Workshop "Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen"

Organische und anorganische durchstimmbare photonische Mikrokavitätsbauelemente für die Datenübertragungstechnik

Organic and inorganic tunable photonic micro-cavity devices for optical communications

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Content

Motivation and basics

Novel low-cost technology for optical MEMS devices

Stress investigation

- Macroscopically averaged stress (macro stress)
- Microscopically detected stress (micro stress)
- Impact of the stress on cavity length & FWHM of the filters, shape & ROC of the membranes

Optical devices

- Low-cost tunable dielectric Fabry-Pérot filters
- Tunable and non tunable VCSELs

Organic light emitting devices involving novel materials

Summary and outlook

Motivation

Low-cost components

Dielectric microstructures

→ Material characterization

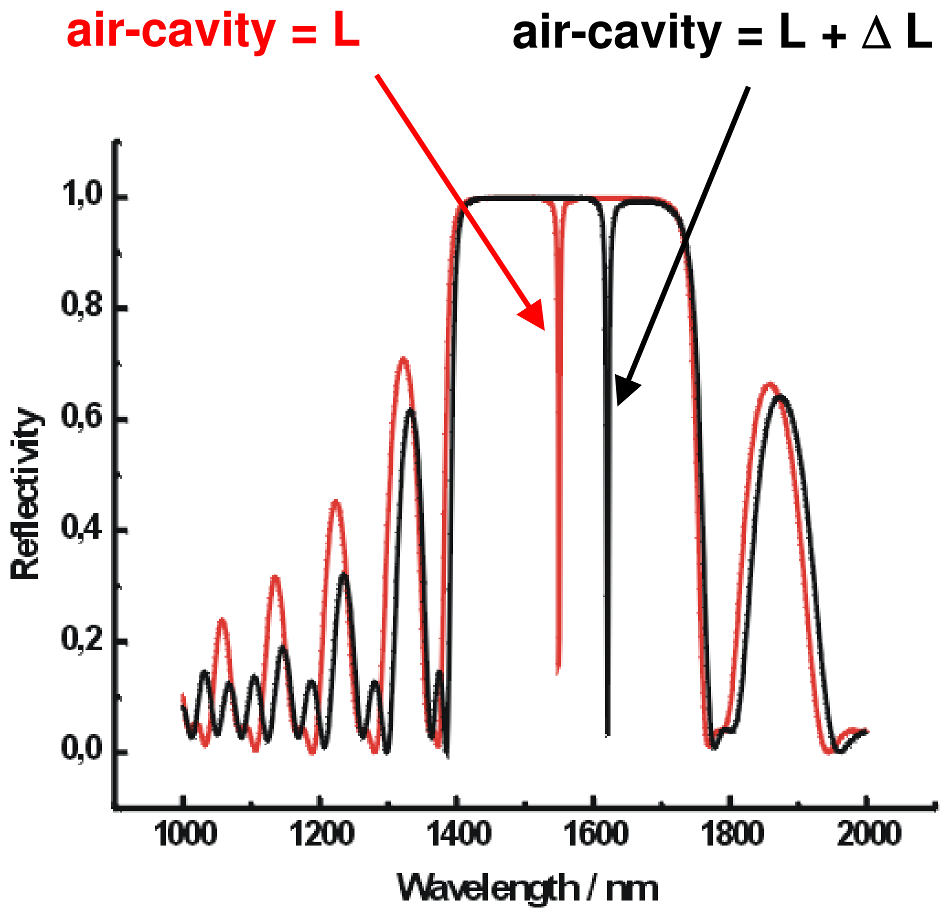
Tunable passive and active air-gap micro-cavity devices

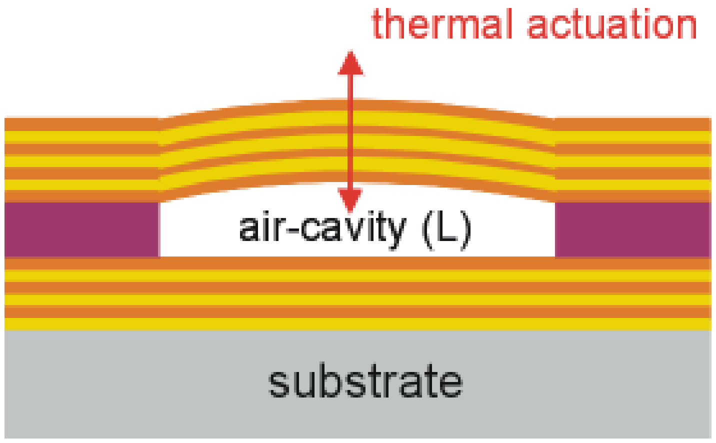
→ Dynamic DWDM systems (filters and VCSELs)
→ Spectroscopy and sensorics
→ Wavelength monitoring
→ Medical applications

Organic light emitting diodes (OLEDs)

→ Display technology (e.g. laser TV, true colors big pannels 10x20m)
→ Information technology (e.g data storage)

Basics

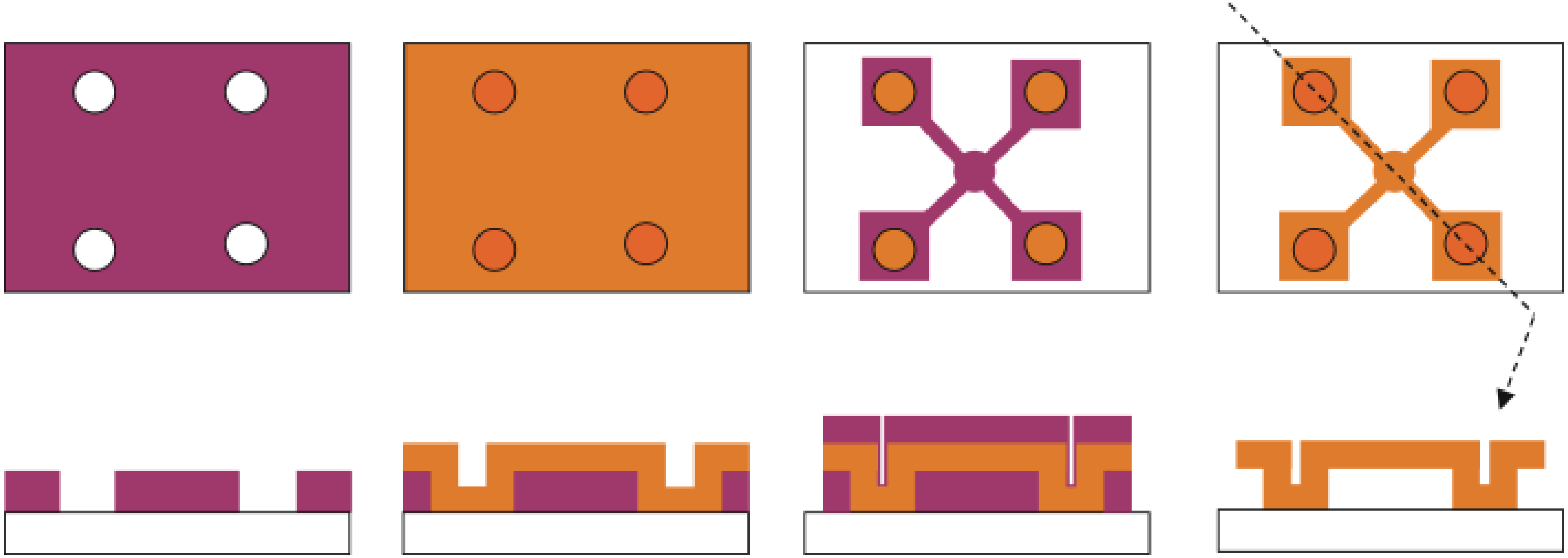




Change in air-cavity length (L)
⇒ Change in optical path
⇒ Shifting of the cavity peak position

Novel low-cost technology

Bridge-like dielectric membranes



Lithography:
Sacrificial layer
(standard photo
resist)

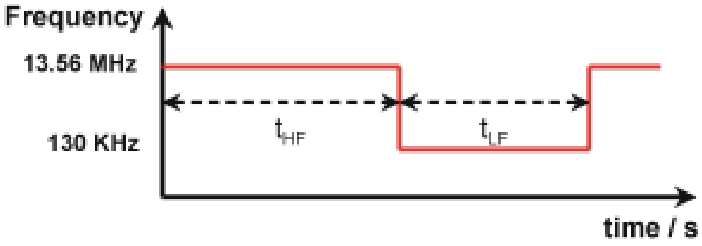
Deposition:
Low temperature
SiO_2 , Si_3N_4
(PECVD)

