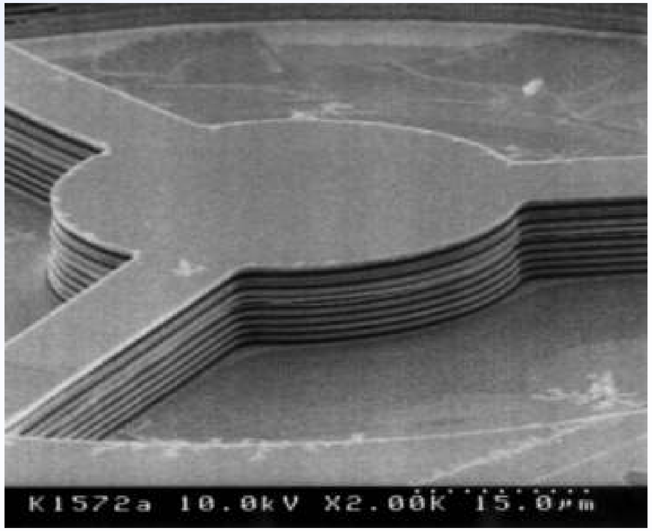
Reaktives Ionenätzen für die Herstellung vertikaler, mikromechanisch aktuierbarer, optischer Bauelemente

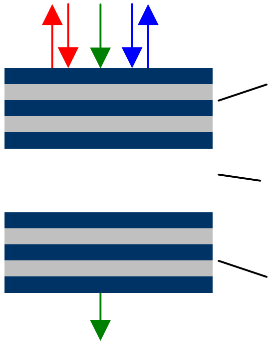


Inhalt:

- Optische Filter: Fabry-Pérot-Filter Konzept, Aufbau, Herstellung
- Reaktives Ionenätzen von InP zur Herstellung von Mesa und Kontakten
  - Ergebnisse der Ätzungen
  - Optimierungen
- Zusammenfassung / Ausblick

Optical Filters: Fabry-Pérot-Filter

Fabry-Pérot-Filter (FPF):



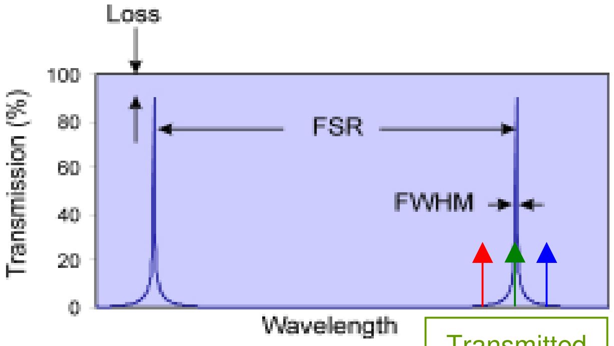
mirror 1

cavity
(air=variable in length=tunable)

mirror 2

mirrors:
distributed bragg reflectors (DBR)

Properties of FPF:



Transmitted Channel

$$\mathrm{FWHM} = \frac{\lambda^2}{2\mathrm{L}} \cdot \frac{1}{\mathrm{F}}$$

$$F \approx \pi \frac{\sqrt{R \cdot A}}{1 - R \cdot A}$$

$$\mathrm{FSR} = \frac{\lambda^2}{2\mathrm{L}}$$

L: Length of the cavity
λ: Wavelength
R: Reflectivity
A: Loss factor ($1-\alpha$)
F: Finess

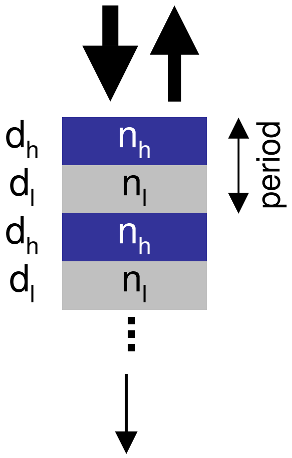
Optimization / Goals:

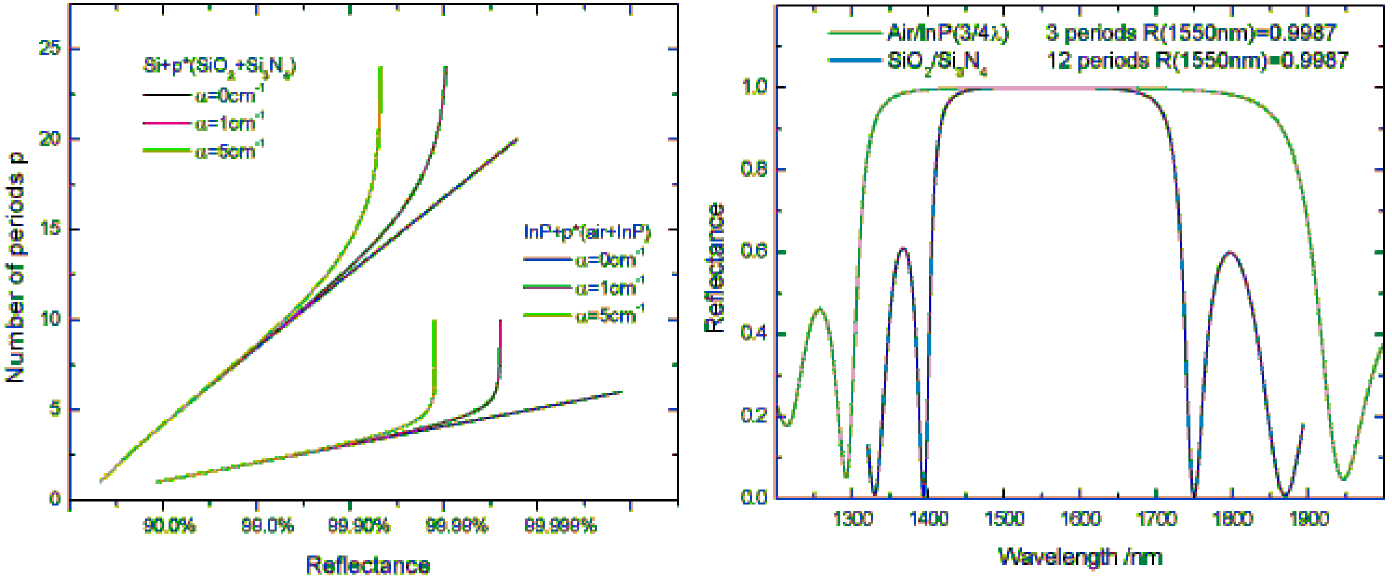
- small FWHM, large FSR
- small loss
- tunability

$\}$ R=0.99..
L=λ..3λ

Material aspects *Fabry-Pérot-Filter / DBR‘s*

DBR‘s:





Comparison (λ=1550nm): 1) **SiO_2 (n_l=1.47,d=λ/4)** and **Si_3N_4 (n_h=1.94,d=λ/4)** on **Si (n_{Si}=3.6)**
2) **InP (n_h=3.17,d=3λ/4)** and **air (n_l=1.0,d=λ/4)** on **InP**.

- to achieve good filter properties -> DBR materials having high refractive index contrast advantageous
- selected channel depends on cavity length (cavity=air=>tunable)
- integration of active materials

