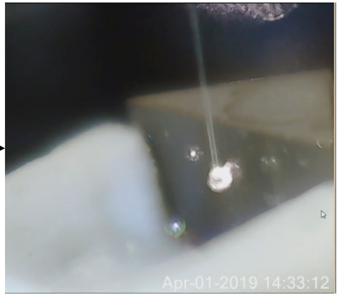
PANI has lower quality factor and broader resonances but the they appear to shift faster

Shift induced by evaporation of glucose drop



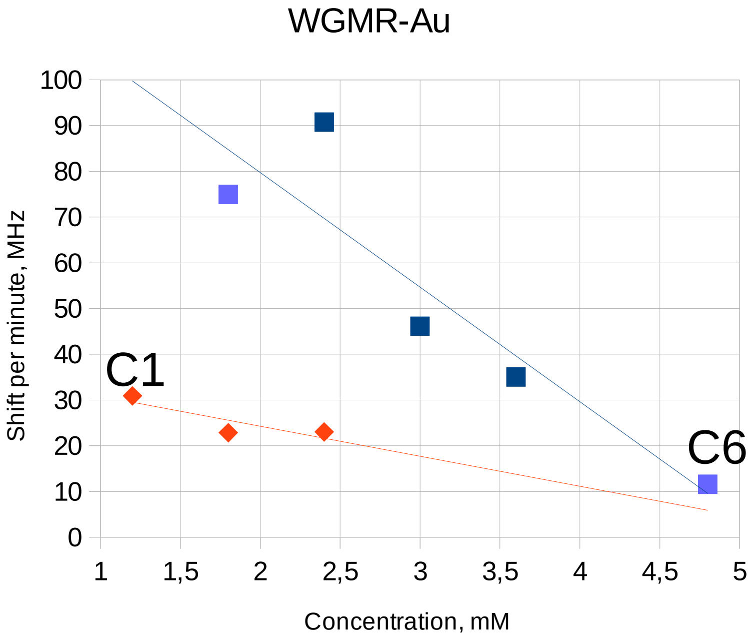
Evoparation is important when working with liquid drops.

To separate or refuce the evaporation effects from sensor behavior:
1) increase volume of liquid drop;
2) perform control measurments;
3) reduce the measurement time.