Patterning:
Vertical (Mesa): dry
etching (CHF_3 /Ar)
Lateral: lithography

Underetching:
Wet etching:
Aceton/2-isopropanol
Dry etching: O_2-
plasma

Material characterization

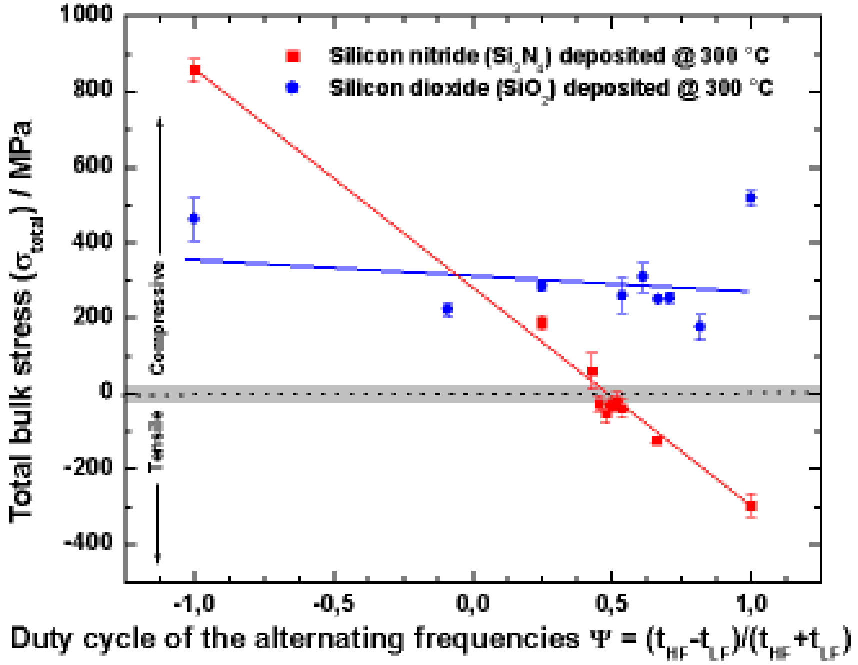
Stress of PECVD Si_3N_4 and SiO_2

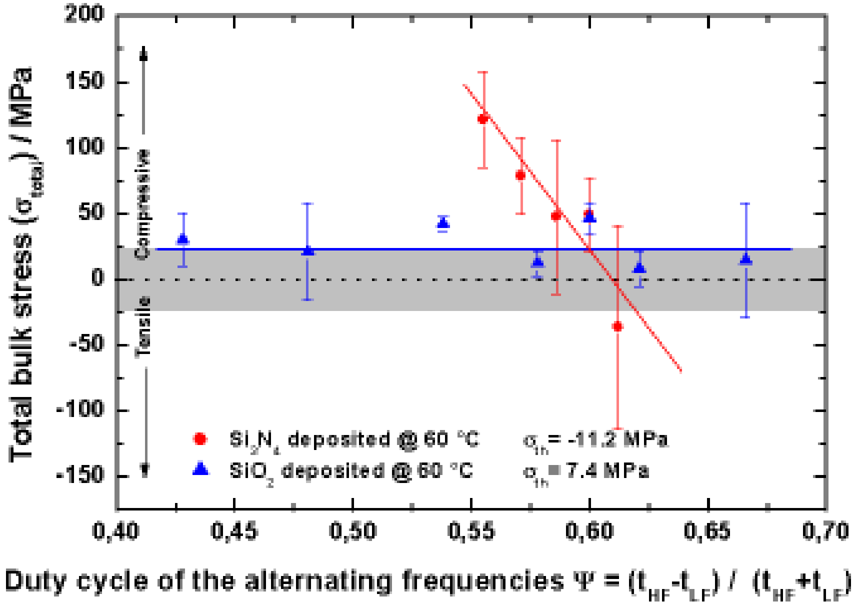


Stress control

Range: 850 MPa → -300 MPa
for SiNx @ 300°C

Silicon dioxide does not depend strongly on the frequency

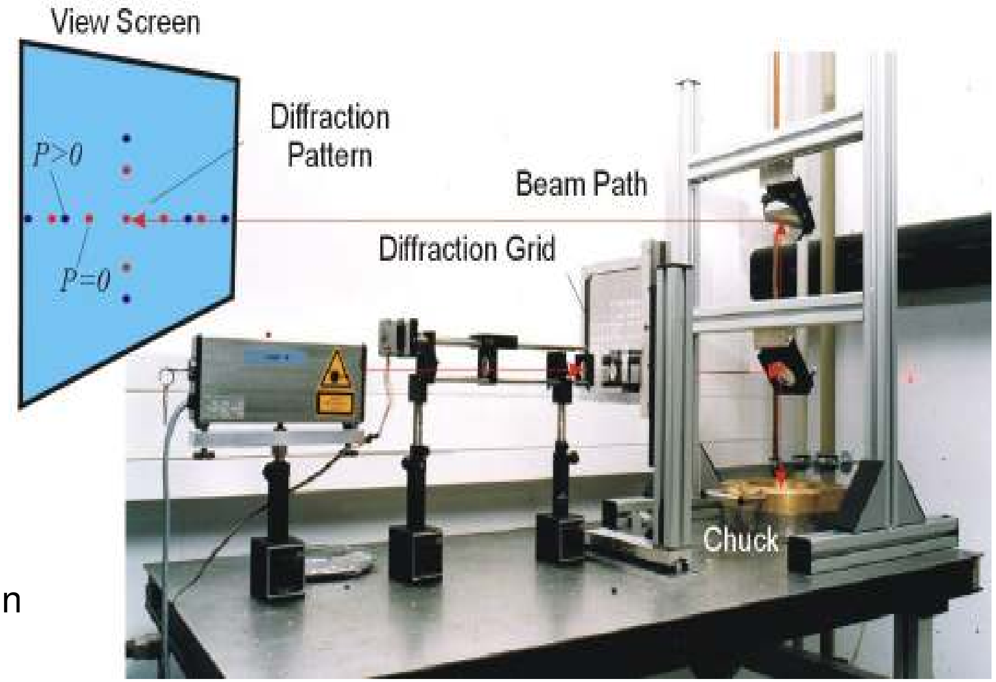




Material characterization

Macro stress measurement set-up

$$\sigma_{Bulk,\ total} = \frac{E_s}{6\,(1-\nu_s)}\,\frac{t_s^2}{t_f}\left(\frac{1}{R_2}-\frac{1}{R_1}\right)$$

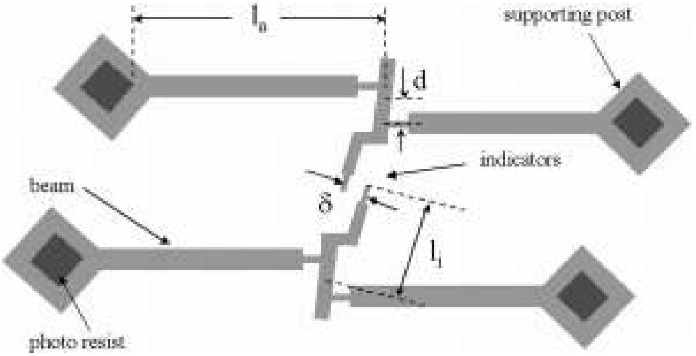


E_s	Young modulus of the substrate
ν_s	Poisson ratio of the substrate
t_s	Thickness of the substrate
t_f	Thickness of the layer
R_2	Radius of curvature before the deposition
R_1	Radius of curvature after the deposition

Advantage: fast estimation of the global stress
Disadvantage: inhomogeneities in the layers can not be considered

Material characterization

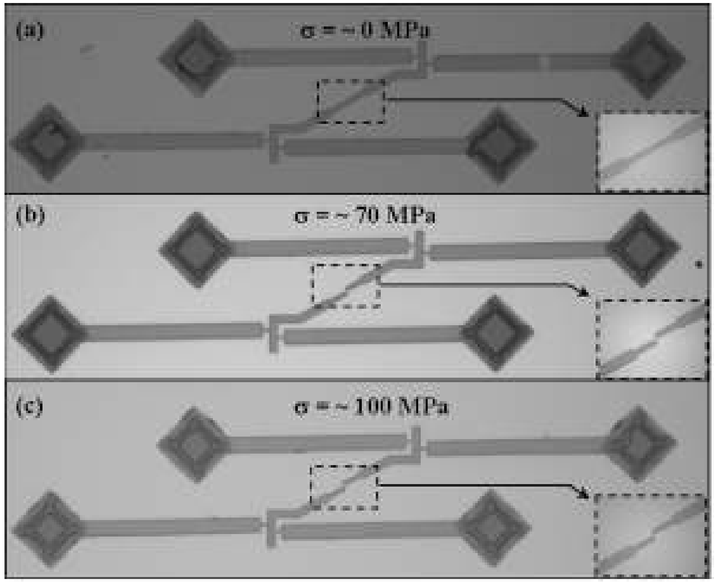
Stress measurement: micro stress



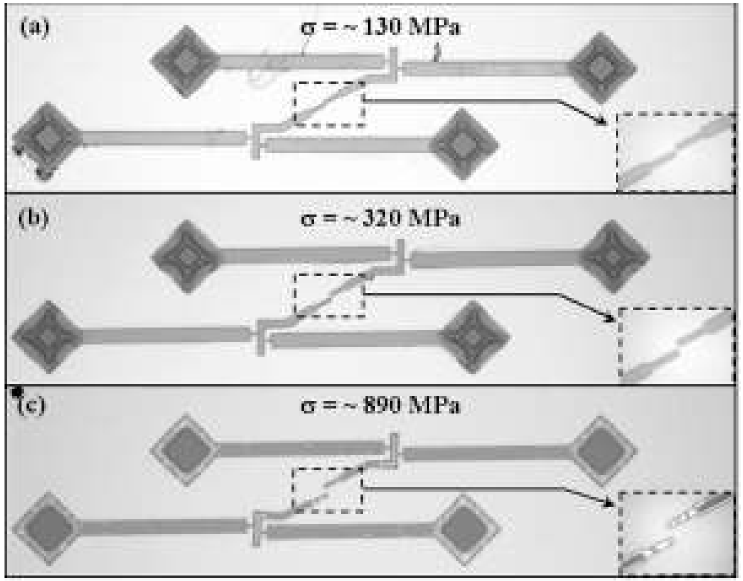
$$\sigma_{Bulk} = \frac{E}{1 - \nu} \frac{d}{2 l_i l_a} \delta$$

σ_{hom}	Homogeneous stress
E	Young modulus of the layer
ν	Poisson ratio of the layer

SiO_2



Si_3N_4



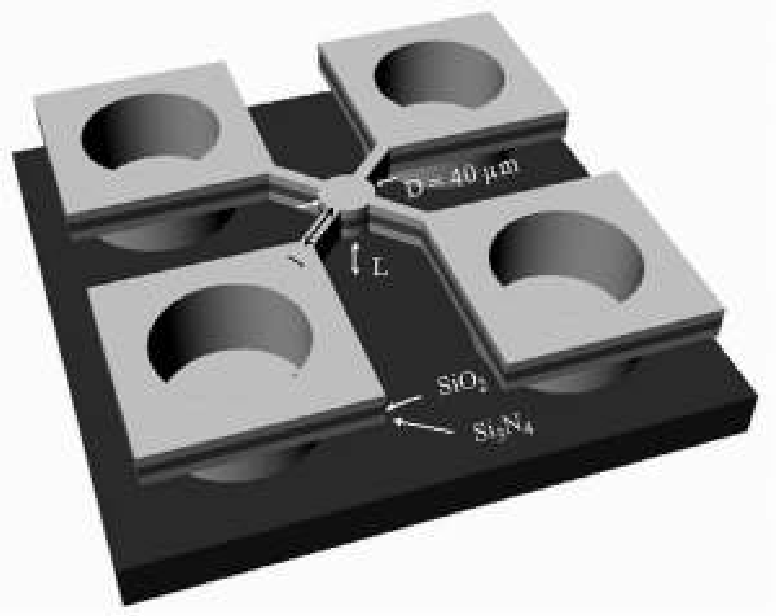
Micro devices

Impact of stress

Cavity length (L), ROC and FWHM of the filters are affected by the stress and lateral design

Different structures on the mask ensure a wide range of variation of the optical parameters in one Batch-Process:

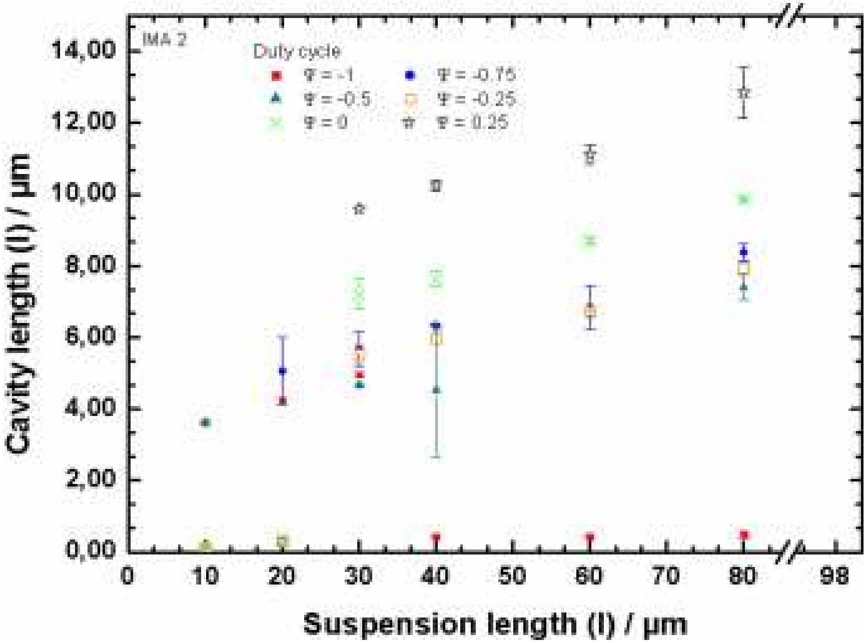
ROC:	-9 mm……15 mm
Cavity length:	130 nm……13 µm
FWHM:	1.5 nm……70 nm
$\Delta\lambda$ =	200 nm (Filter dip positions)

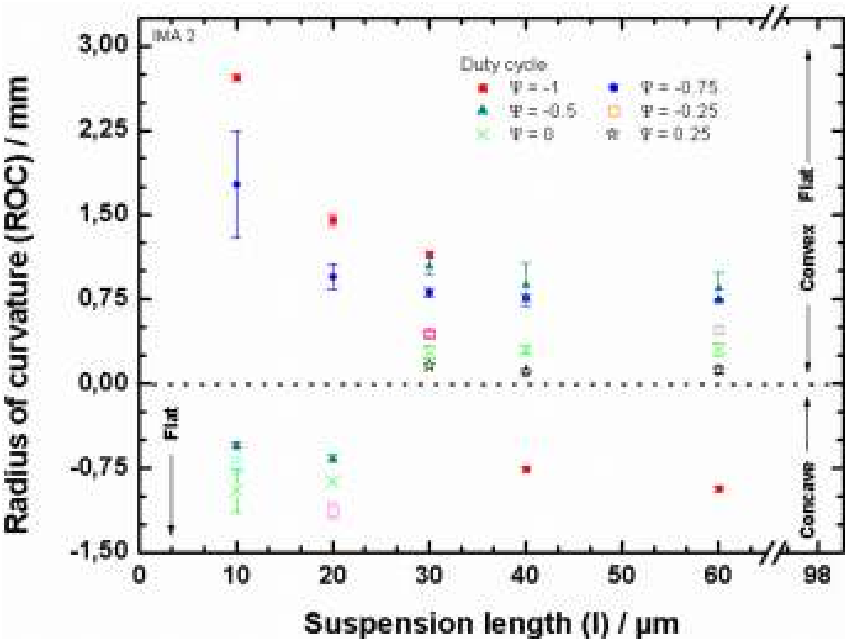


3D view of a suspended membrane, implemented bei the mask set **IMA2**

Micro devices

Examples of optical parameters variation





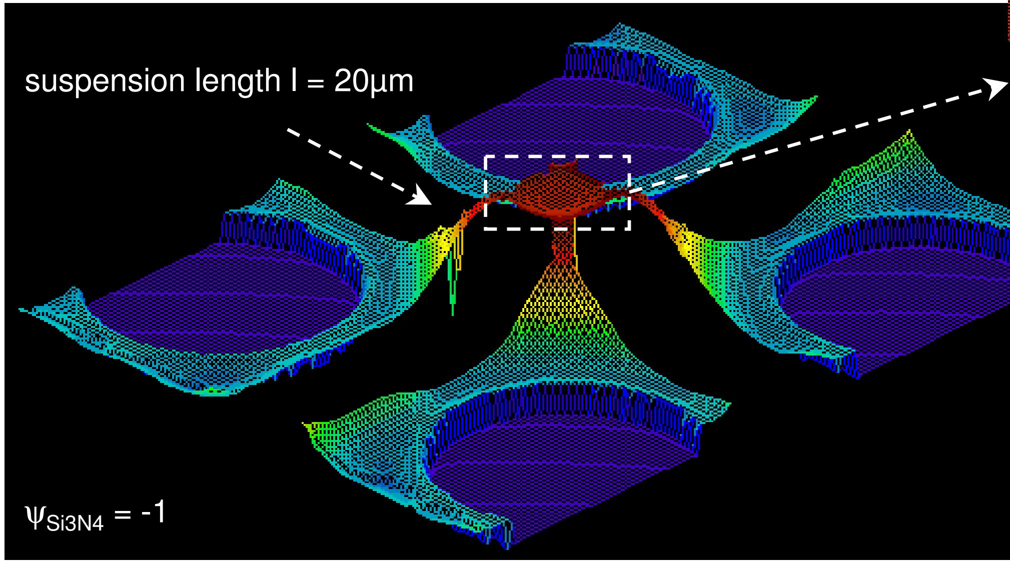
Examples:

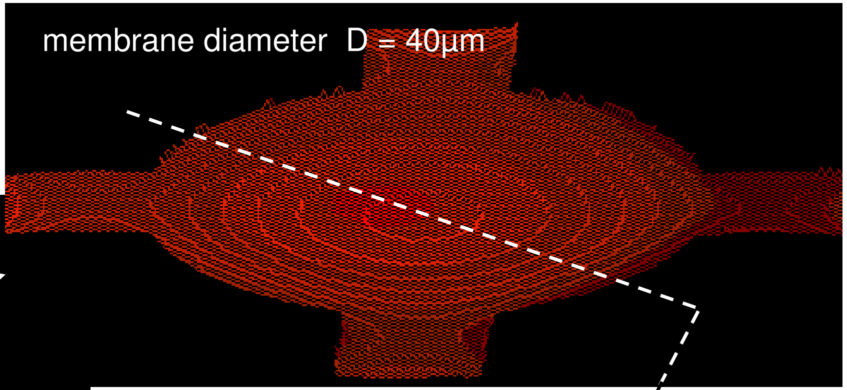
Variation of the optical properties of micro devices in a Batch-Process

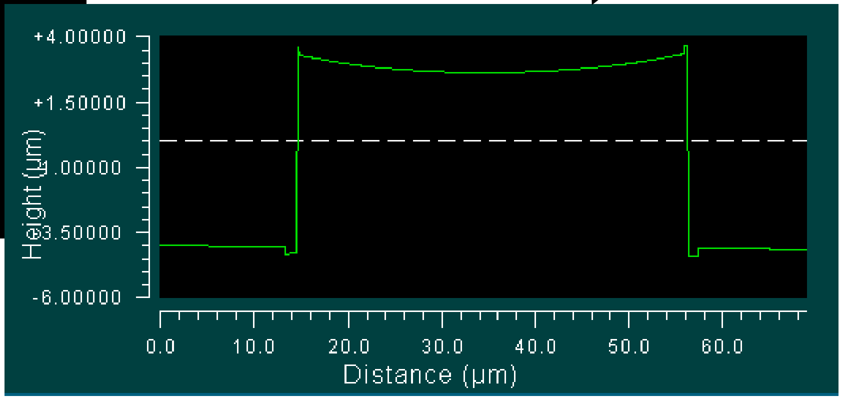
Curved dielectric membrane

Concave DBR

White light interferometry graphs of dielectric (Si_3N_4/SiO_2) membranes, directly in contact to the base plane