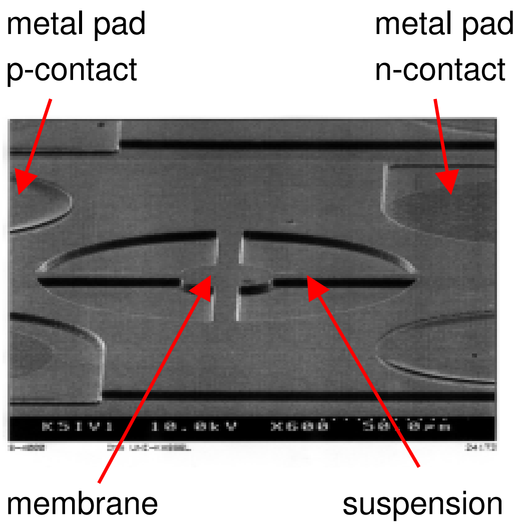
=> InP / **Air-Gap**

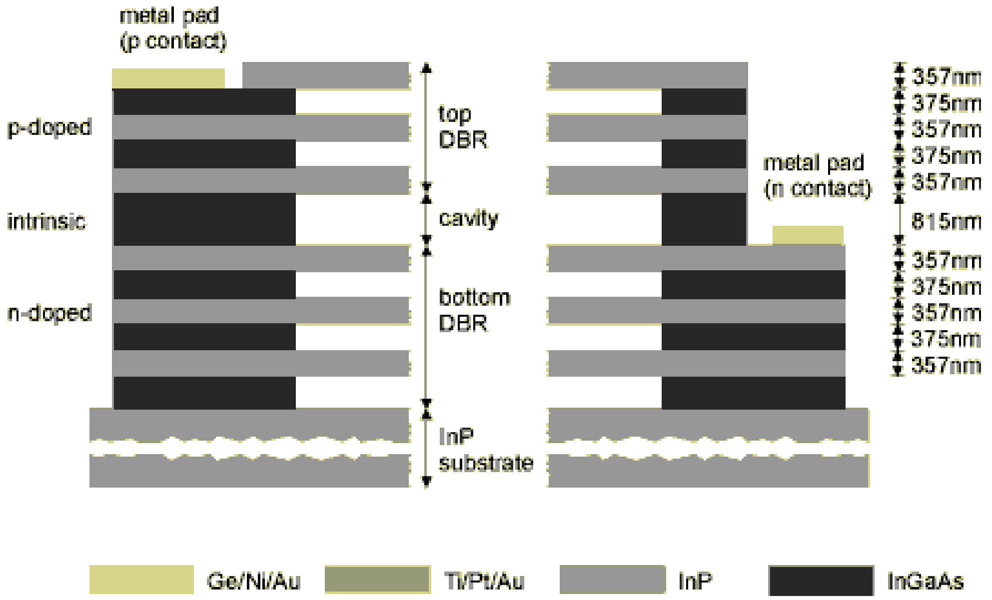
Filter design

DBR's using InP (n=3.17) + air (n=1.0):

- High index contrast (>1:3)
- High reflectance (4p: 99.9%)
- Large stop-band (>500 nm)
- Semiconductor => electrostatic tuning

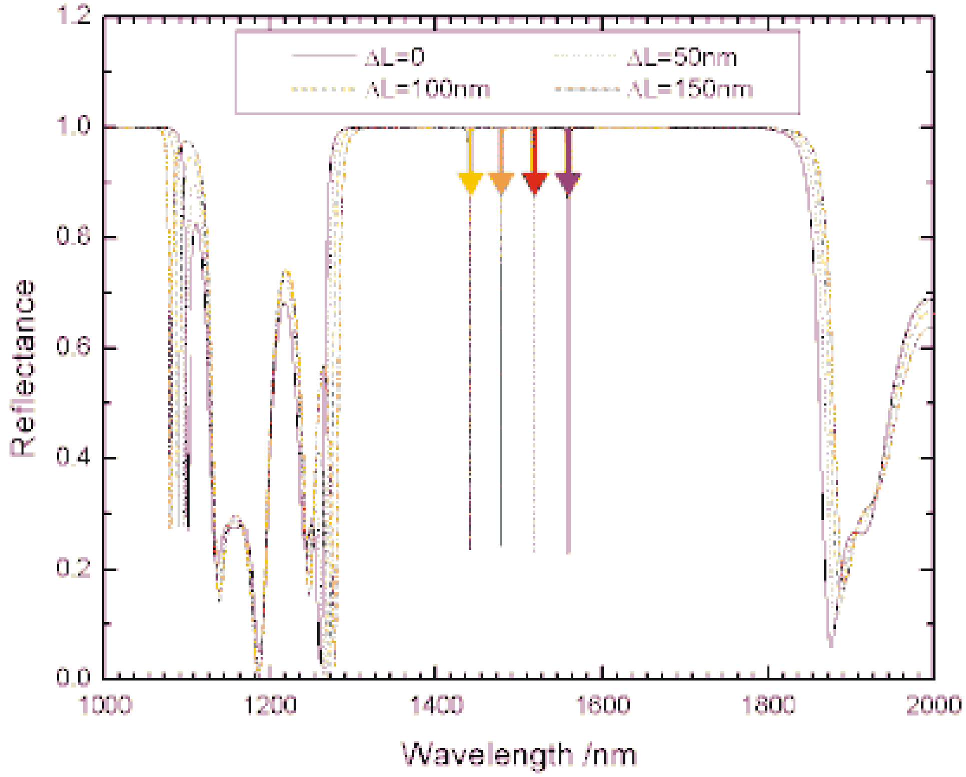
Fabricated filters:

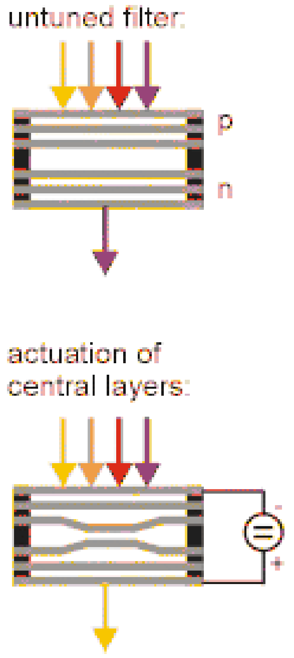




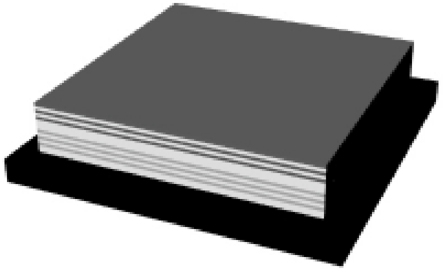
Actuation / Tuning *InP/Air - Filter*

simulation of filter + tuning by central layers:



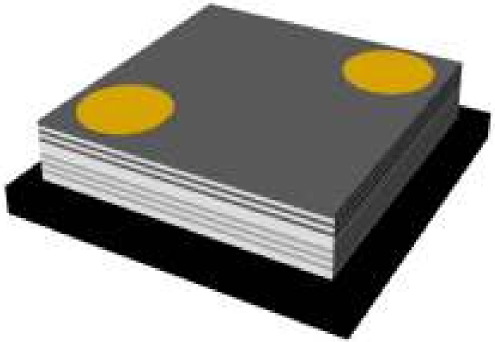


Fabrication Process



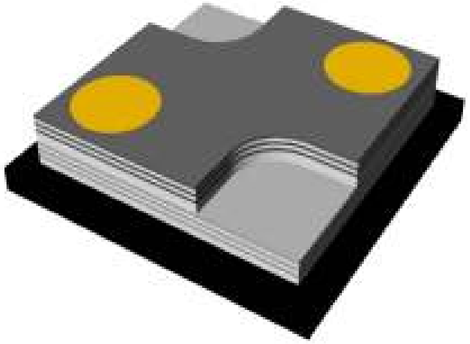
Epitaxial structure

Ł MOCVD-InP/GaInAs



Deposition of p-contacts

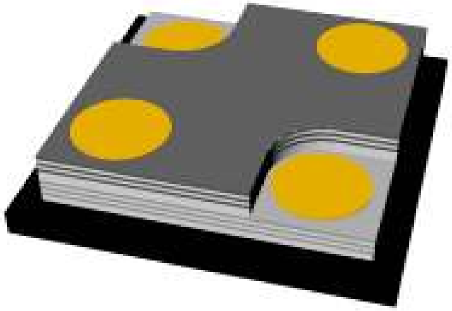