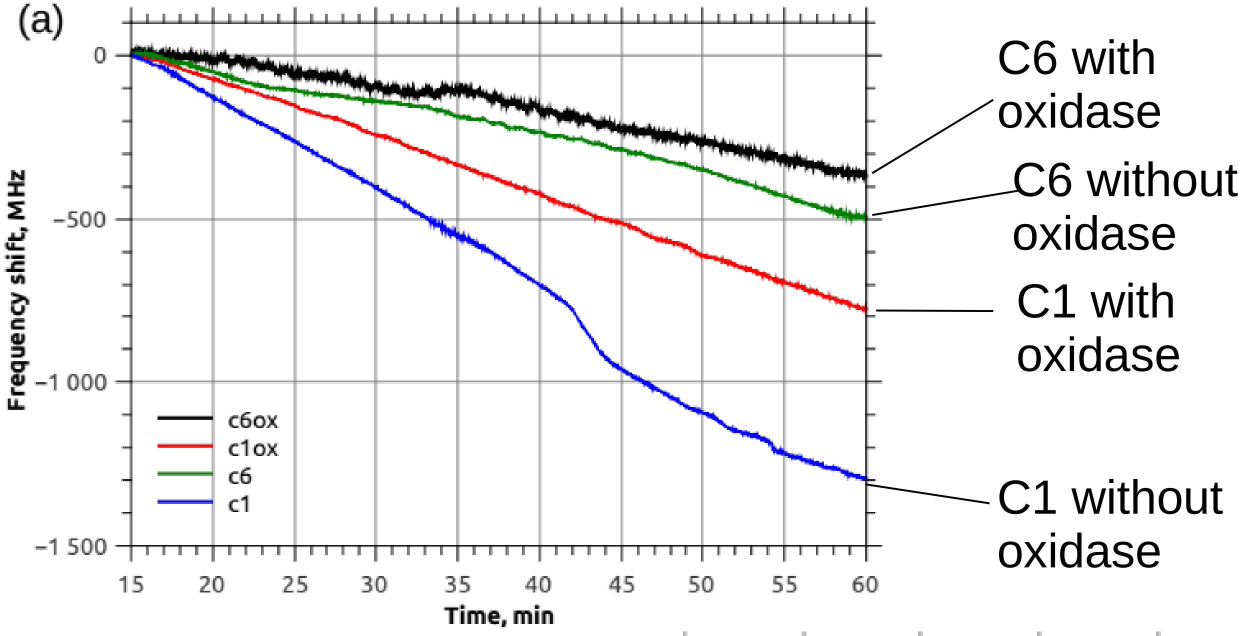


Bigger teflon bath

WGMR-Au Glucose sensor resonance shift speed per 1 min



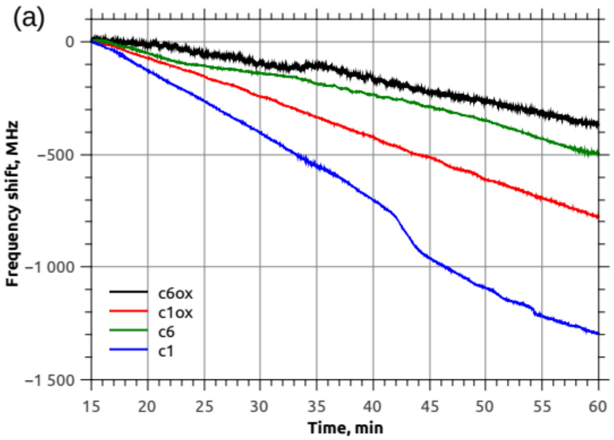
Blue squares Day 1 fresh glucose oxidase,
Red Diamonds Day 2 once frozen glucose oxidase



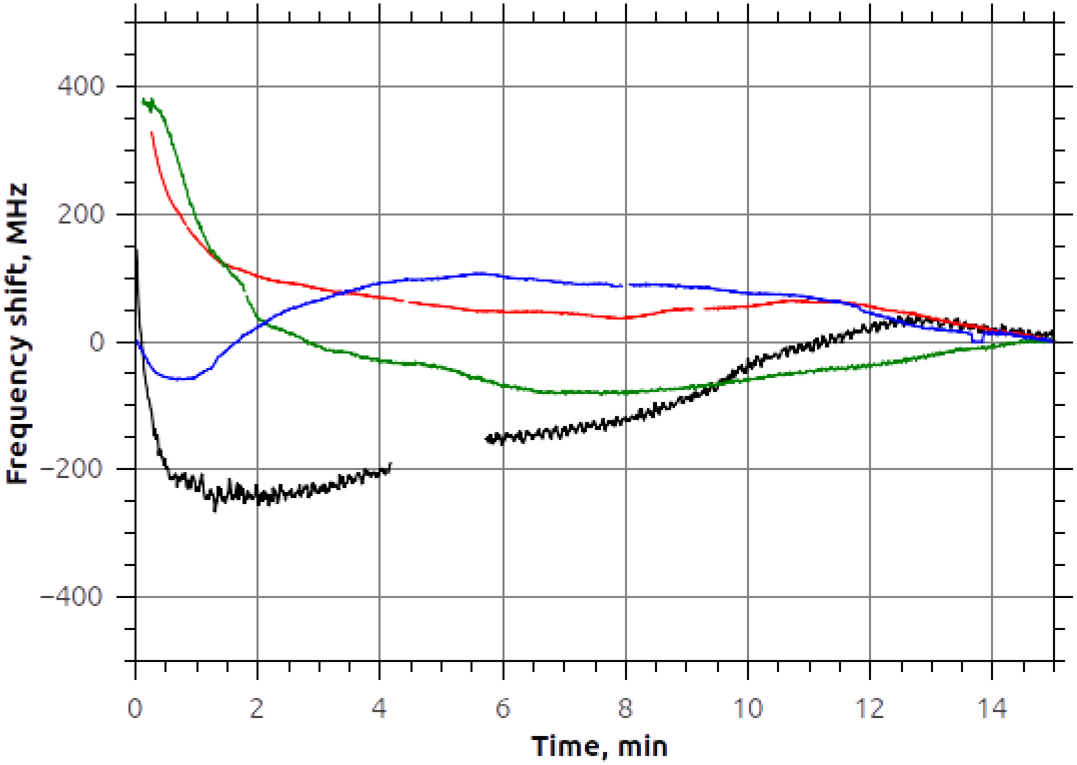
Control measurement performed with and without glucose oxidase

