LU ASI
pētnieka
vietas pretendents

Inga Brice
22.04.2021.

Izglītība - iegūta

Augstākā

Dabaszinātņu maģistra grāds fizikā, Latvijas Universitāte, 2013

Izglītība - doktorantūra

- Fizika, astronomija un mehānika Doktora studiju programma
- Lāzeru fizika un spektroskopija virziens
- Promocijas darba vadītājs Dr. Jānis Alnis, LU Atomfizikas un spektroskopijas institūta vadošais pētnieks
- Šobrīd zinātniskā grāda pretendents

LATVIJAS UNIVERSITĀTE
Studiju departaments

IZZIŅA
Rīgā

14.07.2020 SD – S20 /80

Apliecinām, ka **Inga Brice (020989-10909)** ir studējusi Latvijas Universitātes Fizikas, astronomijas un mehānikas doktora studiju programmas pilna laika klātienes doktorantūrā no 01.10.2013. līdz 01.10.2017.

I.Brice ir eksmatrikulēta ar LU 06.10.2017. rīkojumu Nr. 3.2/1727 kā doktora studiju programmu izpildījusi.

Studiju departamenta direktore A.Līgotne

I.Danusēviča 67033966

Valodas

Latviešu valoda - dzimtā valoda (runātprasme C2, lasītprasme C2, rakstītprasme C2)

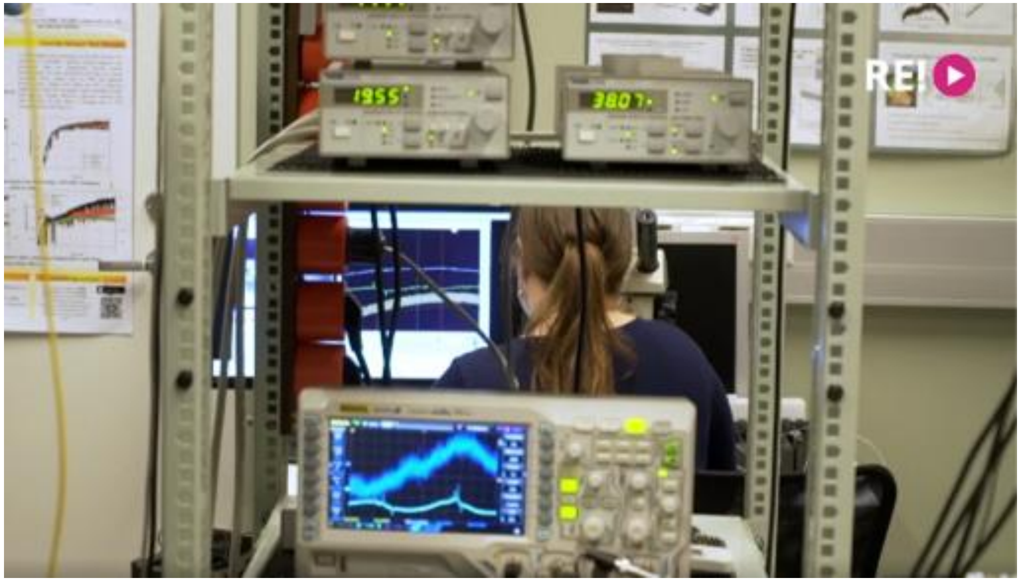
Angļu valoda - brīvi runāju, rakstu (runātprasme C1, lasītprasme C1, rakstītprasme C1)

Krievu valoda - sarunvalodas līmenī (runātprasme B2, lasītprasme B2, rakstītprasme A2)

Vācu valoda – pamatzināšanas (runātprasme A2, lasītprasme A2, rakstītprasme A2)

Darba pieredze

no 14.06.2016. - Atomfizikas un spektroskopijas institūts, zinātniskais asistents



01.10.2013. - 13.06.2016., Atomfizikas un spektroskopijas institūts, dabaszinātņu laborants

01.10.2013. - 01.08.2018, Ogres valsts ģimnāzija, laborants, fizikas skolotāja

03.- 12.2011. un 05. - 12.2012., Latvijas Universitātes Cietvielu fizikas institūts, inženieris

Darbs projektu realizācijā

- LZP un citu valsts finansēto pētījumu projektu, programmu dalībnieks

LZP projekts Nr. Lzp-2018/1-0510 “Optiski čukstošās galerijas modu mikrorezonatoru sensori” 31.08.2018.–31.08.2021. zinātniskais asistents.

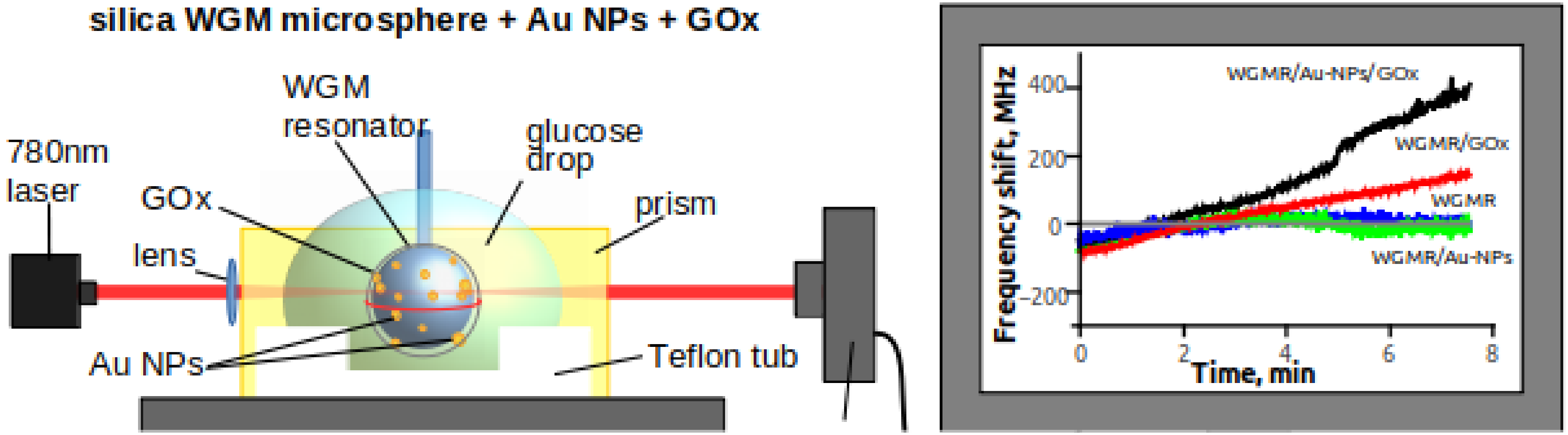
- Starptautisko pētījumu projektu dalībnieks

ERAF projekts Nr. 1.1.1.1/16/A/259 “Jaunu čukstošās galerijas modu mikrorezonatoru izstrāde optisko frekvenču standartu un biosensoru pielietojumiem, un to raksturošana ar femtosekunžu optisko frekvenču ķemmi”, 01.03.2017. - 28.02.2020, zinātniskais asistents (arī administratīvais projekta vadītājs).