Ł Ti/Pt/Au, Lift-off, RTA



RIE of Mesa for n-contact

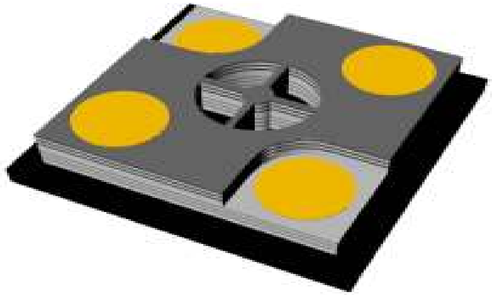
Ł PECVD SiN_x mask, ✸

Ł RIE CHF_3, RIE CH_4/H_2



Deposition of n-contacts

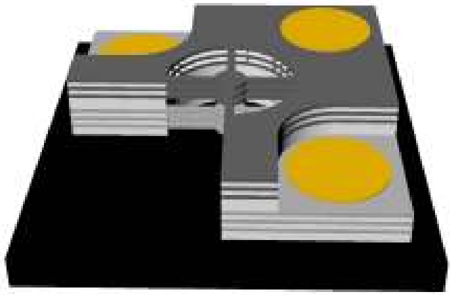
Ł Ni/Ge/Au, Lift-off, RTA



RIE of Mesa

Ł PECVD SiN_x mask, ✸

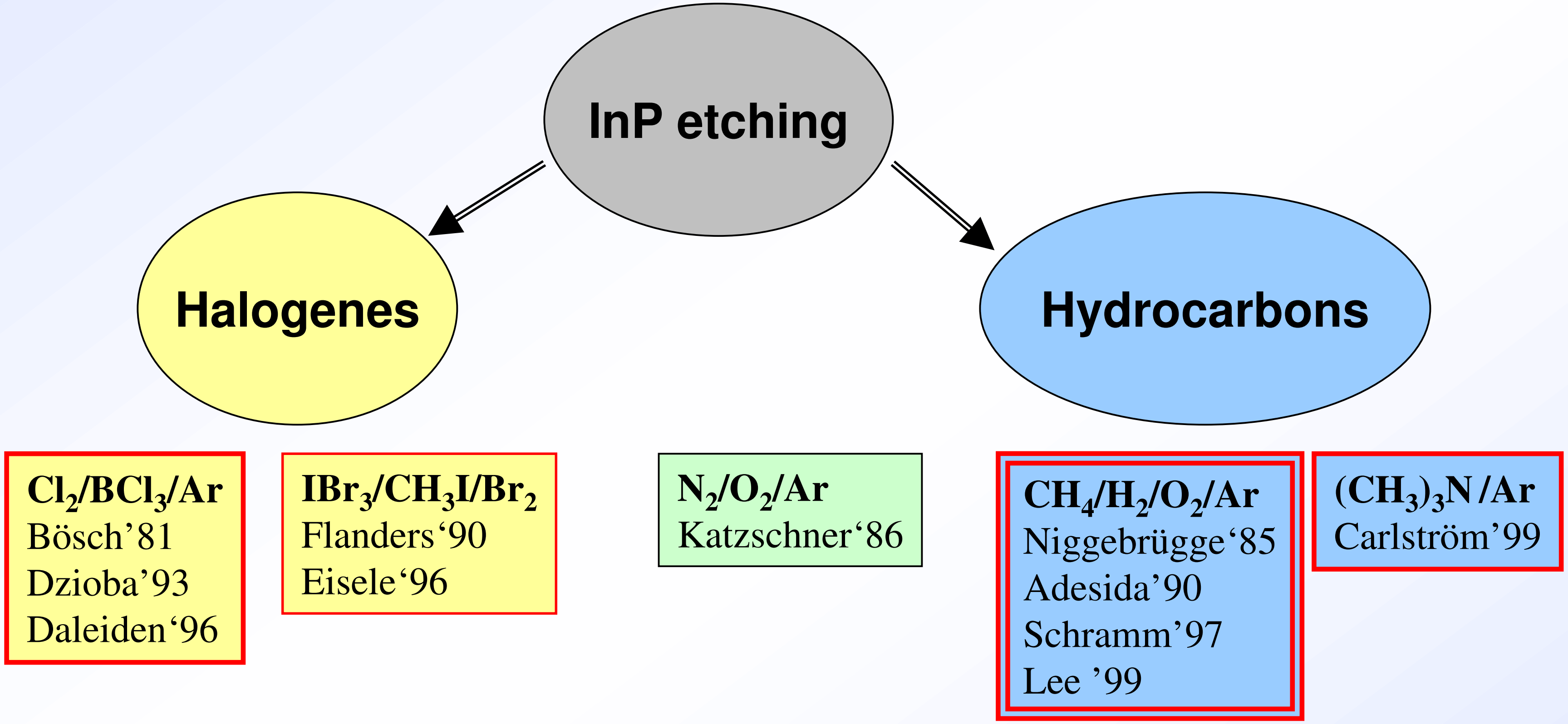
Ł RIE CHF_3, RIE CH_4/H_2



Underetching by $FeCl_3$

Ł Removal of sacrificial layers (GaInAs)

