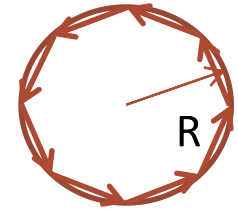
Fabrication and Coating Different Types of Optical Microcavities

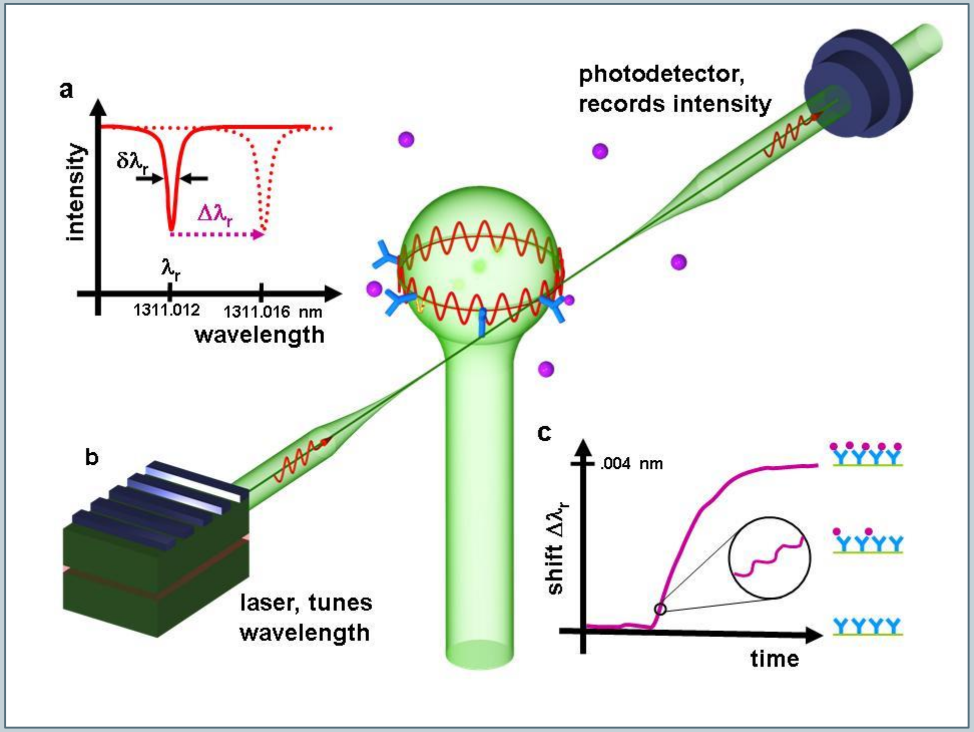
D.S. ZHIVOTKOV[1], D. RISTIĆ[1],
M. IVANDA[1], E.A. ROMANOVA[2], V.S. SHIRYAEV[3]

[1]RUĐER BOŠKOVIĆ INSTITUTE, CROATIA
[2]SARATOV STATE UNIVERSITY, RUSSIAN FEDERATION
[3]INSTITUTE OF CHEMISTRY OF HIGH PURITY SUBSTANCES OF RAS, RUSSIAN FEDERATION

Whispering gallery modes



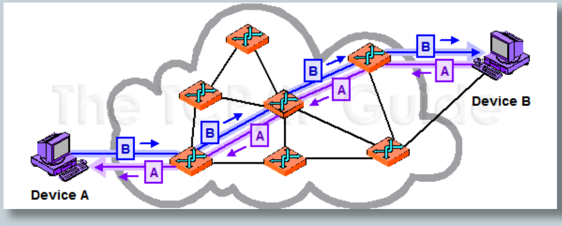
Fiber based optical microcavities



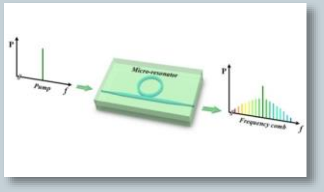
"Whispering-gallery-mode biosensing: label-free detection down to single molecules", Frank Vollmer & Stephen Arnold, http://www.rowland.harvard.edu/rjf/vollmer/images/nmethods.pdf

Applications

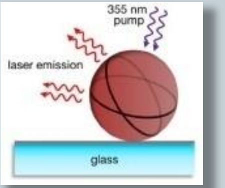
- optical signal processing at telecom wavelengths



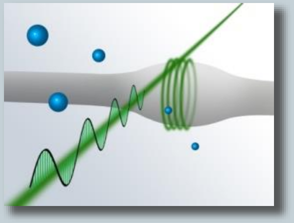
- frequency comb generation



- lasing



- sensing



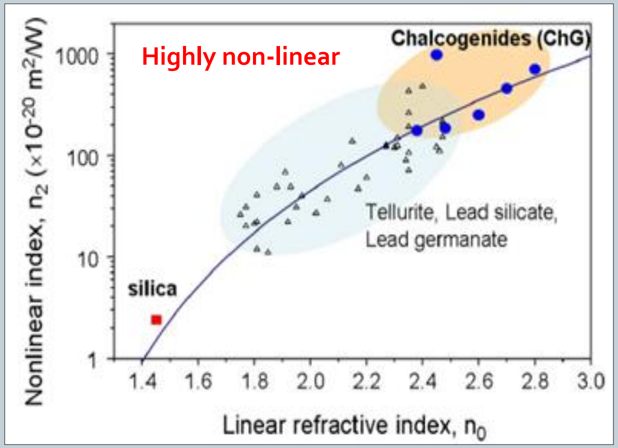
Outline:

- theory of WGMr and materials
- fabrication methods of WGMr for various materials
- characterisation of the fabricated microcavities: measurement of the Q-factors
- depositing thin films onto the surface of the silica microresonators and applications