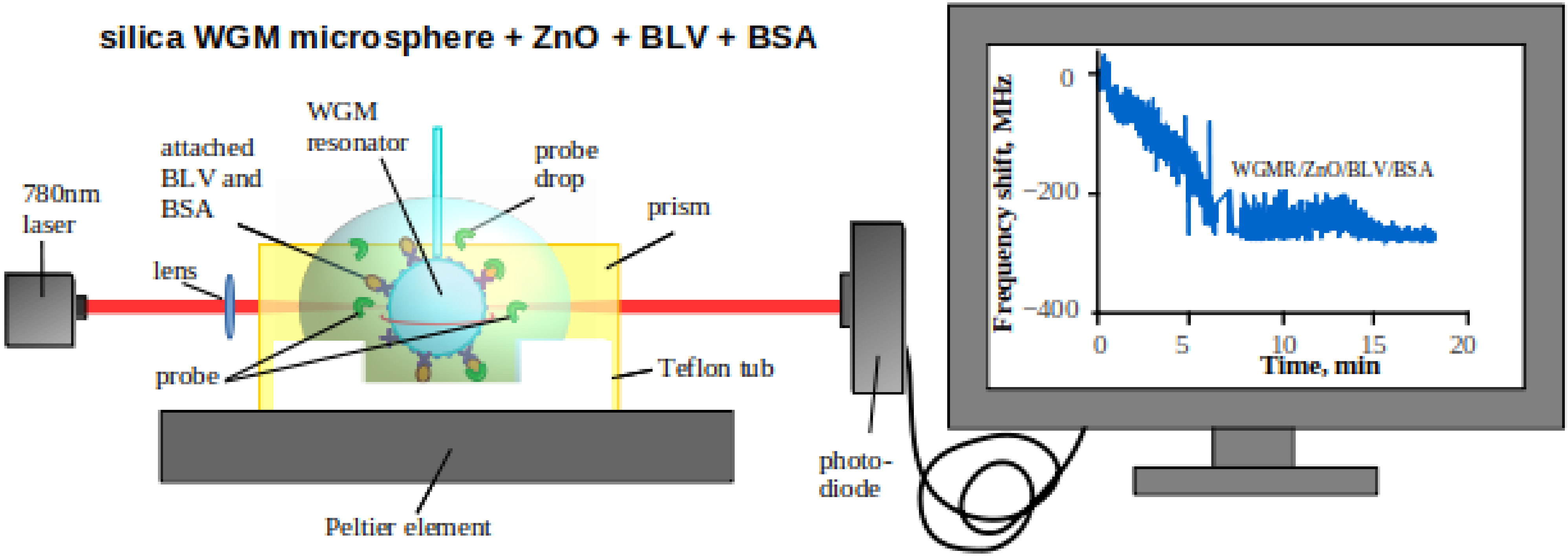
ERAF projekts Nr. 1.1.1.1/18/A/155 “Uz čukstošās galerijas modas mikrorezonatora bāzes veidota optisko frekvenču ķemmes ģeneratora izstrāde un tā pielietojumi telekomunikacijās”, 16.05.2019. - 15.05.2022., zinātniskais asistents.