fit c6 ox(-7.41±0.02) MHz/min
fit c1 ox (-17.16±0.01) MHz/min
fit c6 (-10.20±0.01) MHz/min
fit c1 (-29.88±0.03) MHz/min

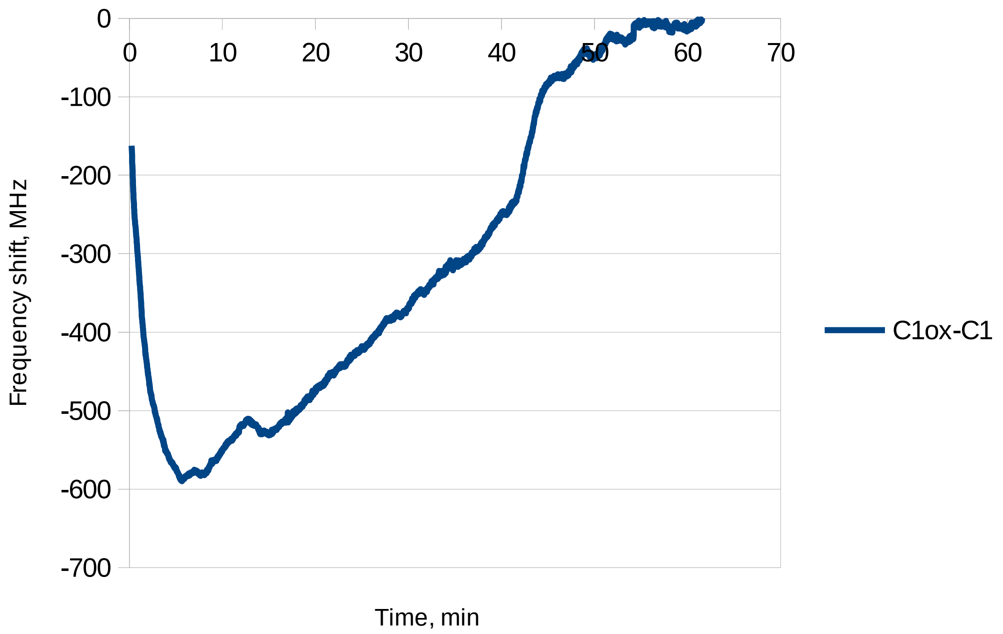
WGMR-Au Glucose sensor response might be a fast process