Chalcogenide glasses for nonlinear photonics

<u>Typical compositions</u>:

Ge - S
Ge - Se
As - S
As - Se
Ge - S - P
Ge - As - Se
Ge - Se - Te
As - Se - Te
Ge - As - Se – Te



-optical signal processing at telecom wavelengths

-frequency combs generation in mid-IR

-lasing in mid-IR

-sensing in mid-IR

Light propagation in optical microresonators

Lugiato-Lefever's equation

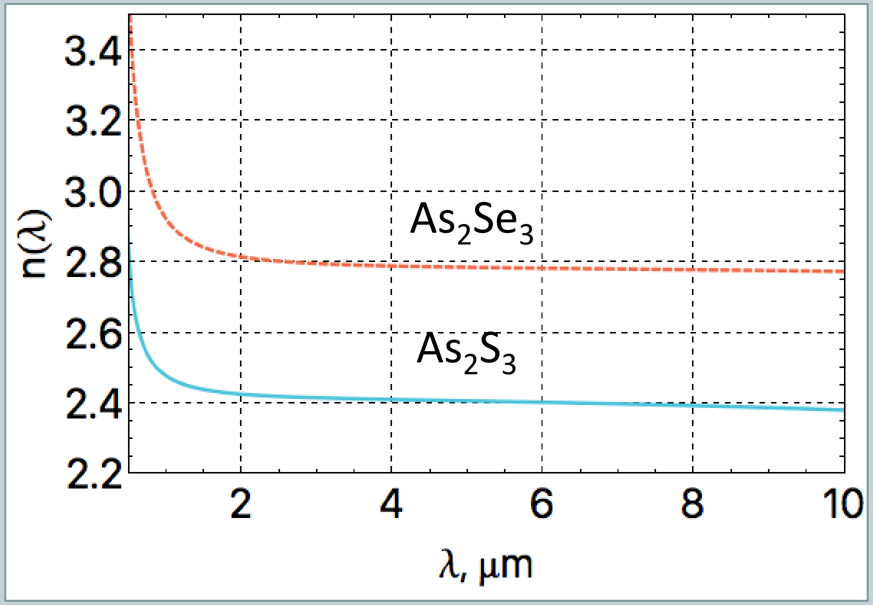
$$\tau_0 \frac{\partial A}{\partial \tau} + \frac{i}{2} \beta_{2\Sigma} \frac{\partial^2 A}{\partial t^2} - i\gamma_\Sigma |A|^2 A = -\left(\alpha_\Sigma + \frac{T_c}{2} + i\delta_0\right) A + \sqrt{T_c} A_{in}$$

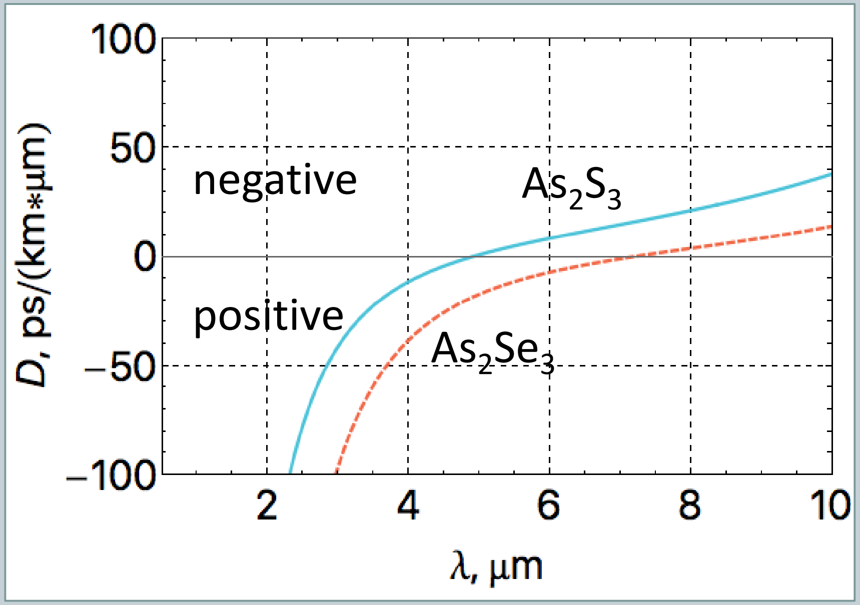
Kerr non-linearity

$\Upsilon = k \cdot n_2$

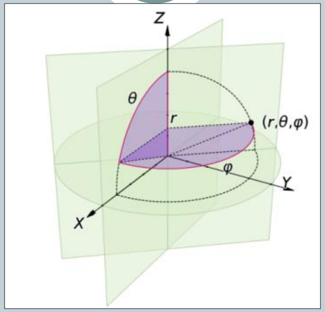
Group velocity dispersion

$$\beta_{2\Sigma} \sim D = -\frac{\lambda}{c} \cdot \frac{d^2 n(\lambda)}{d\lambda^2}$$





Whispering gallery modes of a microsphere



TM$_{lq}$ ($H_r = 0$)

$$\psi_l^{'}(kna)/\psi_l(kna) = n\zeta_l^{'}(ka)/\zeta_l(ka)$$

TE$_{lq}$ ($E_r = 0$)