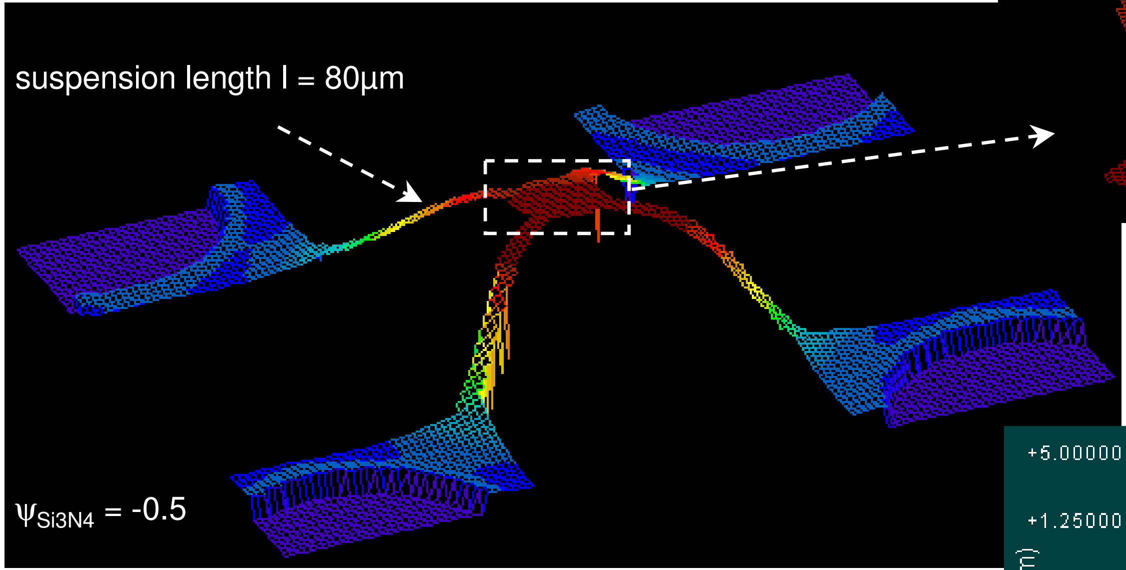


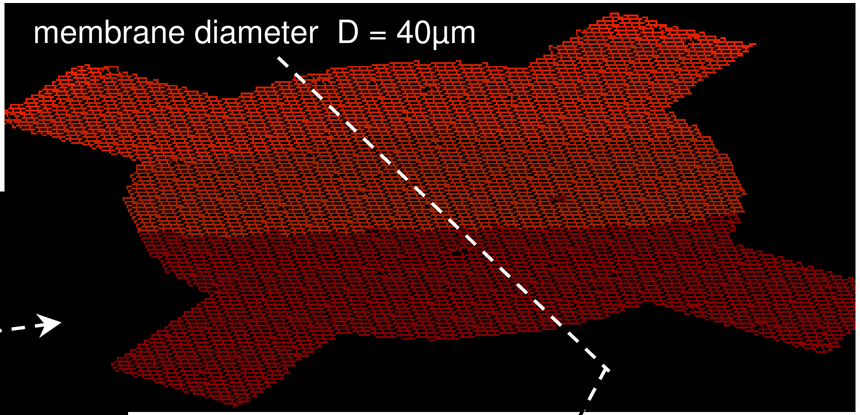


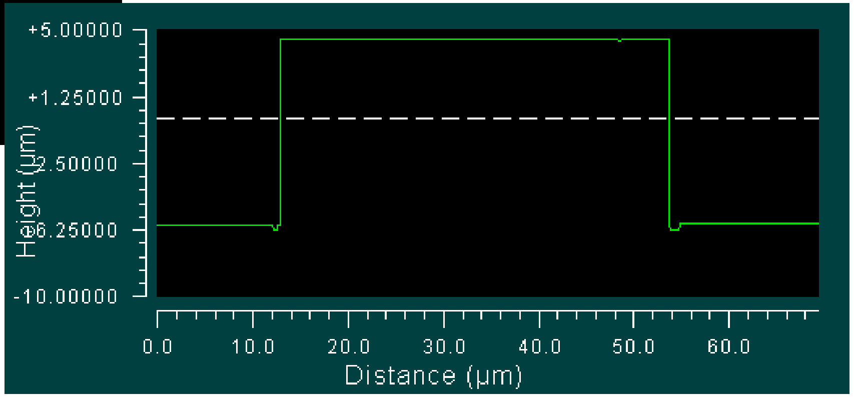
surface profile of a dielectric membrane with a radius of curvature = - 0.31 mm

Curved dielectric membrane

White light interferometry graphs of dielectric (Si_3N_4/SiO_2) membranes, directly in contact to the base plane





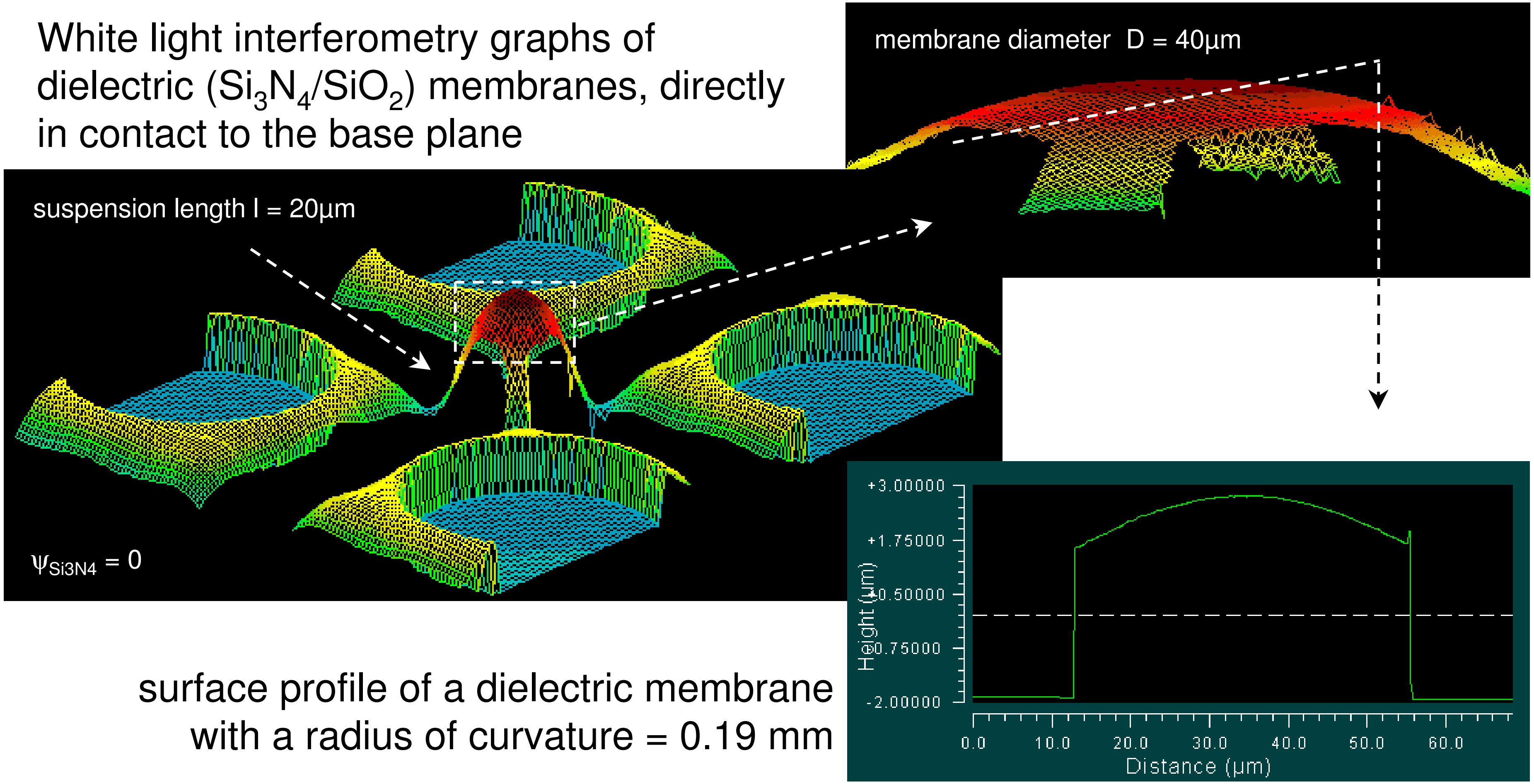


surface profile of a dielectric membrane with a radius of curvature = - 184.71 mm

Curved dielectric membrane

Convex DBR

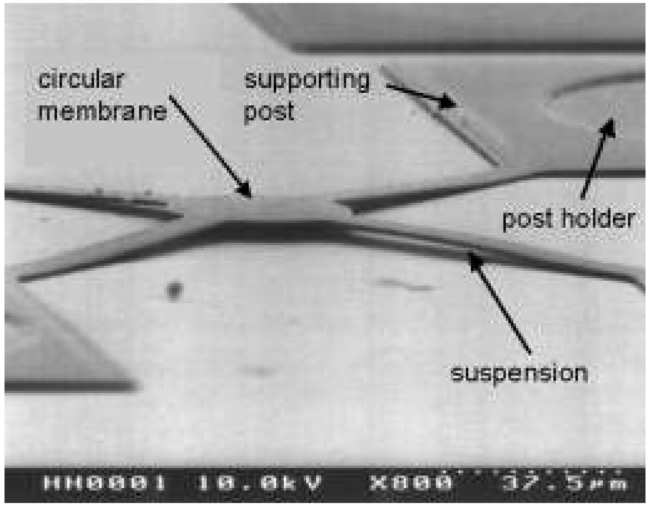
White light interferometry graphs of dielectric (Si_3N_4/SiO_2) membranes, directly in contact to the base plane



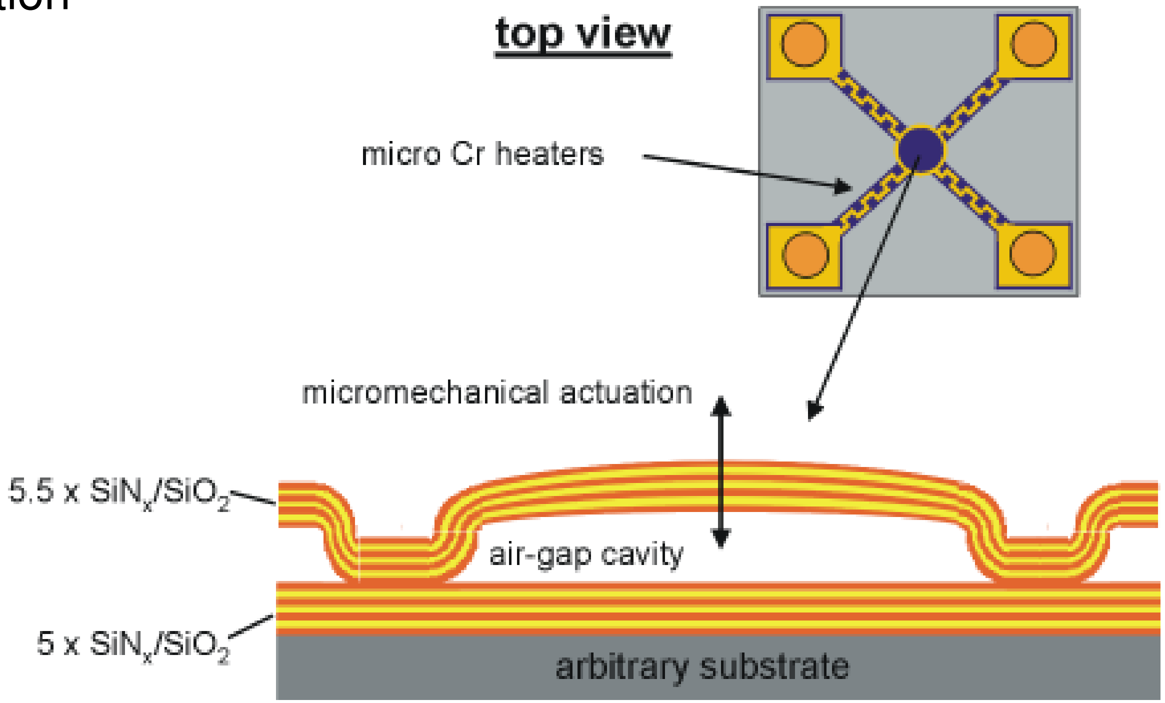
surface profile of a dielectric membrane
with a radius of curvature = 0.19 mm

Design of novel tunable low-cost dielectric filter

Integration of active polymers possible
High index contrast in DBR´s
Tuning by thermal actuation
Arbitrary substrates
Low-cost