Darba pieredze

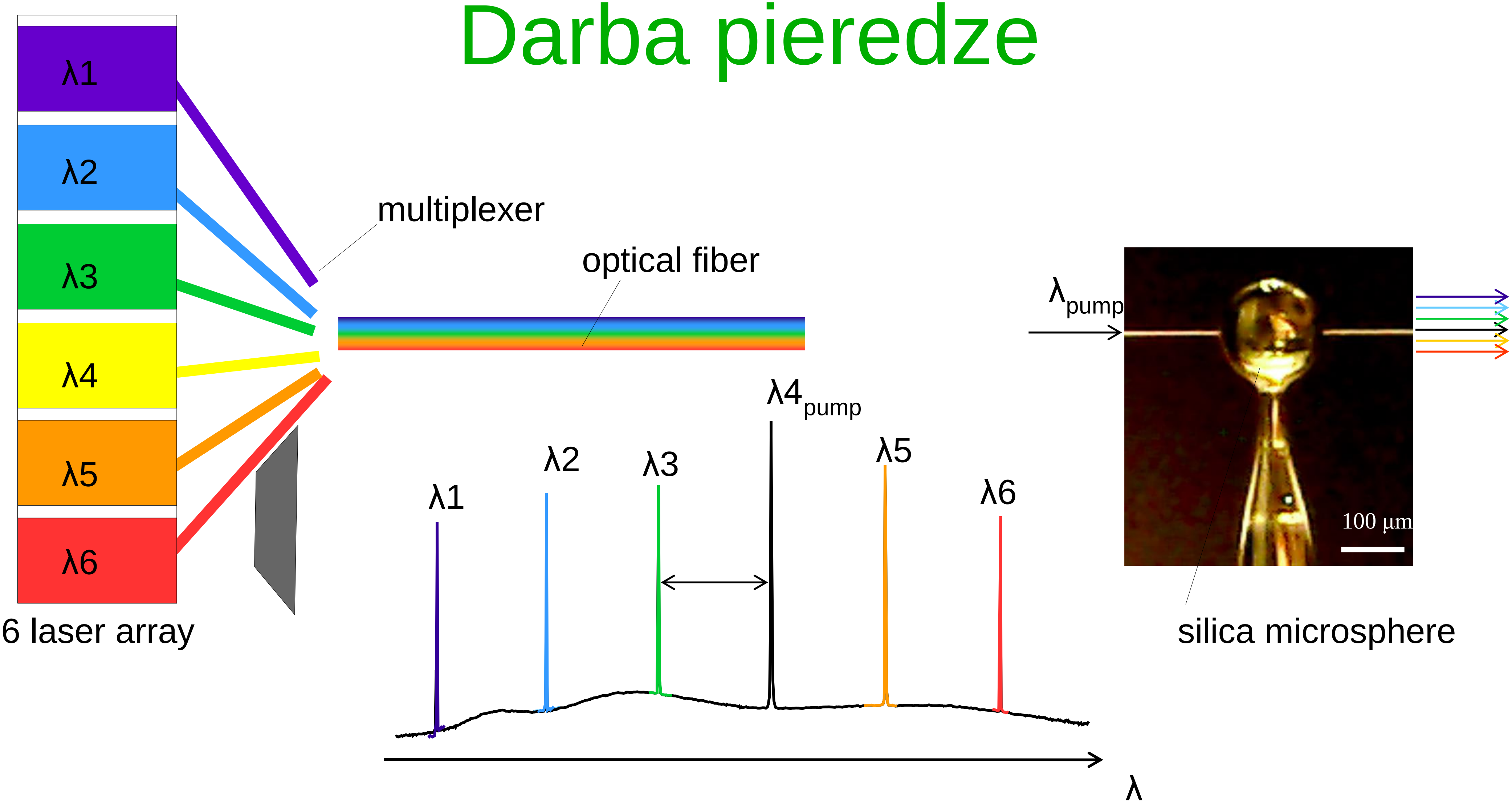
silica WGM microsphere + Au NPs + GOx



silica WGM microsphere + ZnO + BLV + BSA



Darba pieredze



Līdzdalība konferencēs

Fifth International School and Conference on Photonics "Photonica 2015" Belgrade, Serbia, (August 24-28, 2015), poster presentation **"Measurements of Rb hyperfine splitting with a femtosecond optical frequency comb"**, I. Brice, J. Alnis, J. Rutkis, p. 98 (2015)

12th International Young Scientist conference "Developments in Optics and Communications Riga", Latvia (March 21.-23, 2016), poster presentation **"Measurements of Rb 5S-5P Transition with a femtosecond optical frequency comb"**, Inga Brice, Janis Alnis, Jazeps Rutkis, p. 11 (2016)

60th International Conference for Students of Physics and Natural Sciences "Open readings 2017" Vilnius, Lithuania (March 14-17, 2017), poster presentation **"TOWARDS WGM RESONATOR STABILISED ON Rb 5S-5P TRANSITION LINES"** Inga Brice, Antons Pribitoks, Janis Alnis, p. 212 (2017)

Measurements of Rb

Institute

In Latvia within a Fotonika-LV project a modern commercial femtosecond optical frequency comb system (Model FC1500-250-WG made by *Menlo Systems, Germany*) was acquired. The Optical frequency comb is installed at the Quantum Optics Laboratory, LU ASI, Riga Skunu str. 4 (see Fig. 1).

Fig. 1. Femtosecond optical frequency comb system installed in Riga.

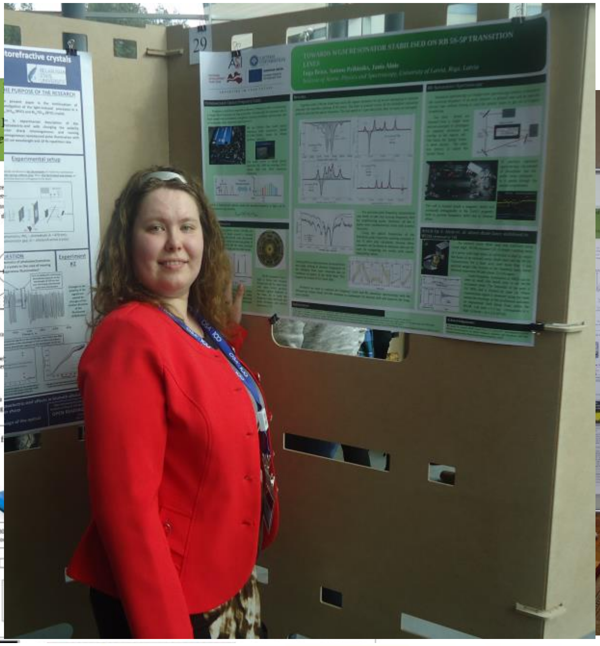
The optical frequency comb synthesizer is Erbium-fiber based therefore it covers a broad optical spectrum 530...1000 nm emitting 150 fs pulses with 250 MHz repetition frequency.

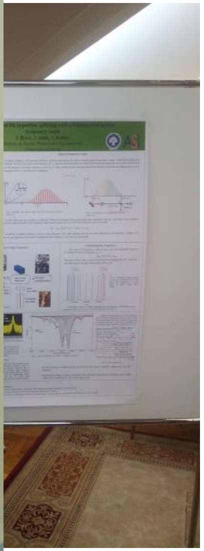
System requires a 10 MHz reference signal. We use GPS monitored Rb clock as frequency reference and achieve 11 digits of precision.

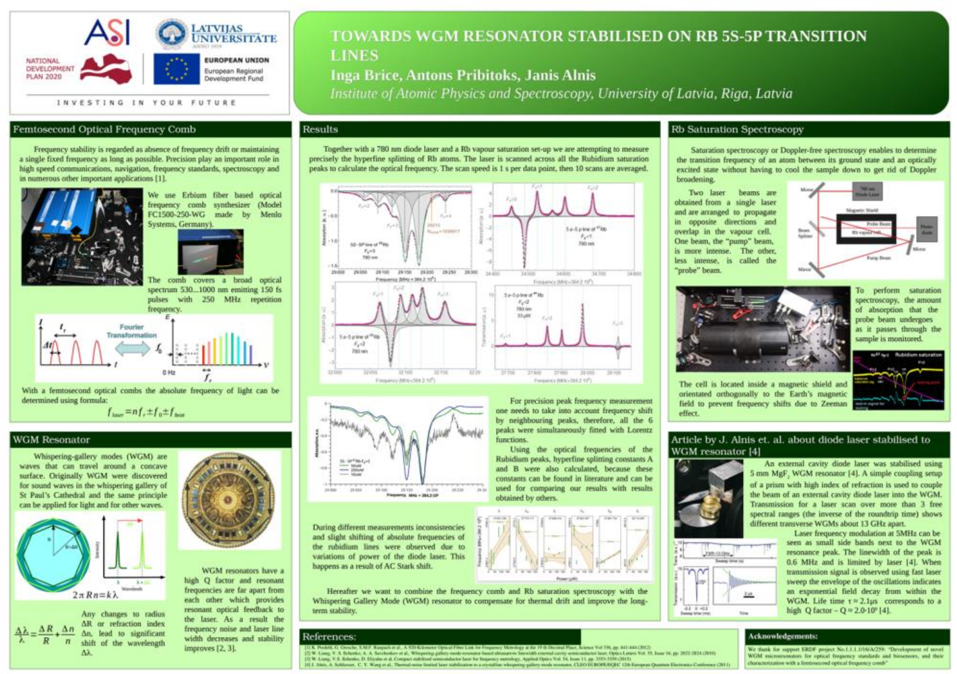
The optical frequency comb is used for practicing the use of the system by re-measuring precisely optical transition frequencies in Rb atoms. Afterwards it will be used to measure precisely positions of the Te molecular lines.