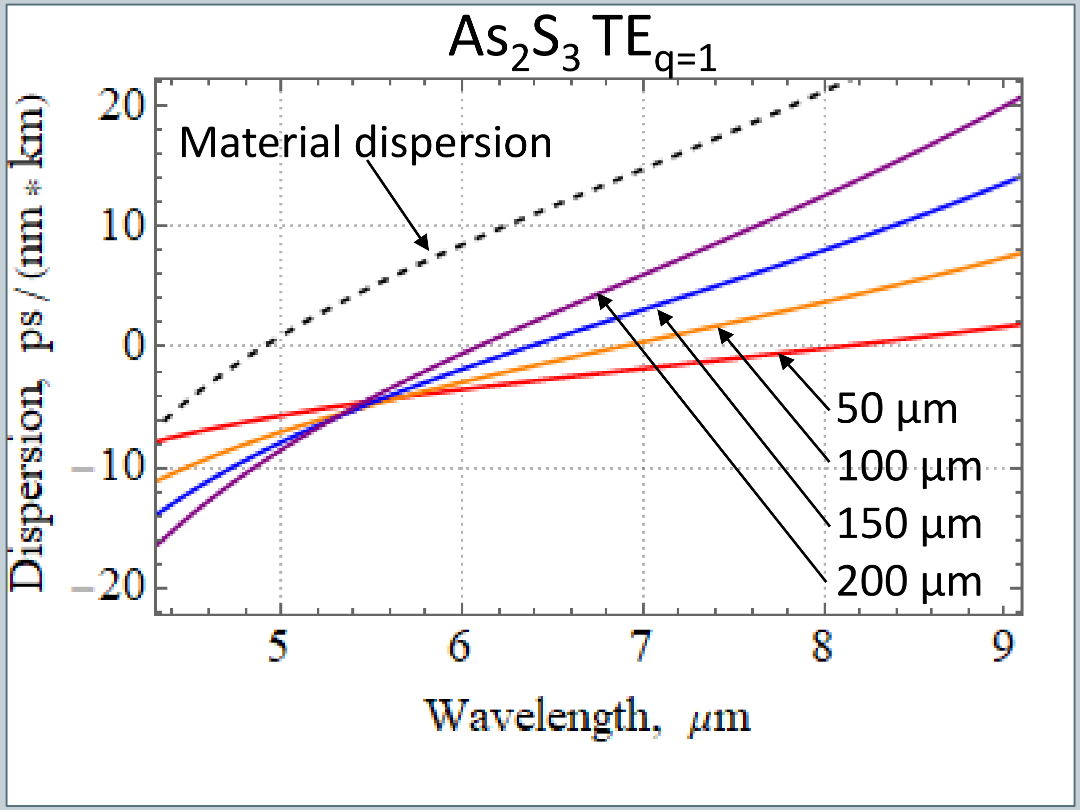
$$n\psi_l^{'}(kna)/\psi_l(kna) = \zeta_l^{'}(ka)/\zeta_l(ka)$$

$$k = \frac{2\pi\nu}{c}$$

ψ_l ζ_l - Riccati-Bessel spherical functions

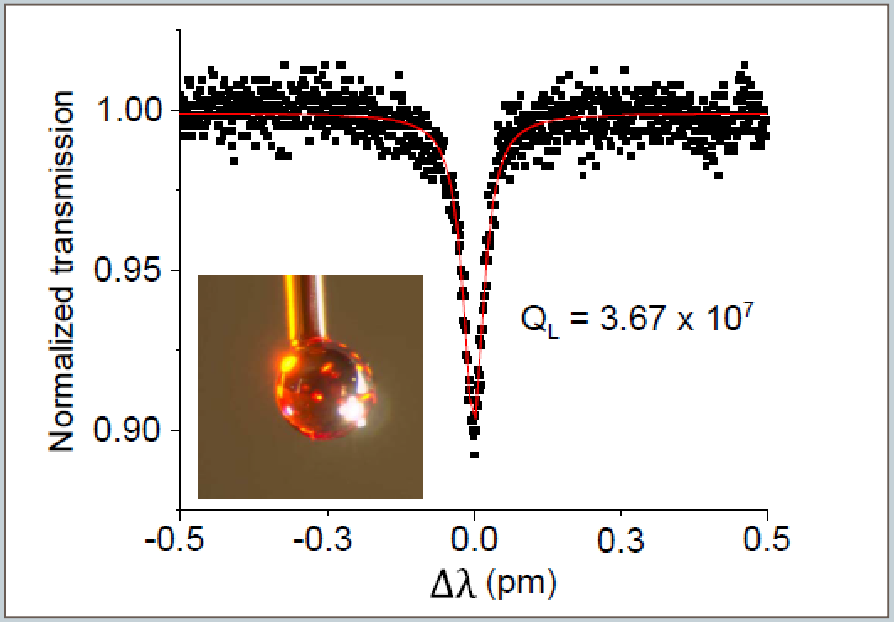
Total dispersion of the whispering gallery modes

$$D = \frac{\nu_l^2}{2\pi a c} \frac{\Delta(\Delta \nu_l)}{(\Delta \nu_l)^3}$$



Q-factor of WGM microspheres

$$Q^{-1} = Q_{rad}^{-1} + Q_{mat}^{-1} + Q_{coupl}^{-1}$$



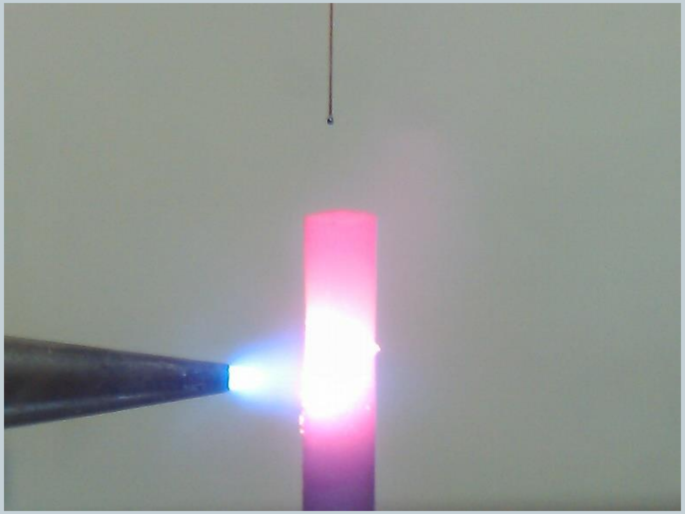
Vanier, F., P. Bianucci, N. Godbout, M. Rochette and Y. A. Peter, "As_2S_3 microspheres with near absorption-limited quality factor," in *Proceedings of 2012 International Conference on Optical MEMS and Nanophotonics*, Banff, AB, 2012, 45-46.