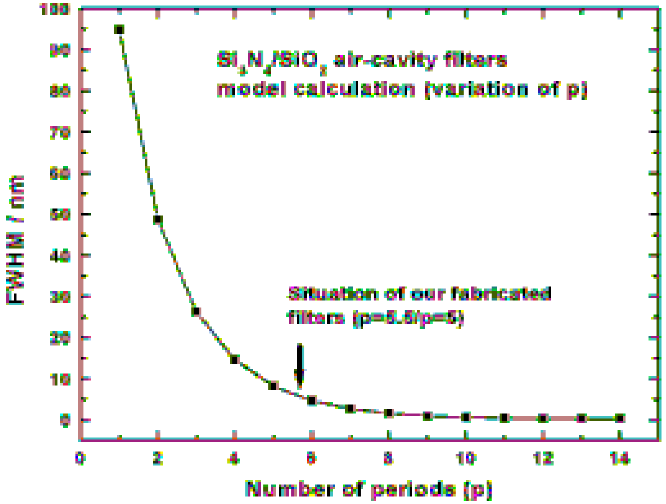


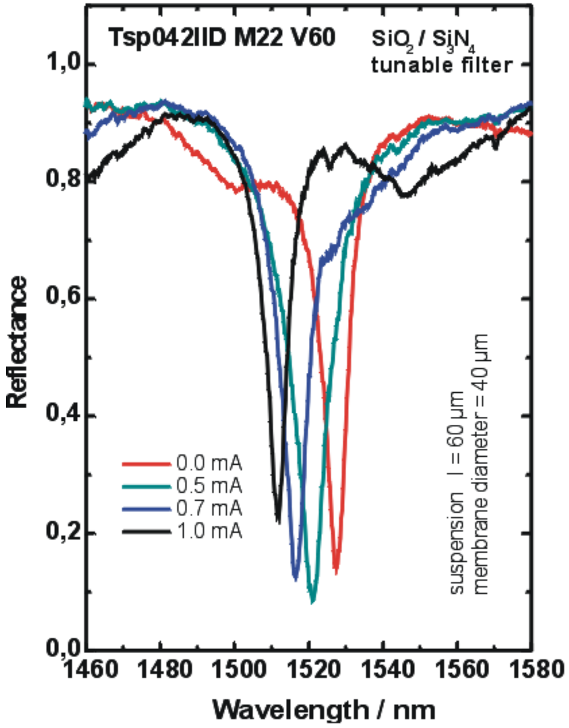
SEM picture of a 3.5 periods Si_3N_4/SiO_2 suspended membrane

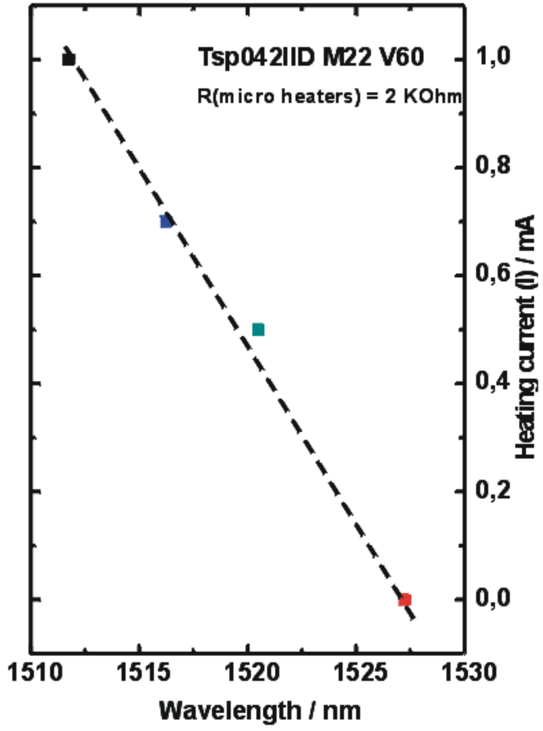


Tunable dielectric filter

FWHM = 8 nm
Tuning = 15 nm/mA @
2 kOhm heaters resistance



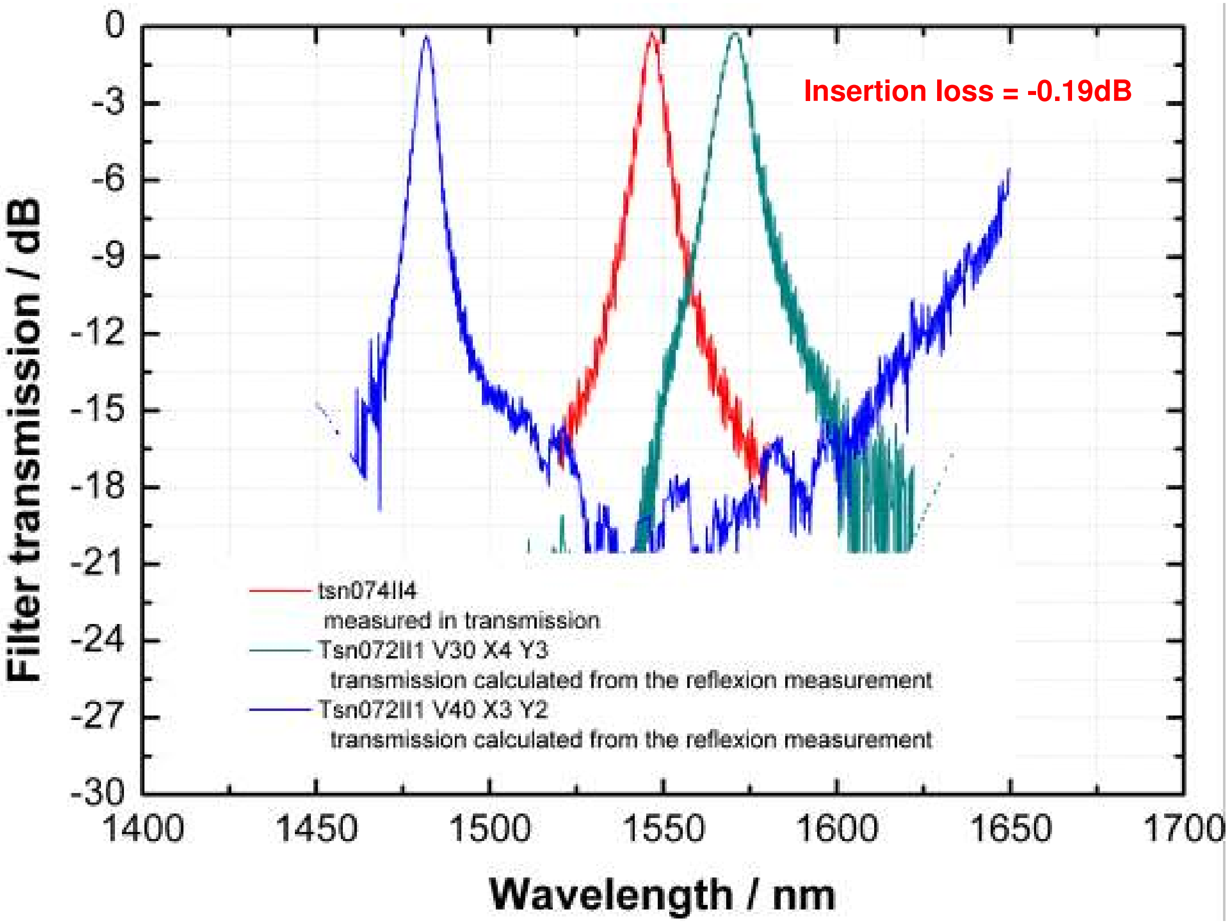




FWHM can be improved
by increasing the reflectivity
of the DBRs and by increasing
the cavity length (L)

Dielectric filter

Insertion loss

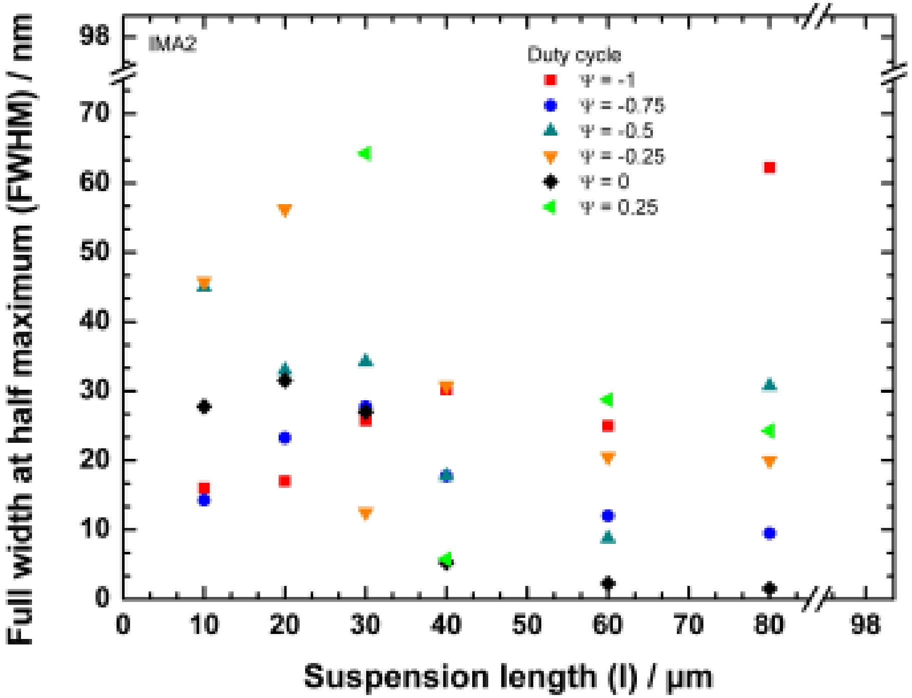


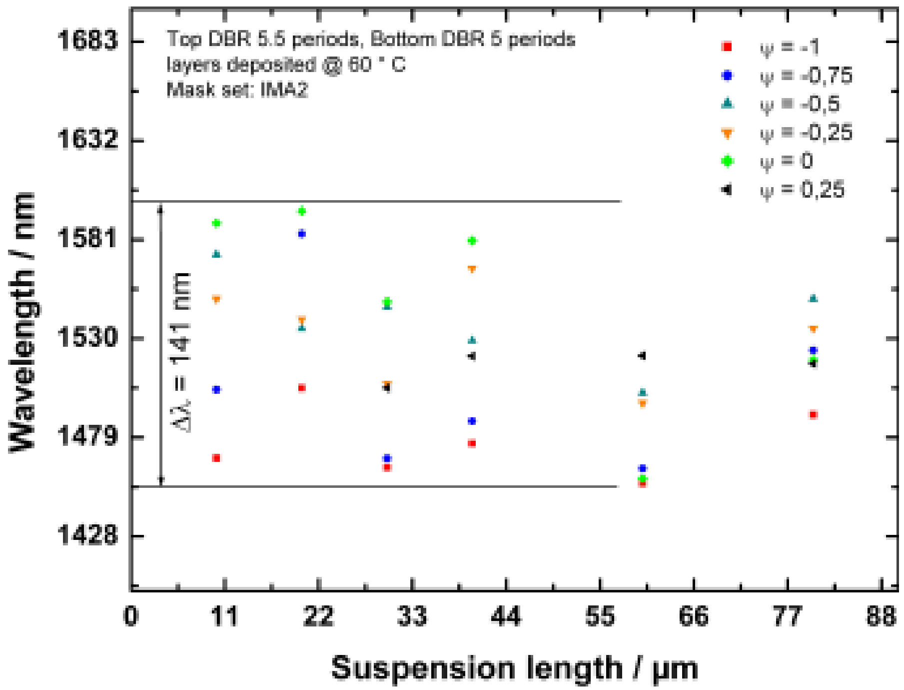
Insertion loss = -0.19 dB
FWHM = 5.5 nm
DBR1 = 5 periods
DBR2 = 5.5 periods
Sacrificial layer = 2.2 µm