Precision measurement of light

Fig. 4. The setup for the measurements of the Rb hyperfine splitting frequencies.







TOWARDS WGM RESONATOR STABILISED ON RB 5S-5P TRANSITION LINES

Inga Brice, Antons Pribitoks, Janis Alnis

Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia

Femtosecond Optical Frequency Comb

Frequency stability is regarded as absence of frequency drift or maintaining a single fixed frequency as long as possible. Precision play an important role in high speed communications, navigation, frequency standards, spectroscopy and in numerous other important applications [1].

We use Erbium fiber based optical frequency comb synthesizer (Model FC1500-250-WG made by Menlo Systems, Germany).

The comb covers a broad optical spectrum 530...1000 nm emitting 150 fs pulses with 250 MHz repetition frequency.

With a femtosecond optical combs the absolute frequency of light can be determined using formula:

$$f_{laser} = n f_r \pm f_0 \pm f_{beat}$$

WGM Resonator

Whispering-gallery modes (WGM) are waves that can travel around a concave surface. Originally WGM were discovered for sound waves in the whispering gallery of St Paul's Cathedral and the same principle can be applied for light and for other waves.

$$2\pi R n = k\lambda$$

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta R}{R} + \frac{\Delta n}{n}$$

Any changes to radius ΔR or refraction index Δn, lead to significant shift of the wavelength Δλ.

WGM resonators have a high Q factor and resonant frequencies are far apart from each other which provides resonant optical feedback to the laser. As a result the frequency noise and laser line width decreases and stability improves [2, 3].

Results

Together with a 780 nm diode laser and a Rb vapour saturation set-up we are attempting to measure precisely the hyperfine splitting of Rb atoms. The laser is scanned across all the Rubidium saturation peaks to calculate the optical frequency. The scan speed is 1 s per data point, then 10 scans are averaged.

For precision peak frequency measurement one needs to take into account frequency shift by neighbouring peaks, therefore, all the 6 peaks were simultaneously fitted with Lorentz functions.

Using the optical frequencies of the Rubidium peaks, hyperfine splitting constants A and B were also calculated, because these constants can be found in literature and can be used for comparing our results with results obtained by others.

During different measurements inconsistencies and slight shifting of absolute frequencies of the rubidium lines were observed due to variations of power of the diode laser. This happens as a result of AC Stark shift.

Hereafter we want to combine the frequency comb and Rb saturation spectroscopy with the Whispering Gallery Mode (WGM) resonator to compensate for thermal drift and improve the long-term stability.

Rb Saturation Spectroscopy

Saturation spectroscopy or Doppler-free spectroscopy enables to determine the transition frequency of an atom between its ground state and an optically excited state without having to cool the sample down to get rid of Doppler broadening.

Two laser beams are obtained from a single laser and are arranged to propagate in opposite directions and overlap in the vapour cell. One beam, the "pump" beam, is more intense. The other, less intense, is called the "probe" beam.

To perform saturation spectroscopy, the amount of absorption that the probe beam undergoes as it passes through the sample is monitored.

The cell is located inside a magnetic shield and orientated orthogonally to the Earth's magnetic field to prevent frequency shifts due to Zeeman effect.

Article by J. Alnis et. al. about diode laser stabilised to WGM resonator [4]

An external cavity diode laser was stabilised using 5 mm MgF_2 WGM resonator [4]. A simple coupling setup of a prism with high index of refraction is used to couple the beam of an external cavity diode laser into the WGM. Transmission for a laser scan over more than 3 free spectral ranges (the inverse of the roundtrip time) shows different transverse WGMs about 13 GHz apart.

Laser frequency modulation at 5MHz can be seen as small side bands next to the WGM resonance peak. The linewidth of the peak is 0.6 MHz and is limited by laser [4]. When transmission signal is observed using fast laser sweep the envelope of the oscillations indicates an exponential field decay from within the WGM. Life time $\tau \approx 2.1 \mu s$ corresponds to a high Q factor – $Q \approx 2.0 \cdot 10^9$ [4].

References:

[1] K. Predehl, G. Grosche, S.M.F. Raupach et al., A 920-Kilometer Optical Fiber Link for Frequency Metrology at the 19th Decimal Place, Science Vol 336, pp. 441-444 (2012)
[2] W. Liang, V. S. Ilchenko, A. A. Savchenkov et al., Whispering-gallery-mode-resonator-based ultranarrow linewidth external-cavity semiconductor laser, Optics Letters Vol. 35, Issue 16, pp. 2822-2824 (2010)
[3] W. Liang, V.S. Ilchenko, D. Eliyahu et al. Compact stabilized semiconductor laser for frequency metrology, Applied Optics Vol. 54, Issue 11, pp. 3353-3359 (2015)
[4] J. Alnis, A. Schliesser, C. Y. Wang et al., Thermal-noise limited laser stabilisation to a crystalline whispering-gallery mode resonator, CLEO EUROPE/EQEC 12th European Quantum Electronics Conference (2011)

Acknowledgements:

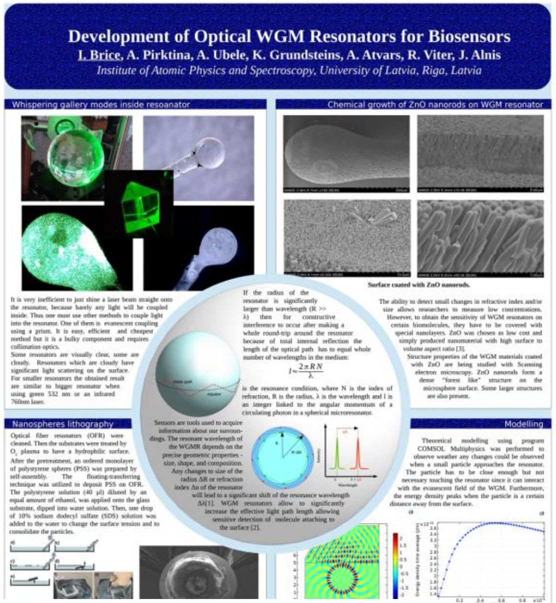
We thank for support ERDF project No.1.1.1.1/16/A/259: "Development of novel WGM microresonators for optical frequency standards and biosensors, and their characterization with a femtosecond optical frequency comb"

Līdzdalība konferencēs

13th International Young Scientist conference "Developments in Optics and Communications Riga", Latvia (April 6-7, 2017), oral presentation **"Acetone and benzene detection using CRDS",** Inga Brice, Gita Revalde, Karlis Grundsteins, Janis Alnis, p. 25 (2017)

2nd International Conference "Biophotocis Riga 2017" Riga, Latvia (August 27-29, 2017), poster presentation **"Development of Optical WGM Resonators for Biosensors"**, I. Brice, A. Pirktina, A. Ubele, K. Grundsteins, A. Atvars, R. Viter, J. Alnis, Proceedings of SPIE: Biophotonics—Riga 2017. Vol. 10592. p. 105920B (2017)

International conference "Nanomaterials for biosensors and biomedical applications" Jurmala, Latvia (July 2-4, 2019), poster presentation **"WGMR coated with Au NPs to enhance the sensitivity"** I. Brice , K. Grundsteins, A. Atvars, R. Viter, J. Alnis, p. 62 (2019)



Development of Optical WGM Resonators for Biosensors

I. Brice, A. Pirktina, A. Ubele, K. Grundsteins, A. Atvars, R. Viter, J. Alnis

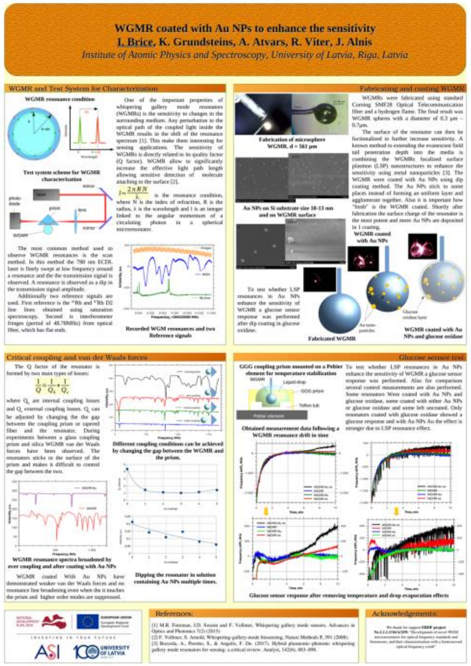
Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia

Whispering gallery modes inside ressonator

Chemical growth of ZnO nanorods on WGM resonator

Nanospheres lithography

Modelling



WGMR coated with Au NPs to enhance the sensitivity

I. Brice, K. Grundsteins, A. Atvars, R. Viter, J. Alnis

Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia

WGMR and Test System for Characterization

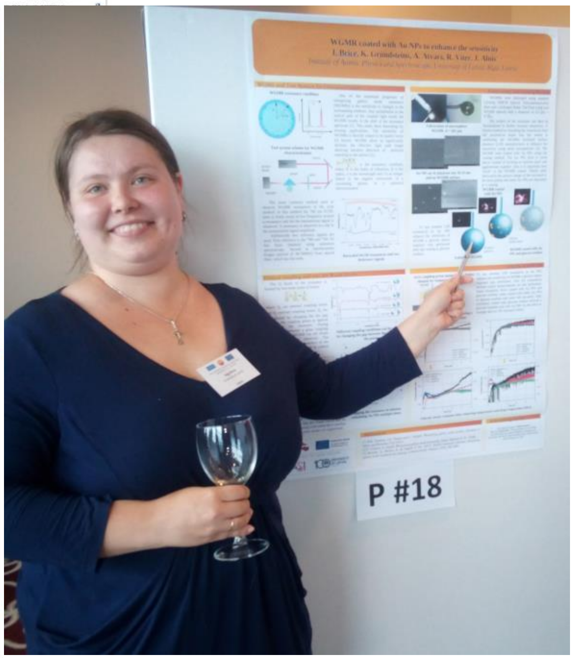
Fabricating and coating WGMR

Critical coupling and van der Waals forces

Glucose sensor test

References:

Acknowledgements:

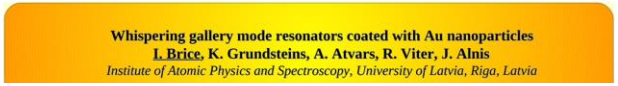


Līdzdalība konferencēs

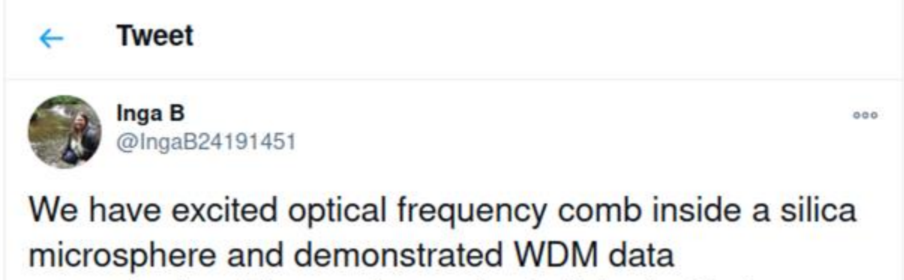
"SPIE Optics + Photonics 2019" San Diego, USA (August 11-15 2019), poster presentation **“Whispering gallery mode resonators coated with Au nanoparticles”** I. Brice, K. Grundsteins, A. Atvars, J. Alnis, R. Viter. Proceedings of SPIE: Nanoengineering: Fabrication, Properties, Optics, Thin Films, and Devices XVI. Vol. 110892019 p. 110891T (2019)

Third edition of Photonics Online Meet-up "POM2021" USA - online event (January 11-14, 2021), poster presentation **"Optical frequency comb generated inside silica microsphere for WDM Data Transmission System"** Inga Brice, Karlis Grundsteins, Toms Salgals, Janis Alnis, p. 132 (2021)

"SPIE Photonics West 2021" San Francisko, USA - online event (March 6-11, 2021), poster presentation **"Frequency comb generation in whispering gallery mode silica microsphere resonators"** Inga Brice, Karlis Grundsteins, Arvids Sedulis, Toms Salgals, Sandis Spolitis, Vjaceslavs Bobrovs, Janis Alnis, Proceedings of SPIE: Laser Resonators, Microresonators, and Beam Control XXIII. Vol. 11672, p. 1167213 (2021).