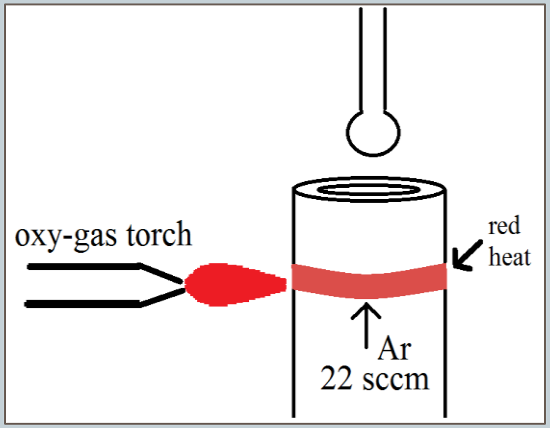
Methods of the microspheres fabrication

- Mostly, spheres are creates by the surface tension
- Silica Spheres can be produced by an oxygen torch or by a electrical arc.
- Chalcogenide cannot be produced by this way due to the lower melting temperature (>300^{0}C) and high oxidation.
- Chalcogenide spheres can be produced by laser heating or heating by the flow of a inert gas.

1. T_g ~ 300^{0}C
2. $As_2S_3 + 9O_2 \rightarrow 2As_2O_3 + 6SO_2$

Fabrication method:



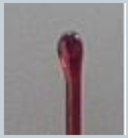


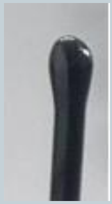
Fabrication of chalcogenide microspheres

Parameters of chalcogenide fibers at λ = 1.55 µm (Institute of Chemistry of High Purity Substances of RAS (Nizhny Novgorod, Russia))

Fiber specification	Glass composition	Outer diameter, µm	Refractive index	Optical losses of the fiber, dB/m
AsS -1	$As_{40}S_{60}$	~270	~2.4	~0.15
AsS -2	$As_{40}S_{60}$	~390	~2.4	~0.15
AsSe	$As_{40}Se_{60}$	~600	~2.8	~2.0
AsS -3	$As_{36.6}S_{63.4}$	~300	~2.4	~0.15
GeSbS	$Ge_{25}Sb_{10}Se_{60}$	~200	~2.6	~1.0



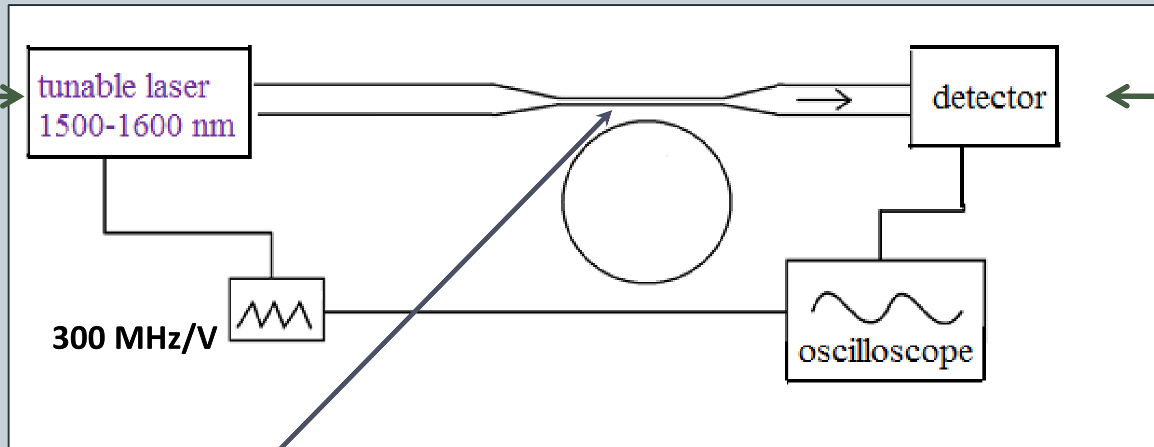




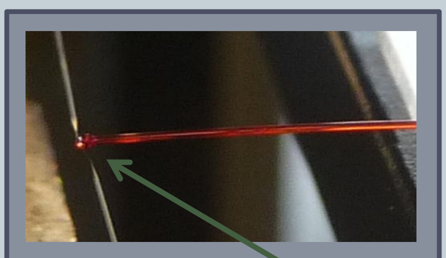
Characterisation of chalcogenide microspheres