Tunable air-gap dielectric filter

FWHM

Depending on the lateral design and stress, different FWHM and filter dip positions are possible



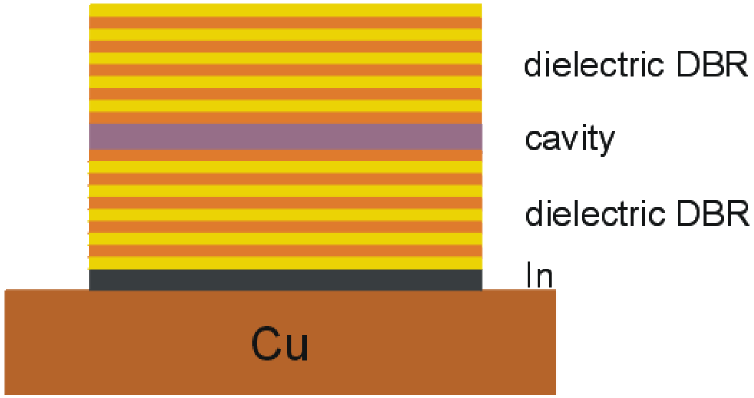


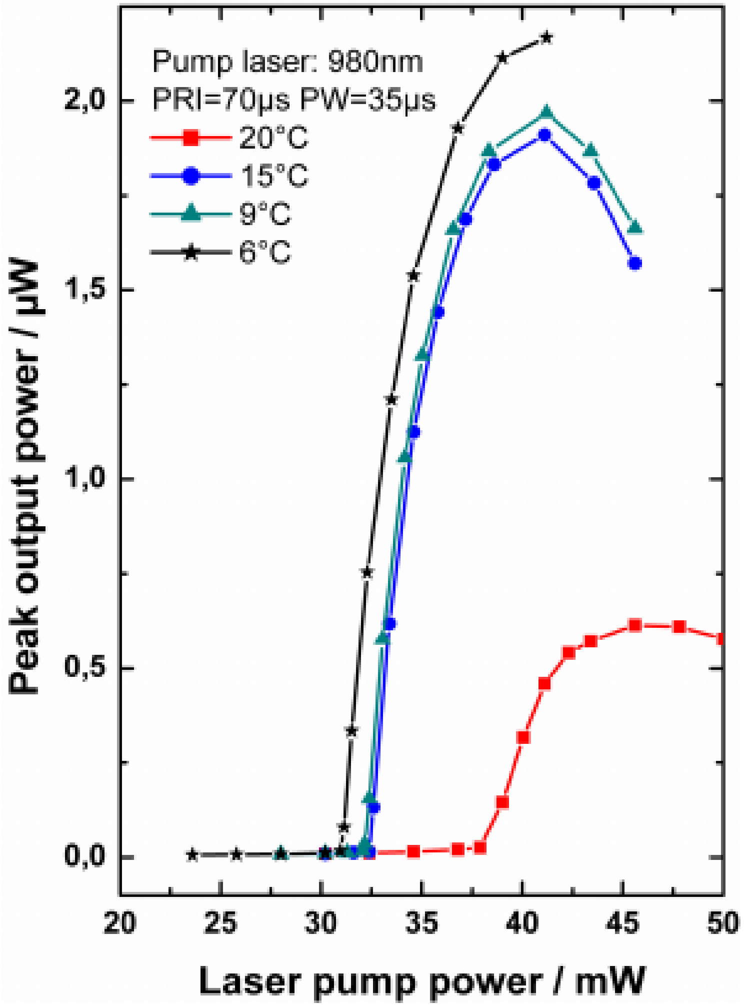
Non tunable VCSEL (optically pumped)

1-Chip concept

VCSEL
Emission wavelength 1566.7 nm
Max. output power 0.5 µW @ RT
FWHM < 0.1 nm
SMSR 25 dBm

Pump laser
Pump wavelength 980 nm
Pulse repetition interval (PRI) 70 µs
Pulse width 35 µs





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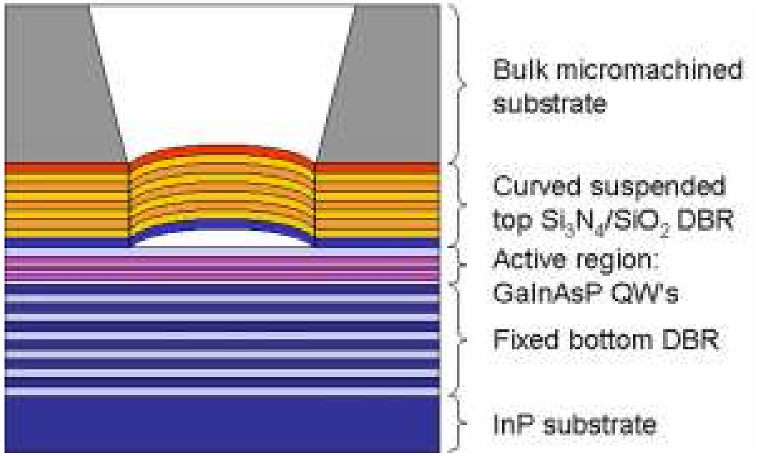
Tunable VCSEL (optically pumped)

2-Chip concept



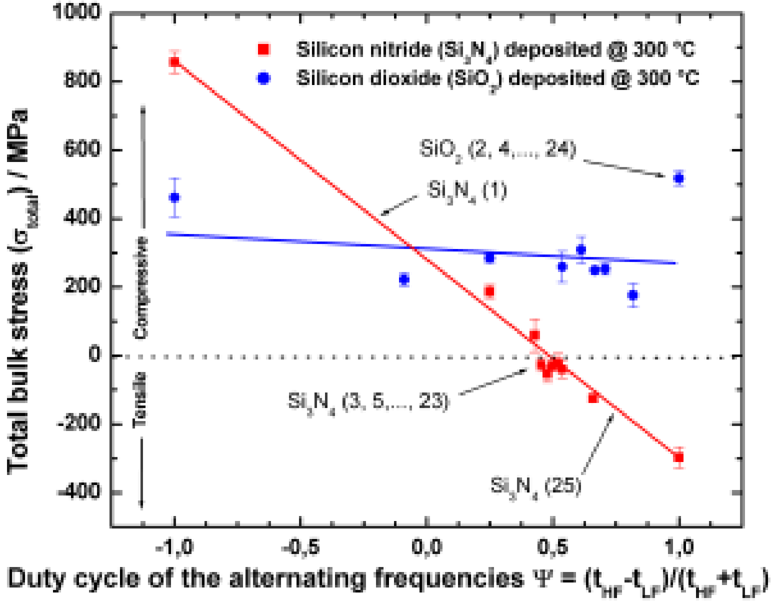
Bulk micromachined substrate

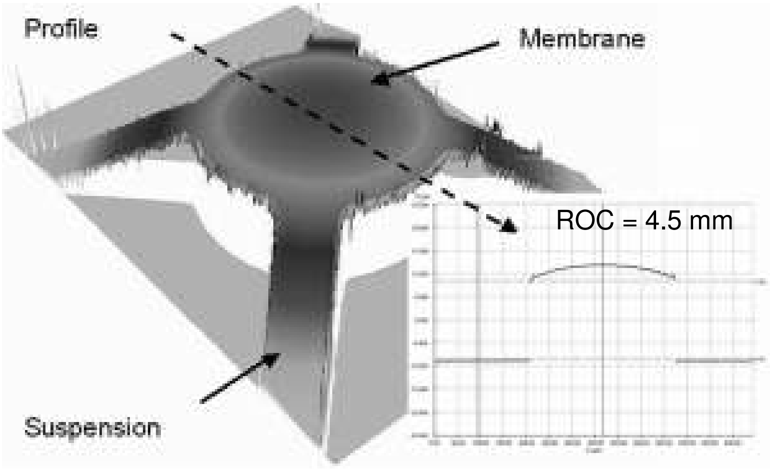
Curved suspended top Si_3N_4/SiO_2 DBR

Active region: GaInAsP QW's

Fixed bottom DBR

InP substrate



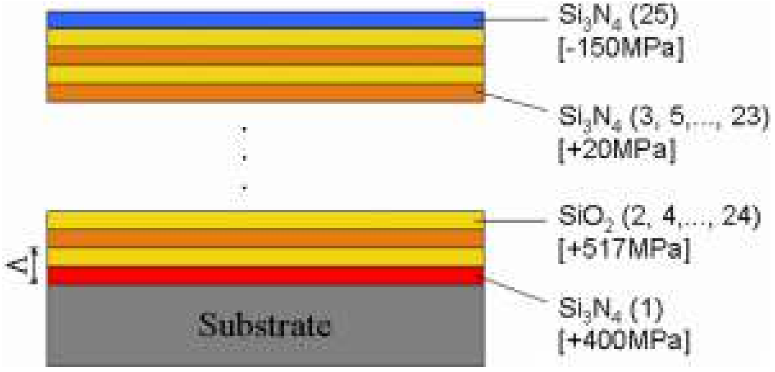


Profile

Membrane

ROC = 4.5 mm

Suspension



Si_3N_4 (25) [-150MPa]

Si_3N_4 (3, 5,..., 23) [+20MPa]

SiO_2 (2, 4,..., 24) [+517MPa]

Si_3N_4 (1) [+400MPa]