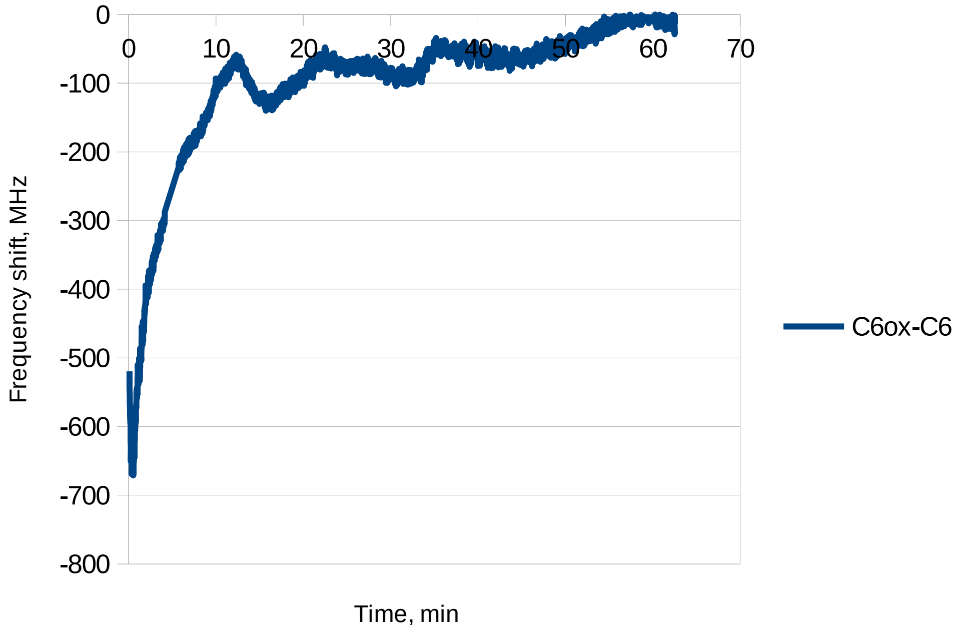


During a discussion with Prof. A. Ramanavičius it was suggested to concentrate more on the first minutes of glucose sensor experiment data acquirement.