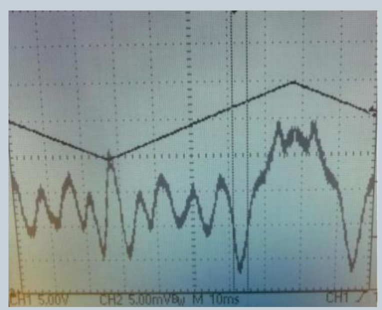
Yenista TUNICS
– T100S-HP,

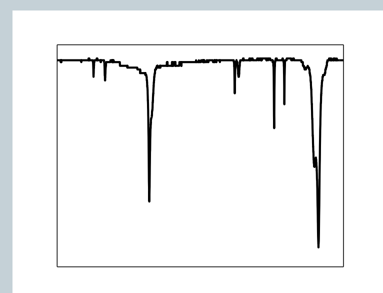
0.5 - 10 mW



InGaAs



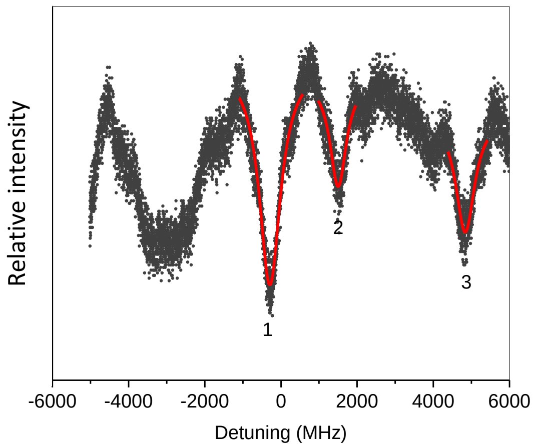




Silica taper of 2-4 µm diameter

Characterisation of chalcogenide microresonators

MR made of AsSe fiber



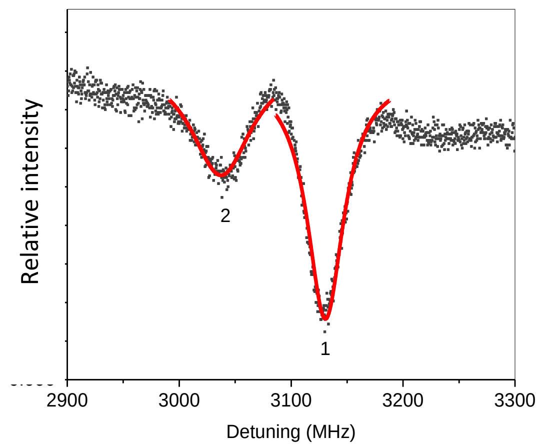
$Q_1 = 3.0*10^5$

$Q_2 = 3.6*10^5$

$Q_3 = 3.3*10^5$

$D_{max} = 870$ µm

MR made of AsS-1

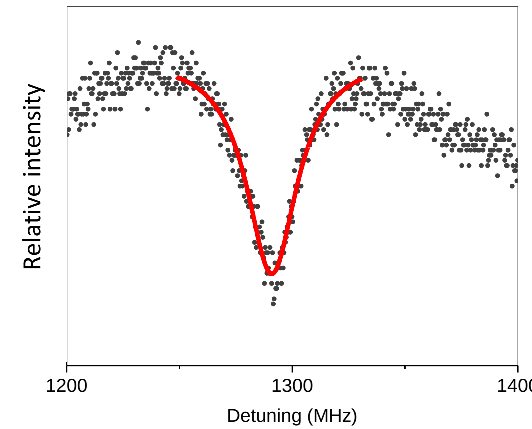


$Q_1 = 4.2*10^6$

$Q_2 = 3.0*10^6$

$D_{max} = 270$ µm

MR made of AsS-2



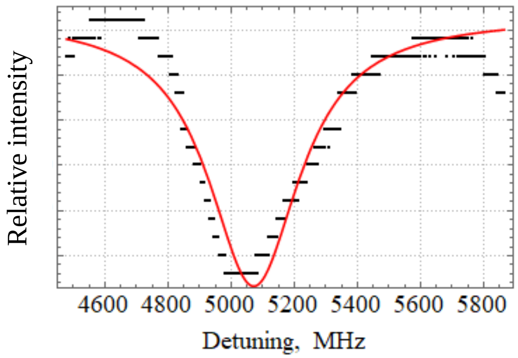
$Q = 7.6*10^6$

$D_{max} = 190$ µm

$Q = \omega_0 / \Delta\omega$ ($\lambda_0 = 1520$ nm)

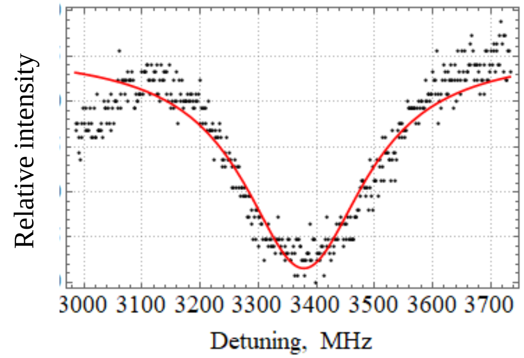
Characterisation of chalcogenide microresonators