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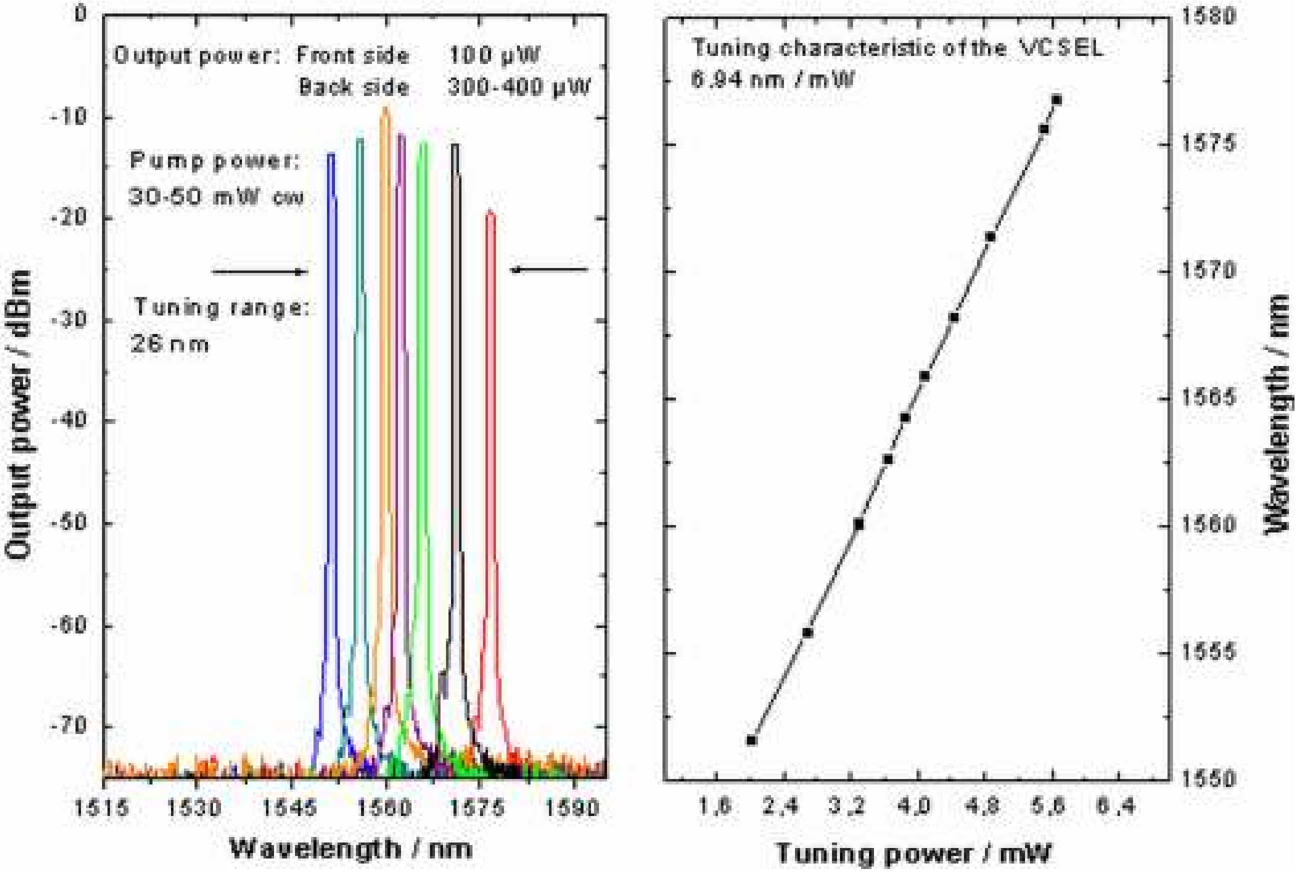
Tunable VCSEL (optically pumped)



New generation of stress induced curved membranes

- 2D modell calculations of the membrane (TUD) + Electrically pumped half-VCSEL (WSI)
- Implementation by PECVD (IMA) delivered ROC = 1mm suitable for elec. pump. tun. VCSEL

Organic active devices

Passive filter device + Active material = Active organic device

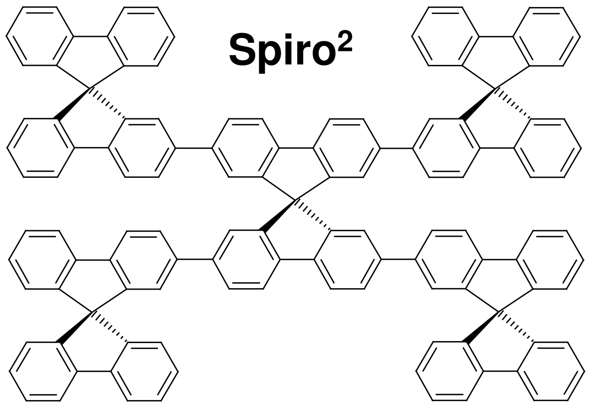
Spiro²: 2,2',7,7'-Tetra-(9,9'-spirobifluoren-2-yl)-9,9'-spirobifluorene

Physical properties

T_g=273℃ T_m=447℃ ⇒ good process ability

Optical properties

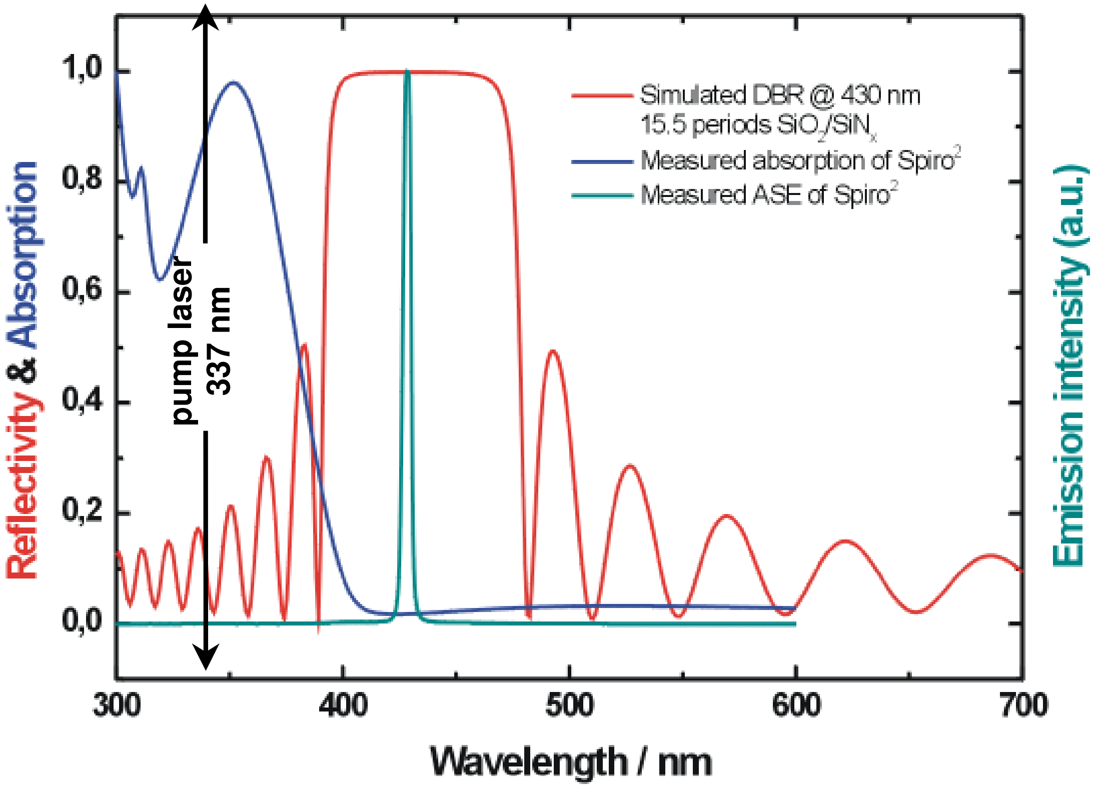
λ_{abs}=353nm λ_{em}=429nm

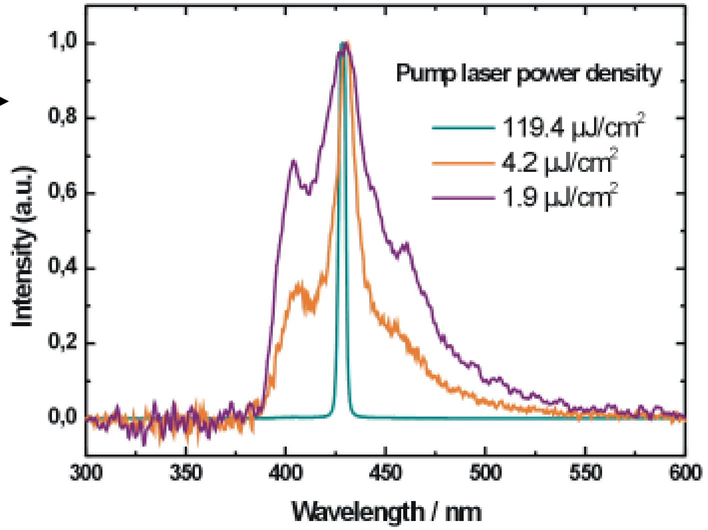


New organic light emitting material

Spiro²

Amplified spontaneous emission (ASE) of Spiro² is observed @ 3.2 µJ/cm² laser pumping threshold power density