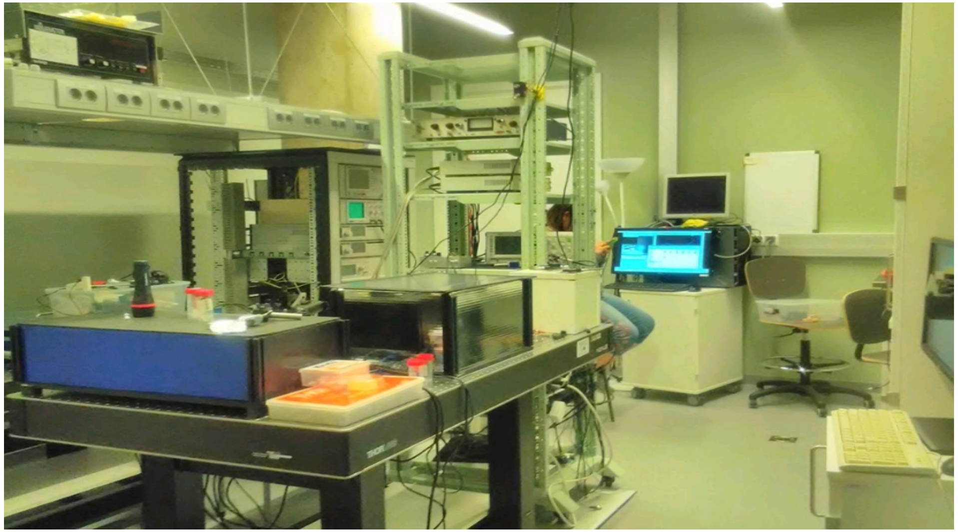
WGMR-Au Glucose sensor hidden signal

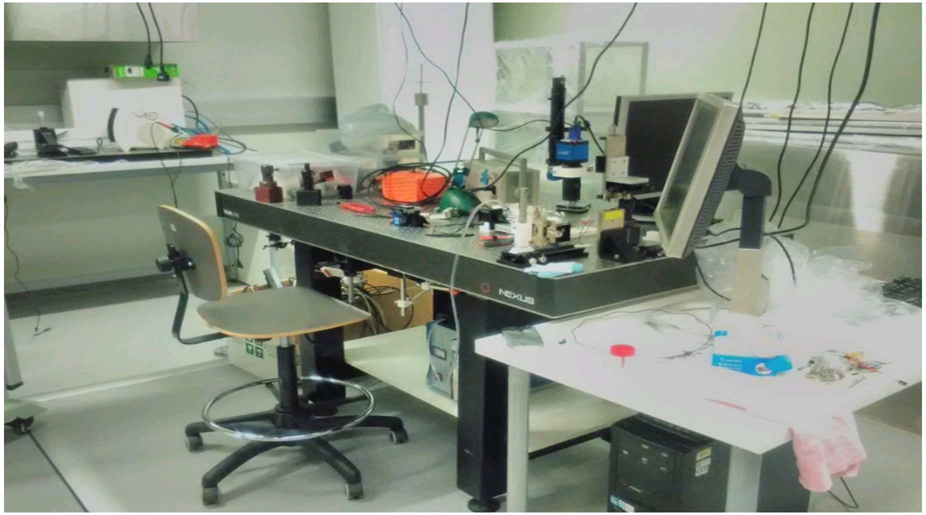




Curves of mesurment data – control mesurments also are important because they describe procese “hiding” under evaporation

Quantum Optics Lab successfully moved to the new LU Science building.
We have two rooms in the basement and one on the 6th floor.





ČGM rezonatoru modelēšana

01.03.2019 -
31.05.2019.