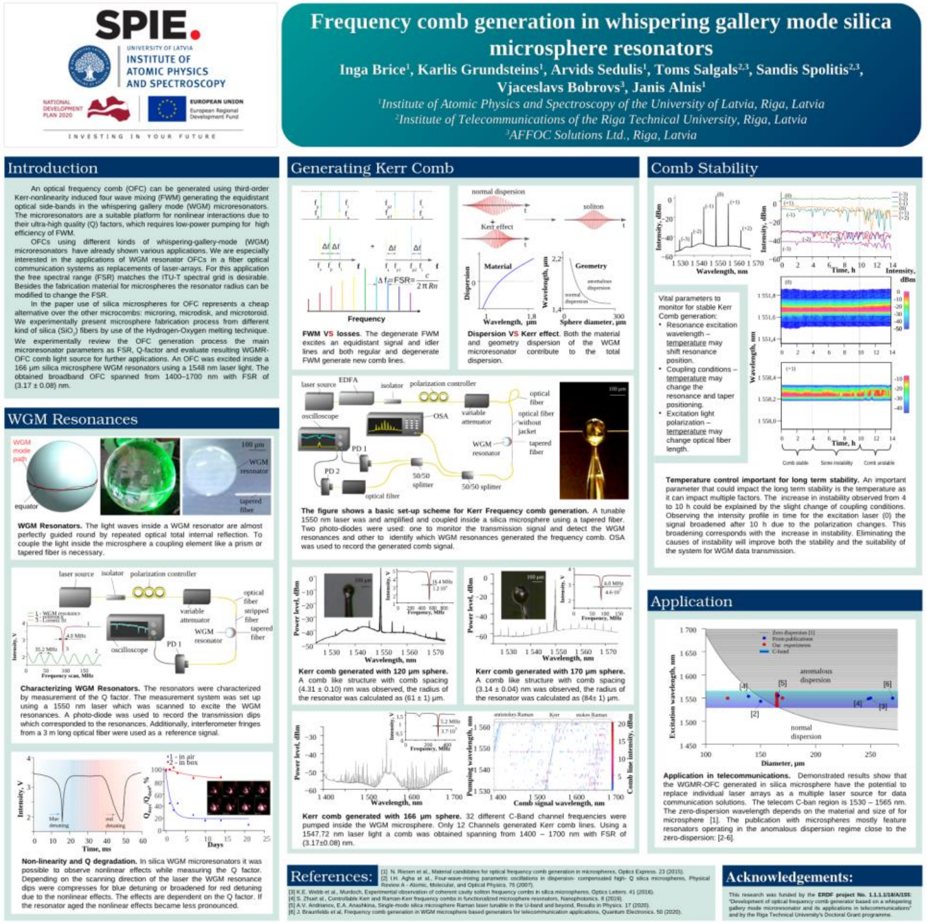


Whispering gallery mode resonators coated with Au nanoparticles
I. Brice, K. Grundsteins, A. Atvars, R. Viter, J. Alnis
Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia



Inga B
@IngaB24191451

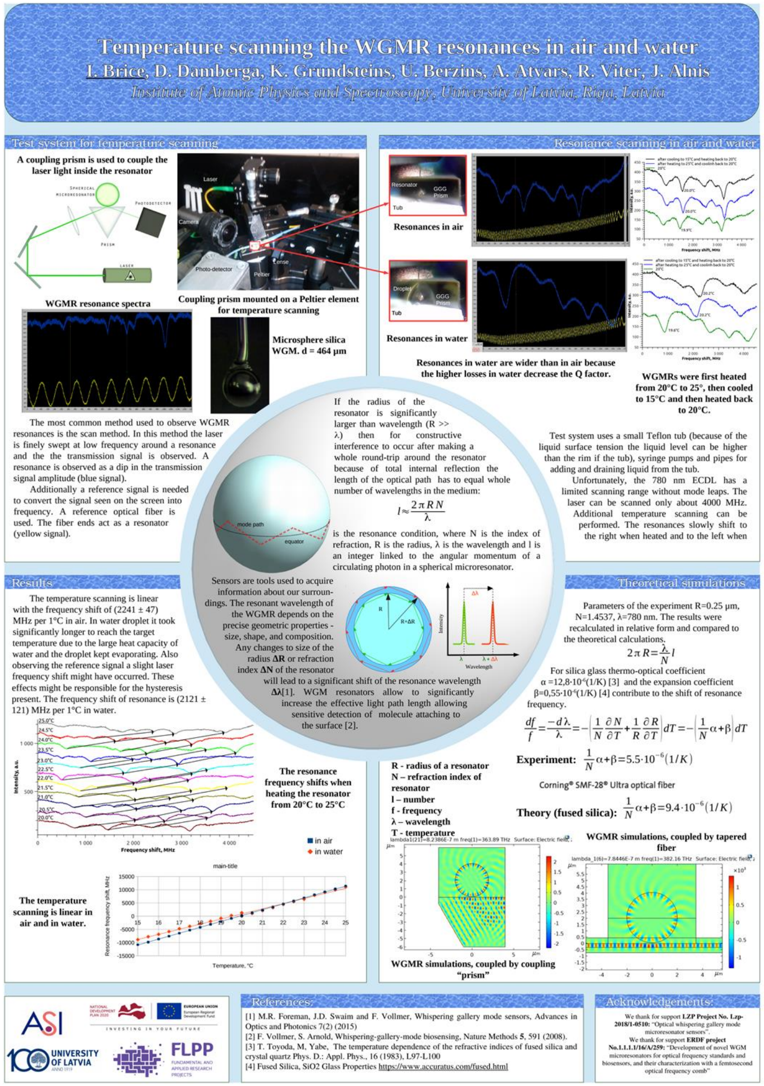
We have excited optical frequency comb inside a silica microsphere and demonstrated WDM data