MR made of GeSbS



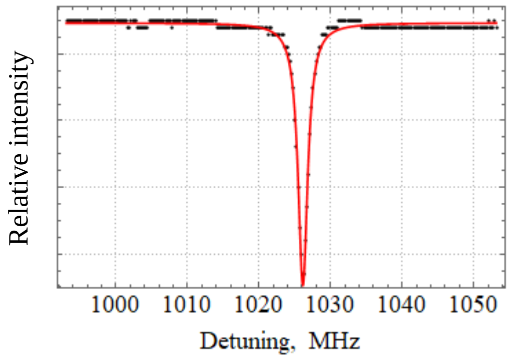
$Q=5.5*10^5$ D_{max} = 280 µm

MR made of AsS-3



$Q=7.6*10^5$ D_{max} = 450 µm

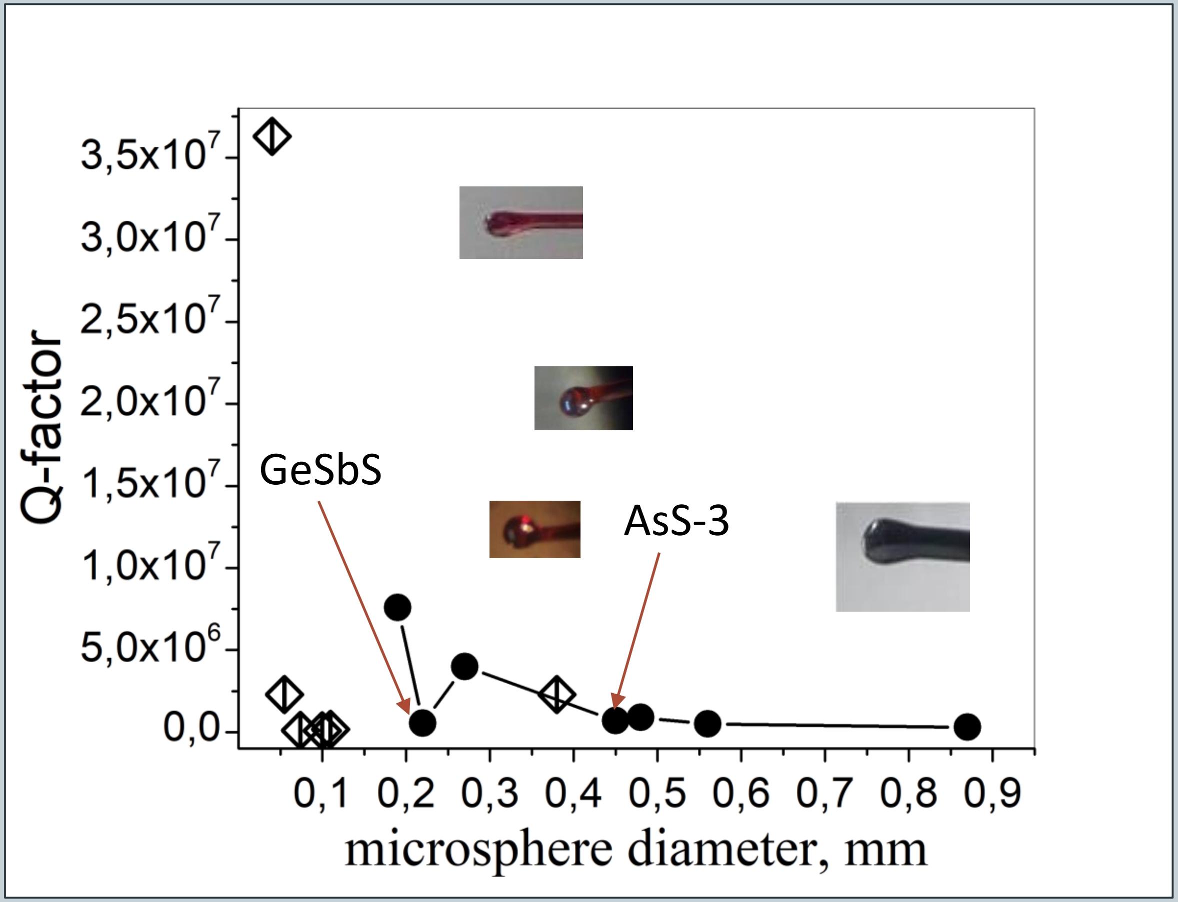
MR made of SiO_2



$Q=1.2*10^8$

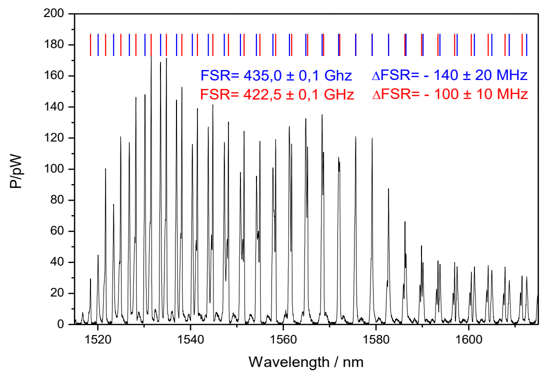
$Q= \omega_0/\Delta \omega$ (λ_0 = 1550 nm)