Dažādu modelēšanas pieeju salīdzināšana

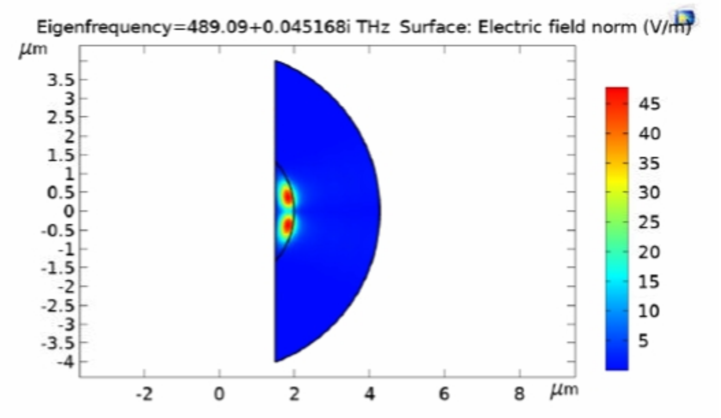
r = 2 μm; n = 1.5, N = 20

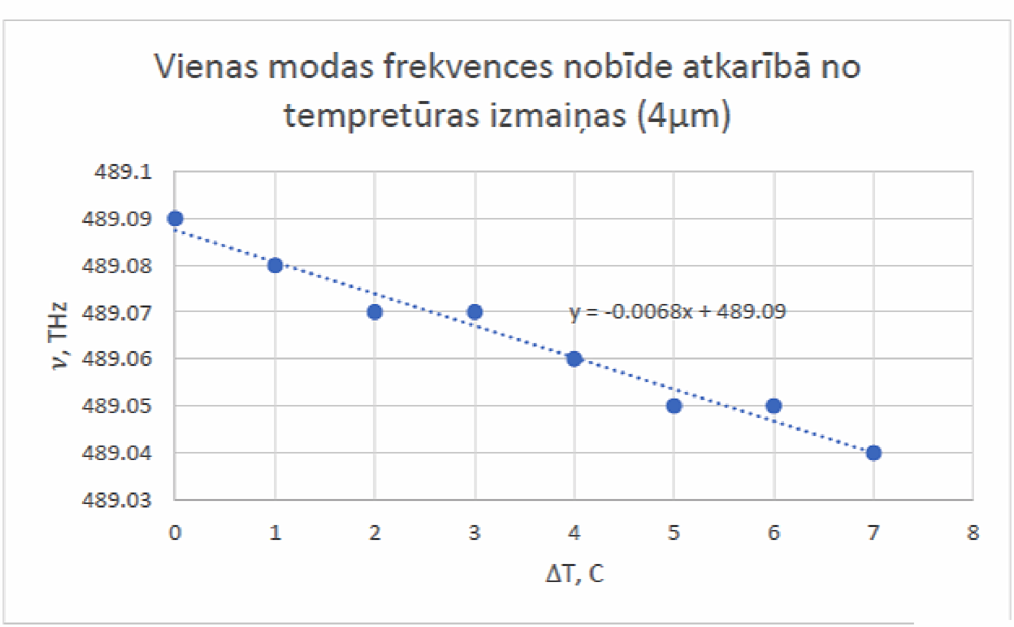
Aprēķina raksturojuma	Rezonanses λ, nm
$\lambda = \frac{2 * \pi * r * n}{N}$	942.48
as a series in $\nu^{-1/3}$, where $\nu = l + 1/2$: $$n x_{l,i} = \nu + 2^{-1/3}\alpha_i \nu^{1/3} - \frac{P}{(n^2-1)^{1/2}} + \left(\frac{3}{10}2^{-2/3}\right)\alpha_i^2 \nu^{-1/3} - \frac{2^{-1/3}P(n^2 - 2P^2/3)}{(n^2-1)^{3/2}}\alpha_i \nu^{-2/3} + O(\nu^{-1}), \quad (1.1)$$ where $$P = \begin{cases} n & \text{for TE modes} \quad (1.2a) \\ 1/n & \text{for TM modes} \quad (1.2b) \end{cases}$$ and α_i are the roots of the Airy function $\mathrm{Ai}(-z)$, presented in Table 1 for easy reference. Yang2015, doi: 10.1002/adom.201500232 (kļūda formulā -); precīzs - https://doi.org/10.1364/JOSAB.9.001585	772.01
COMSOL 2D Eigenfrequency, prism coupling	789.57
COMSOL 2D Eigenfrequency, frequency domain, fiber coupling, numeric port	790.1
COMOSL 2D Axialsymmetric, Eigenfrequency, sfēra	774.02
COMOSL 2D Axialsymmetric, Eigenfrequency, cilindrs, cilindra augstums = 8*r	791.61
COMOSL 2D Axialsymmetric, Eigenfrequency, cilindrs, cilindra augstums = 16*r	791.69

Rezonanšu pozīciju temperatūras atkarības modelēšana

$$n = n_o\left(1 + \beta(T - T_o)\right)$$
$$r = r_o(1 + \alpha(T - T_o))$$

n = 1.5, λ = 760 nm, r = 2 μm





$$\Delta\lambda \approx \frac{2 * \pi * r * n * (\alpha + \beta)\,\Delta T}{N}$$

$$\frac{\Delta\lambda}{\Delta T} \approx \lambda(\alpha + \beta)$$

Priekš SiO_2

$$\alpha = 12.8 \cdot 10^{-6}\ \frac{1}{K},$$

$$\beta = 0.55 \cdot 10^{-6}\ \frac{1}{K}.$$

Vienkāršais modelis uzrāda, ka īpašfrekvences nobīde atkarībā no temperatūras nav atkarīga no rezonatora izmēra