Frequency comb generation in whispering gallery mode silica microsphere resonators
Inga Brice[1], Karlis Grundsteins[1], Arvids Sedulis[1], Toms Salgals[2,3], Sandis Spolitis[2,3], Vjaceslavs Bobrovs[3], Janis Alnis[1]
[1]Institute of Atomic Physics and Spectroscopy of the University of Latvia, Riga, Latvia
[2]Institute of Telecommunications of the Riga Technical University, Riga, Latvia
[3]AFFOC Solutions Ltd., Riga, Latvia

Līdzdalība ziemas skolā

10th Optoelectronics and Photonics Winter School:NLP2019- Nonlinear Photonics, Trento-Andalo, Italy (January 20-26, 2019), poster presentation **"Temperature scanning the WGMR resonances in air and water"** I. Brice, D. Damberga, K. Grundsteins, U. Berzins,



Temperature scanning the WGMR resonances in air and water

I. Brice, D. Damberga, K. Grundsteins, U. Berzins, A. Atvars, R. Viter, J. Alnis

Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia

Test system for temperature scanning

A coupling prism is used to couple the laser light inside the resonator

Coupling prism mounted on a Peltier element for temperature scanning

WGMR resonance spectra

Microsphere silica WGM. d = 464 µm

The most common method used to observe WGMR resonances is the scan method. In this method the laser is finely swept at low frequency around a resonance and the the transmission signal is observed. A resonance is observed as a dip in the transmission signal amplitude (blue signal).

Additionally a reference signal is needed to convert the signal seen on the screen into frequency. A reference optical fiber is used. The fiber ends act as a resonator (yellow signal).

Resonance scanning in air and water

Resonances in air

Resonances in water

Resonances in water are wider than in air because the higher losses in water decrease the Q factor.

WGMRs were first heated from 20°C to 25°, then cooled to 15°C and then heated back to 20°C.

Test system uses a small Teflon tub (because of the liquid surface tension the liquid level can be higher than the rim if the tub), syringe pumps and pipes for adding and draining liquid from the tub.

Unfortunately, the 780 nm ECDL has a limited scanning range without mode leaps. The laser can be scanned only about 4000 MHz. Additional temperature scanning can be performed. The resonances slowly shift to the right when heated and to the left when

If the radius of the resonator is significantly larger than wavelength (R >> λ) then for constructive interference to occur after making a whole round-trip around the resonator because of total internal reflection the length of the optical path has to equal whole number of wavelengths in the medium:

$$l \approx \frac{2\pi R N}{\lambda}$$

is the resonance condition, where N is the index of refraction, R is the radius, λ is the wavelength and l is an integer linked to the angular momentum of a circulating photon in a spherical microresonator.

Sensors are tools used to acquire information about our surroundings. The resonant wavelength of the WGMR depends on the precise geometric properties - size, shape, and composition. Any changes to size of the radius **ΔR** or refraction index **ΔN** of the resonator will lead to a significant shift of the resonance wavelength **Δλ**[1]. WGM resonators allow to significantly increase the effective light path length allowing sensitive detection of molecule attaching to the surface [2].

Results

The temperature scanning is linear with the frequency shift of (2241 ± 47) MHz per 1°C in air. In water droplet it took significantly longer to reach the target temperature due to the large heat capacity of water and the droplet kept evaporating. Also observing the reference signal a slight laser frequency shift might have occurred. These effects might be responsible for the hysteresis present. The frequency shift of resonance is (2121 ± 121) MHz per 1°C in water.

The resonance frequency shifts when heating the resonator from 20°C to 25°C

The temperature scanning is linear in air and in water.

R - radius of a resonator
N – refraction index of resonator
l – number
f - frequency
λ – wavelength
T - temperature

Theoretical simulations

Parameters of the experiment R=0.25 µm, N=1.4537, λ=780 nm. The results were recalculated in relative form and compared to the theoretical calculations.

$$2\pi R = \frac{\lambda}{N} l$$

For silica glass thermo-optical coefficient $\alpha = 12{,}8\cdot10^{-6}(1/K)$ [3] and the expansion coefficient $\beta = 0{,}55\cdot10^{-6}(1/K)$ [4] contribute to the shift of resonance frequency.

$$\frac{df}{f} = \frac{-d\lambda}{\lambda} = -\left(\frac{1}{N}\frac{\partial N}{\partial T} + \frac{1}{R}\frac{\partial R}{\partial T}\right) dT = -\left(\frac{1}{N}\alpha + \beta\right) dT$$

Experiment: $\frac{1}{N}\alpha + \beta = 5.5\cdot10^{-6}(1/K)$

Corning® SMF-28® Ultra optical fiber

Theory (fused silica): $\frac{1}{N}\alpha + \beta = 9.4\cdot10^{-6}(1/K)$

WGMR simulations, coupled by coupling "prism"

WGMR simulations, coupled by tapered fiber

References:
[1] M.R. Foreman, J.D. Swaim and F. Vollmer, Whispering gallery mode sensors, Advances in Optics and Photonics 7(2) (2015)
[2] F. Vollmer, S. Arnold, Whispering-gallery-mode biosensing, Nature Methods **5**, 591 (2008).
[3] T. Toyoda, M, Yabe, The temperature dependence of the refractive indices of fused silica and crystal quartz Phys. D.: Appl. Phys., 16 (1983), L97-L100
[4] Fused Silica, SiO2 Glass Properties https://www.accuratus.com/fused.html

Acknowledgements:
We thank for support **LZP Project No. Lzp-2018/1-0510:** "Optical whispering gallery mode microresonator sensors".
We thank for support **ERDF project No.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"

Publikācijas

Raksti recenzētos izdevumos – WGMR biosensori

Janis Alnis, **Inga Brice**, Andra Pirktina, Alma Ubele, Karlis Grundsteins, Aigars Atvars, and Roman Viter. “Development of optical WGM resonators for biosensors.” Proceedings of SPIE: Biophotonics—Riga 2017. Vol. 10592. p. 105920B (2017)

Inga Brice, Karlis Grundsteins, Aigars Atvars, Janis Alnis, and Roman Viter. “Whispering gallery mode resonators coated with Au nanoparticles.” Proceedings of SPIE: Nanoengineering: Fabrication, Properties, Optics, Thin Films, and Devices XVI. Vol. 110892019 p. 110891T (2019)