Characterisation of chalcogenide microspheres

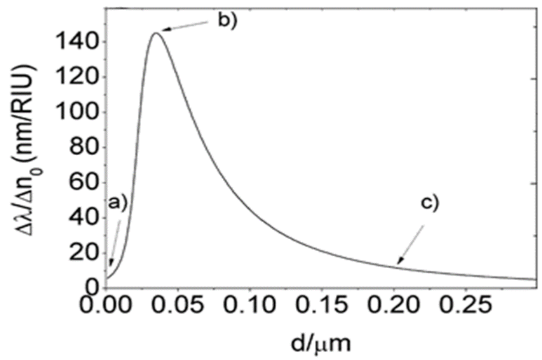


Application of coated microresonators

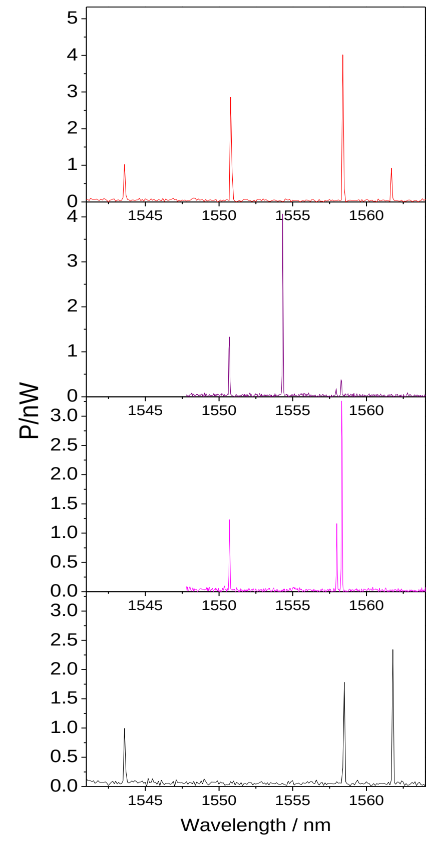
Modal dispersion tailoring



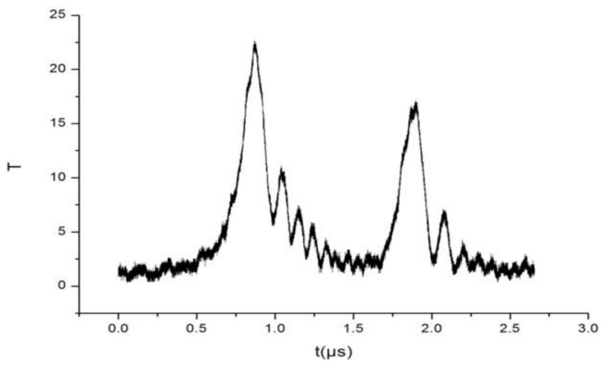
Increase sensing sensitivity



Lasing



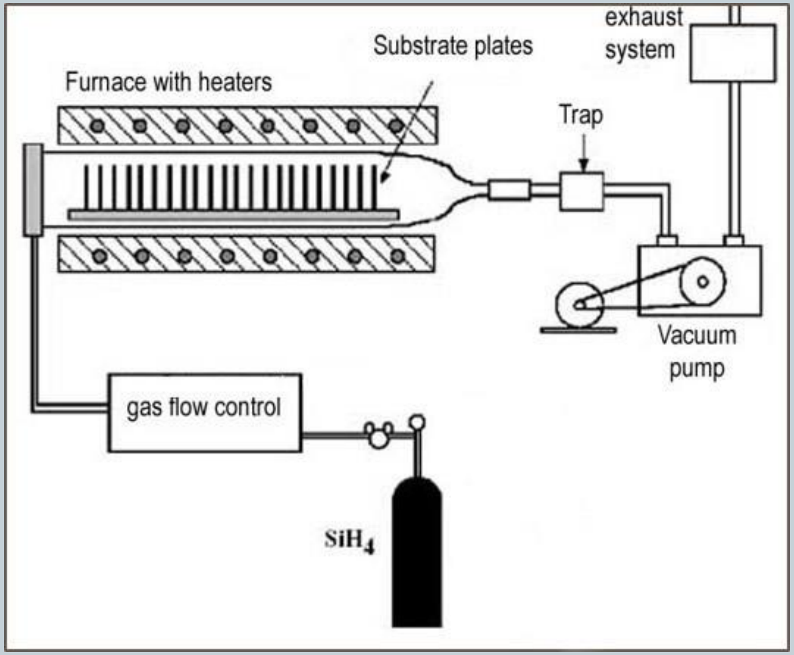
Wavelength selective amplification



Coating of microresonator spheres

- Coating of the spheres is performed by pyrolysis of silane by using LPCVD (Low-Pressure Chemical Vapor Deposition) method

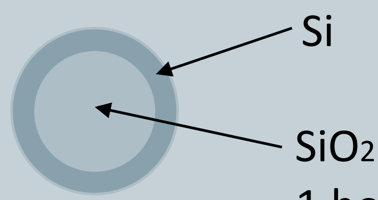
SiH_4 -> Si +$2H_2$



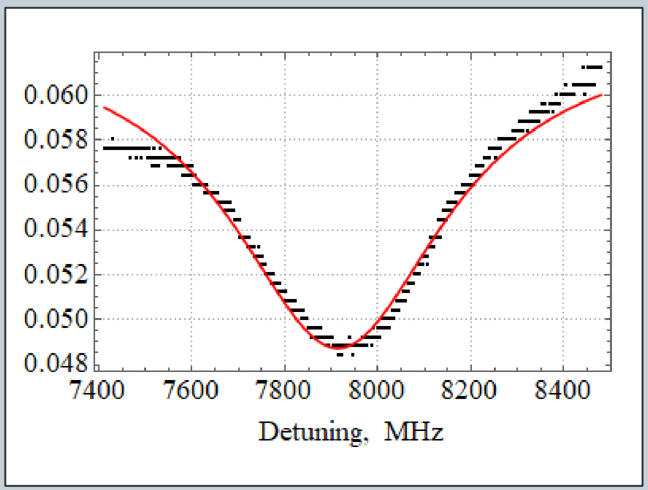
LPCVD machine, Zagreb, Ruđer Bošković Institute