Rezonanšu pozīciju temperatūras atkarības modelēšana

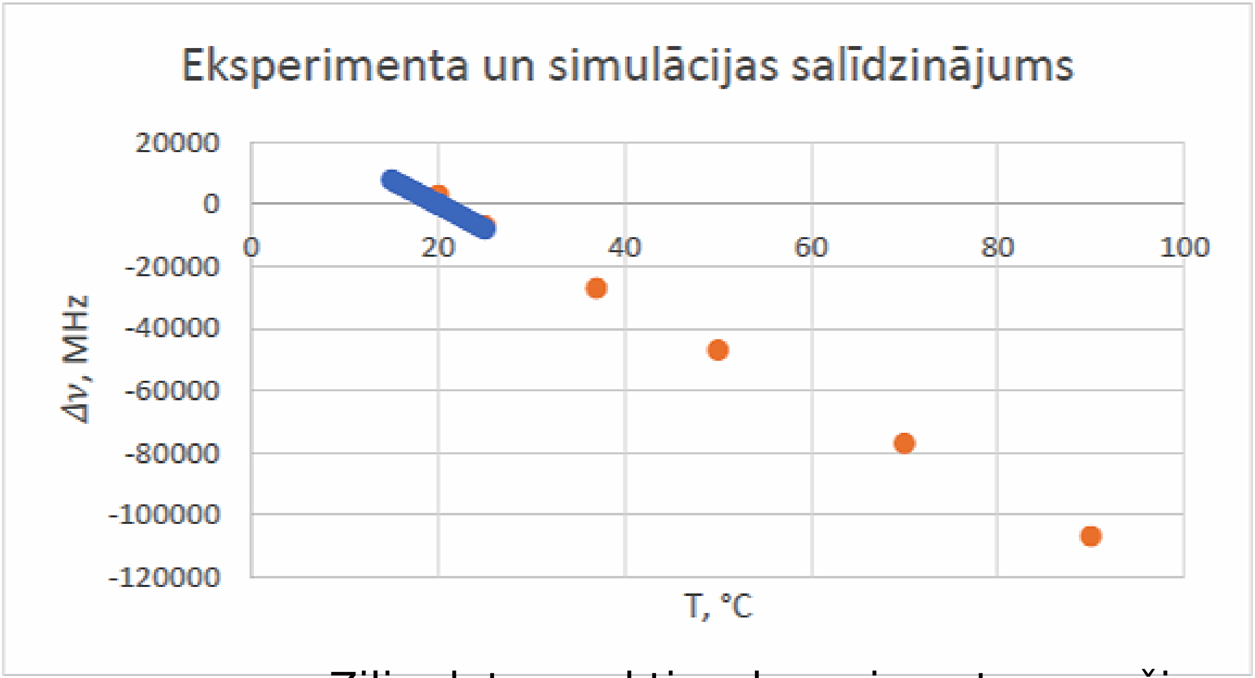
n = 1.5,
λ = 760 nm,
r = 300 μm

Modelēšanas dati:

$\alpha = 3.38 \cdot 10^{-6} \frac{1}{K},$

$\beta = 0.14 \cdot 10^{-6} \frac{1}{K}.$

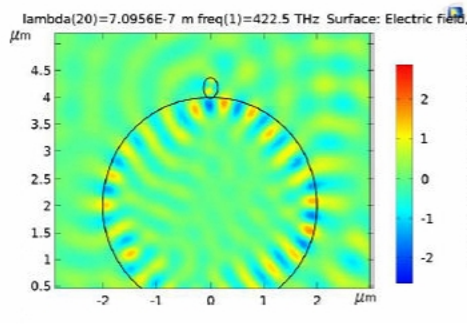
Rezonatori veidoti no Corning SMF 28 šķiedras (tādēļ iegūtās konstantes atšķiras no SiO_2 konstantēm)

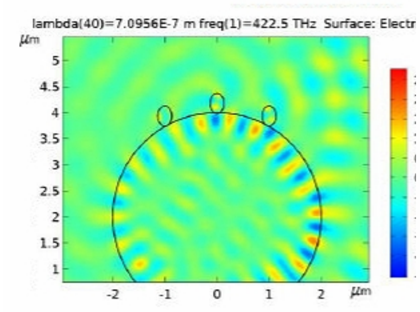


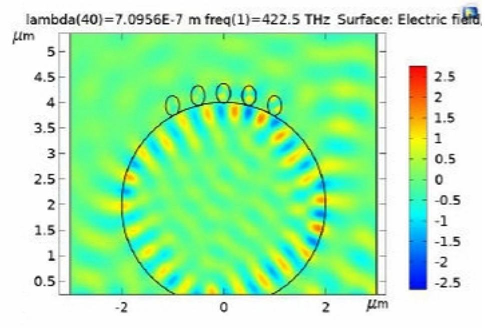
Priekš $\beta = 0.55 \cdot 10^{-6} \frac{1}{K},$ $\alpha = 12.8 \cdot 10^{-6} \frac{1}{K},$