Inga Brice, Karlis Grundsteins, Aigars Atvars, Janis Alnis, Roman Viter, and Arunas Ramanavicius. “Whispering gallery mode resonator and glucose oxidase based glucose biosensor.” Sensors and Actuators B: Chemical 318.March. p. 128004. (2020)

Publikācijas

Raksti recenzētos izdevumos – WGMR frekvenču ķemmes

J. Braunfelds R. Murnieks, T. Salgals, **I. Brice**, T. Sharashidze, I. Lyashuk, A. Ostrovskis, S. Spolitis, J. Alnis, J. Porins “Frequency comb generation in WGM microsphere based generators for telecommunication applications.” Quantum Electronics Vol. 50(11), p. 1043–1049. (2020)

Inga Brice, Karlis Grundsteins, Arvids Sedulis, Toms Salgals, Sandis Spolitis, Vjaceslavs Bobrovs, and Janis Alnis. “Frequency comb generation in whispering gallery mode silica microsphere resonators.” Proceedings of SPIE: Laser Resonators, Microresonators, and Beam Control XXIII. Vol. 11672, p. 1167213 (2021).

Toms Salgals, Janis Alnis, Rihards Murnieks, **Inga Brice**, Jurgis Porins, Alexey Andrianov, Elena Anashkina, Sandis Spolitis, and

Publikācijas

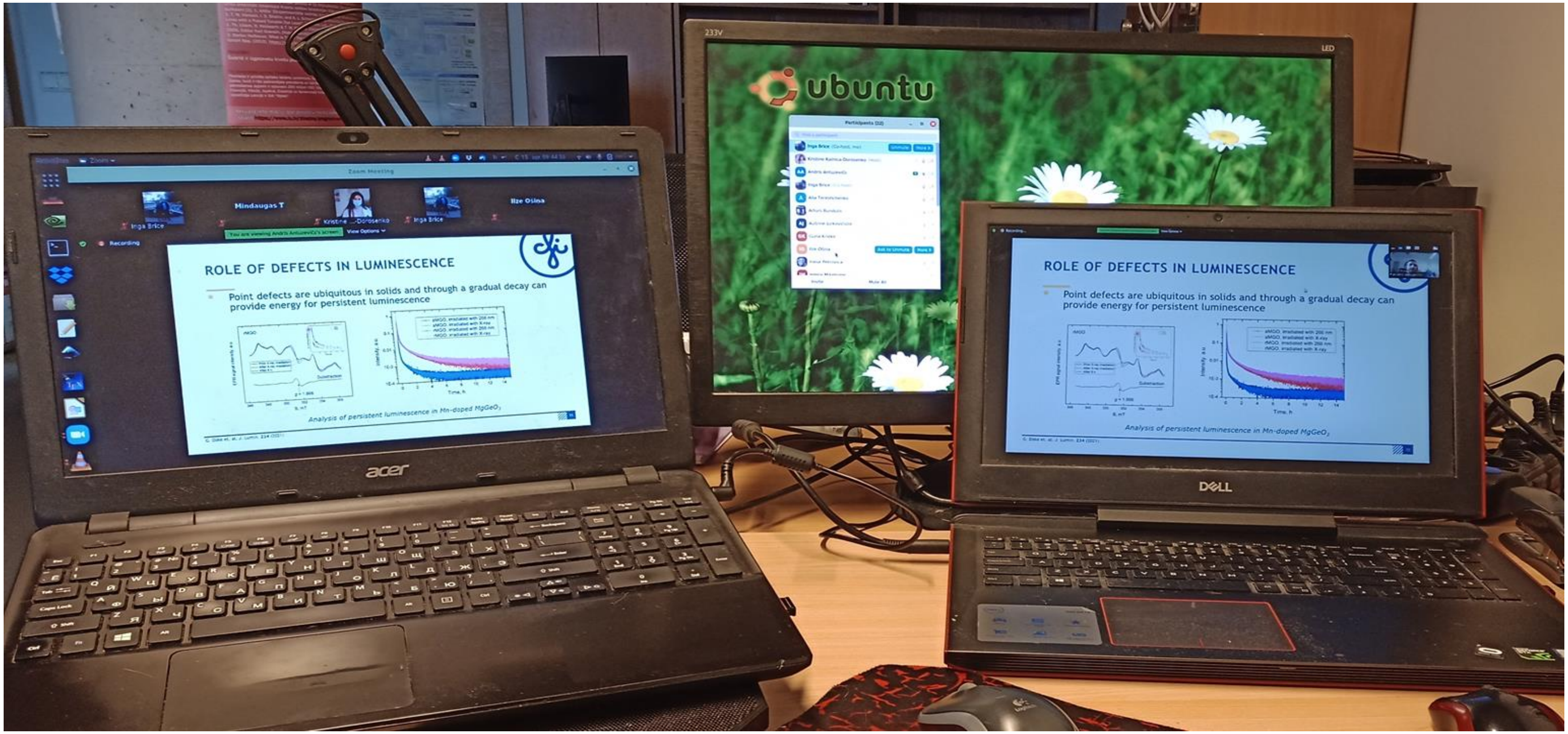
Raksti recenzētos izdevumos – WGMR sensori

Roberts Berkis, Janis Alnis, **Inga Brice**, Aigars Atvars, Kristians Draguns, Kārlis Grundšteins, and Pauls Kristaps Reinis. “Mode family analysis for PMMA WGM micro resonators using spot intensity changes.” Proceedings of SPIE: Laser Resonators, Microresonators, and Beam Control XXIII. Vol. 11672, p. 1167217. (2021)

Kristians Draguns, **Inga Brice**, Aigars Atvars, and Jānis Alnis. “Computer modelling of WGM microresonators with a zinc oxide nanolayer using COMSOL multiphysics software.” Proceedings of SPIE: Laser Resonators, Microresonators, and Beam Control XXIII. Vol. 11672, p. 1167216. (2021)

Pauls Kristaps Reinis, Lase Milgrave, Kristians Draguns, **Inga Brice**, Janis Alnis, and Aigars Atvars. “High-Sensitivity Whispering

Darbība SPIE studentu biedrībā - biedrs kopš 2013. gada, biedrības prezidents no 07.11.2019.



Plāni

Iegūt doktora gradu

Turpināt ČGMR pielietojumu pētījumus

Rakstīt publikācijas un piedalīties konferencēs

Paldies par uzmanību!