Q-factor of coated silica spheres

Coated sphere

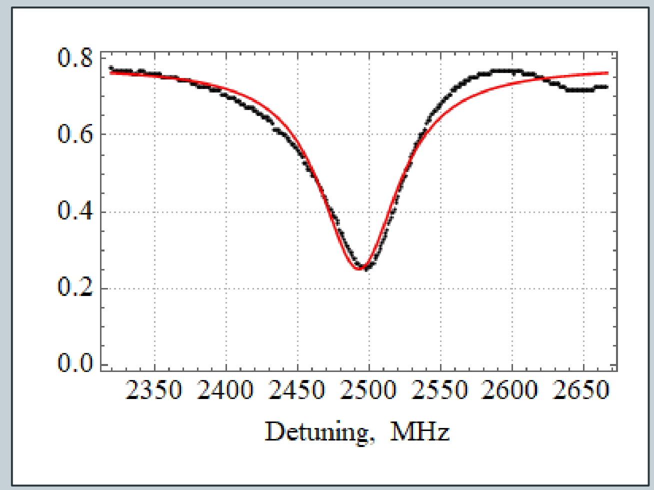


2 hour of silicon depositing



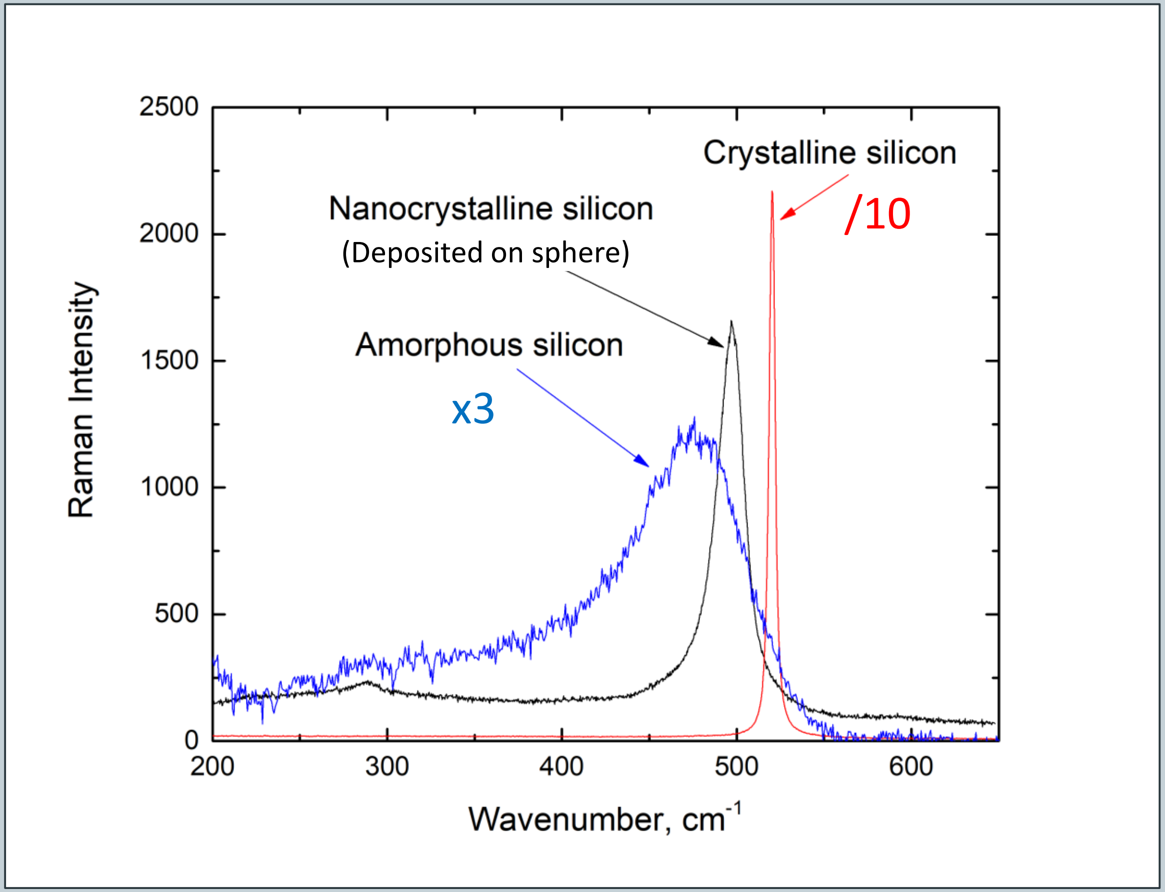
$Q = 3.4*10^5$

1 hour of silicon depositing



$Q = 3*10^6$

Raman



Crystalline silicon
/10
Nanocrystalline silicon
(Deposited on sphere)
Amorphous silicon
x3
Raman Intensity
Wavenumber, cm-1
2500
2000
1500
1000
500
0
200
300
400
500
600

Conclusions

- theoretical GVD of chalcogenide spheres has been investigated
- by using our method of the making chalcogenide spheres microresonators made of GeSbS and AsS-3 with a similar Q-factor order of 10^5 as available in the current literature has been obtained
- we deposited a nanocrystalline silicon on silica spheres having Q-factor at $3*10^6$

Future work

- Improving technique of making chalcogenide spheres
- Investigating nonlinear effects in chalcogenide and coated microresonators
- Measuring thickness of deposited layers

Acknowledgments

- *Ruđer Boškovic Institute*, Zagreb, Croatia
- Saratov State University, Saratov, Russia
- Institute of Chemistry of High Purity Substances of RAS, Nizhny Novgorod, Russia
- *CNR-IFN – Istituto di Fotonica e Nanotecnologia*
- *IFAC-CNR*, Istituto di Fisica Applicata Nello Carrara, Firenze
- *Facoltà di Scienze - Dipartimento di Fisica Univ. Trento*
- *FBK- Center for Materials and Microsystems*
- *Politecnico Bari, Dip. Elettrotecnica ed Elettronica*
- *Ecole Nationale Supérieure des Sciences Appliquées et de Technologies*, Lannion France
- *Centre National d'Etudes Spatiales (CNES), Toulouse, France*

We acknowledge the support of the COST MP1401 action and the support of the project number IP-2014-09-7046 of the Croatian science foundation