The ASE peak is located @ 428nm and has a FWHM of 3.2nm

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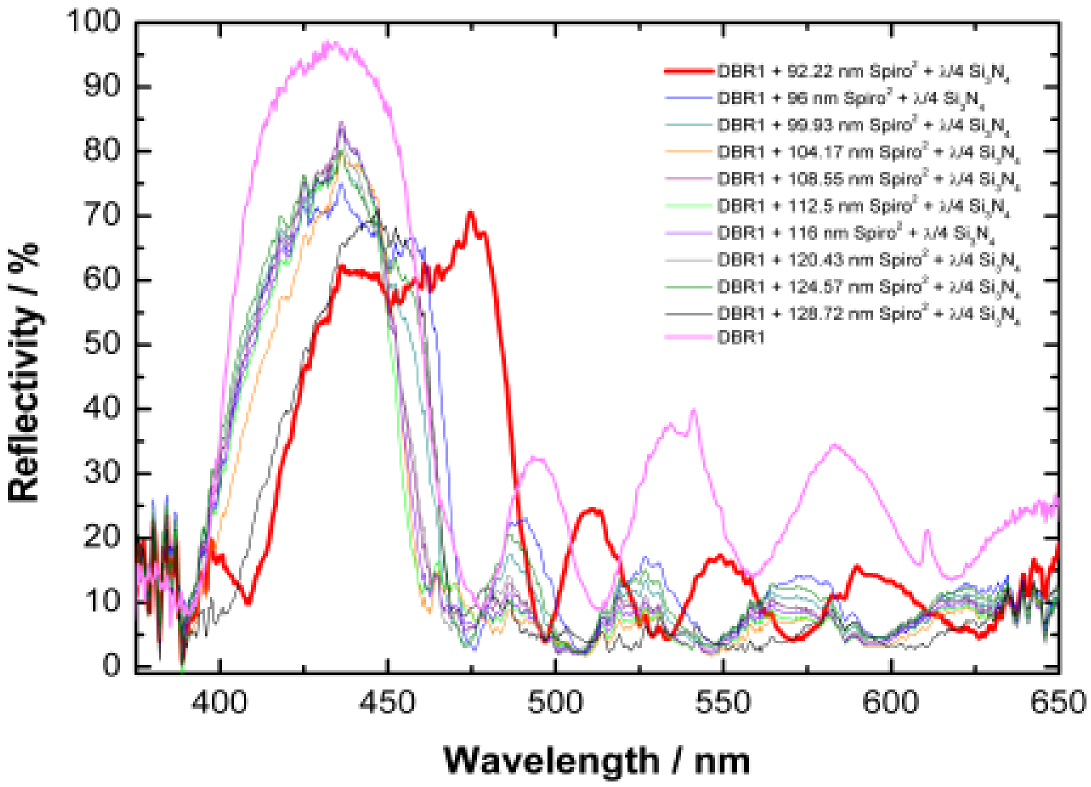
CINSaT

mmCmm

Organic light emitting devices

Spiro^2



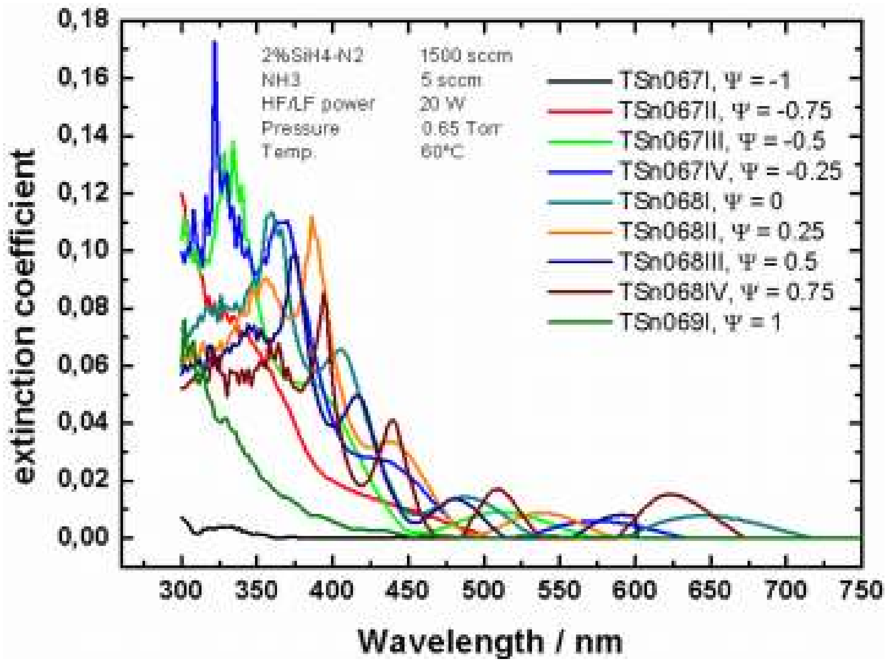
Half cavity dip is observed in organic micro cavity devices: DBR1 + 92.22 nm Spiro^2 + λ /4 Si_3N_4

DBR2: Organic VCSEL in the blue wavelength range ???

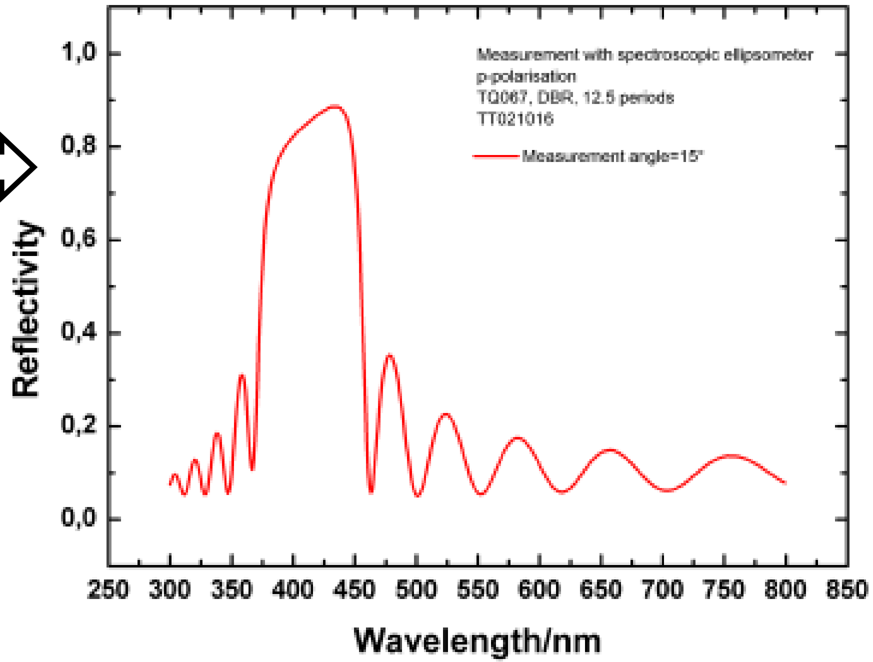
IMA know-how:
Micromechanics tunable organic blue VCSEL

Material disadvantage

Si_3N_4: Absorption



⇨



⇨ Novel optoelectronic devices requires new materials and technologies (e.g. IBD)

Summary / Objectives

Material characterization

→ Stress control in dielectric films

→ Control of the cavity length, ROC, FWHM in optical filters by varying the stress and lateral design

→ Implementation of concave, convex and planar optical suspended membranes

Air-gap micro-cavity devices

→ Tunable filters (thermal actuation, 15nm/mA, FWHM=8nm)

→ Non tunable VCSELs (1-chip concept, output power 2.5 µW)

→ Tunable VCSELs (2-chip concept, output power 300-400 µW, 26nm tuning range)

New organic light emitting material and devices

→ Excellent optical and mechanical properties of Spiro^2

→ Half organic micro cavity devices

Objectives

→ to enhance optical and mechanical device properties

→ Tunable organic blue RCLEDs and maybe tunable organic blue VCSELs??

→ Electrically pumped tunable VCSEL (1.55 µm)

→ Application of new materials (low losses) and new deposition techniques (IBD-systems)

Acknowledgement

IMA: J. Daleiden, D. Gutermuth, H. Hillmer, S. Irmer, T. Tscherner, V. Rangelov, F. Römer

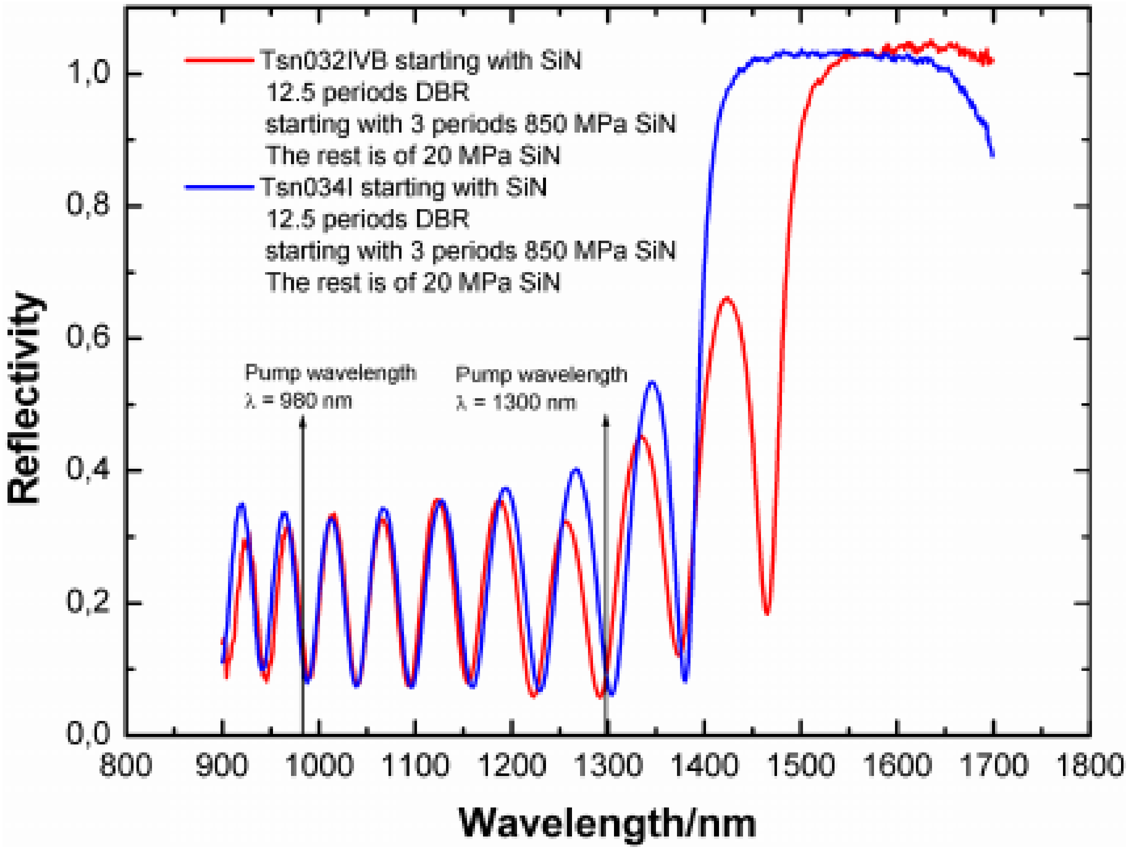
mmCmm: T. Fuhrmann, T. Spehr and J. Salbeck

KTH: M. Strassner and N. Chitica

TUD: F. Riemenschneider, H. Halbritter and P. Meißner

Distributed Bragg reflectors

Suitable for optical pumping



DBRs with different stress values and central wavelengths suitable for optical pumping are possible

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