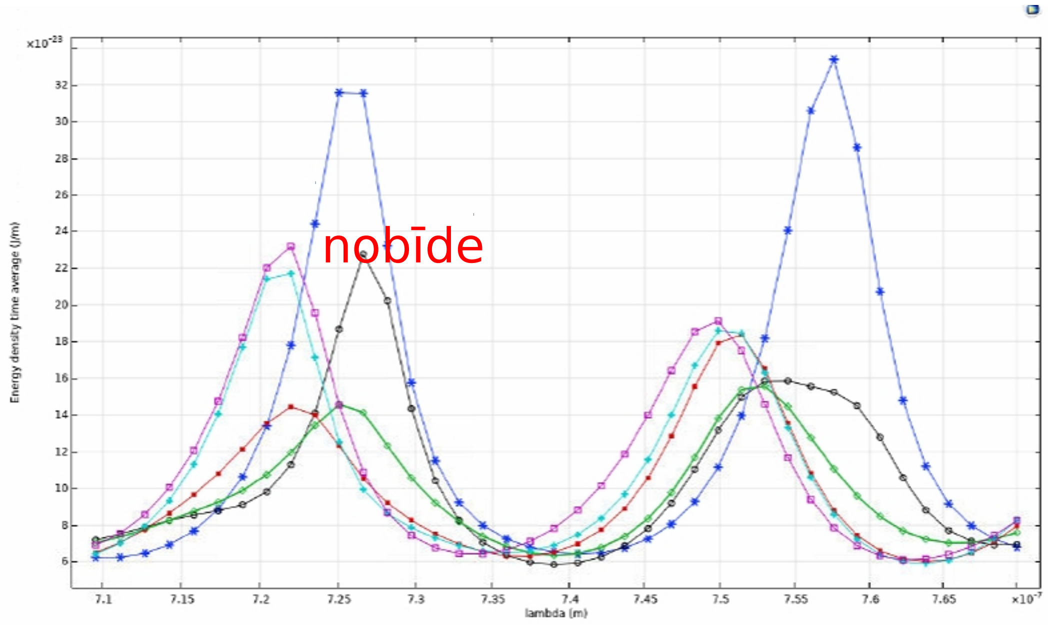
Zilie datu punkti – eksperiments, oranžie punkti – teorija (modelēšanas rezultāti dod īpašfrekvenci ar precizitāti 0.01 THz, tādēļ rezultātu attēlošanai izvēlēts plašs temperatūras reģions)

Biosensoru modelēšana









3.20. att. **Laikā vidējots enerģijas blīvums atkarībā no viļņa garuma pie dažāda nanodaļiņu skaita. Tumši zils – bez molekulas, melns – 1 molekula, zaļa – 2 molekulas, sarkana – 3 molekulas, gaiši zila – 4 molekulas, purpura krāsa – 5 molekulas.**

LATVIJAS UNIVERSITĀTE
FIZIKAS, MATEMĀTIKAS UN OPTOMETRIJAS FAKULTĀTE
FIZIKAS NODAĻA

UZ ČUKSTOŠĀS GALERIJAS MODU MIKROREZONATORU BĀZES VEIDOTU SENSORU MODELĒŠANA

BAKALAURA DARBS

Autors: **Kristians Draguns**
Studenta apliecības Nr.: kd16057

Darba vadītājs:
Dr. Phys. Aigars Atvars
Darbs izstrādāts LU Atomfizikas un Spektroskopijas institūtā.

RĪGA 2019