Etching techniques for InP-based semiconductors



InP etching

Halogenes

Hydrocarbons

$Cl_2/BCl_3/Ar$
Bösch’81
Dzioba’93
Daleiden‘96

$IBr_3/CH_3I/Br_2$
Flanders‘90
Eisele‘96

$N_2/O_2/Ar$
Katzschner‘86

$CH_4/H_2/O_2/Ar$
Niggebrügge‘85
Adesida’90
Schramm’97
Lee ’99

$(CH_3)_3N/Ar$
Carlström’99

InP etching using $CH_4/H_2/Ar$

advantages:

- well established process (standard technique)
- neither corrosive nor toxic
- high selectivity to masks

$CH_4/H_2/Ar$

disadvantages:

- relative low etch rate
  - ⇒ high self bias
  - ⇒ process induced damage
- polymer formation
- rough surfaces

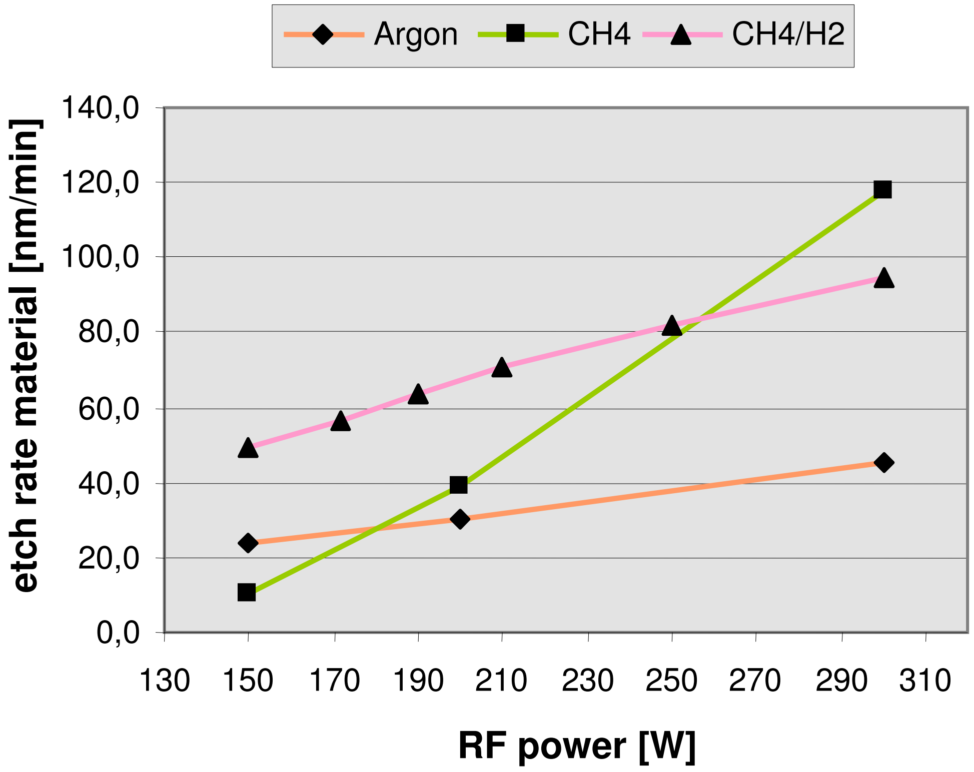
higher rate $[(CH_3)_nIn]$ formation
⇒ **smooth surface planes**

formation of **polymers**
⇒ **rough sidewalls**

lower rate $[(CH_3)_nIn]$ formation
⇒ preferential remove of P
⇒ **rough surfaces**
⇒ Ø physical etch required

formation of polymers suppressed

Results: Etch rate of InP using $CH_4/H_2/Ar$

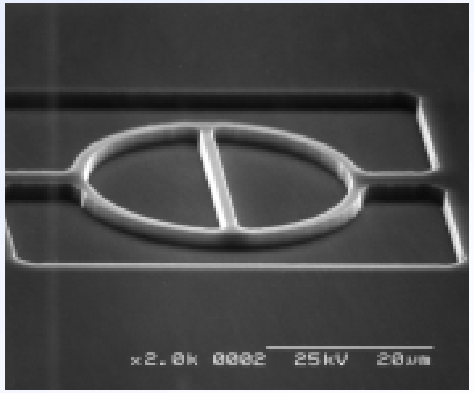


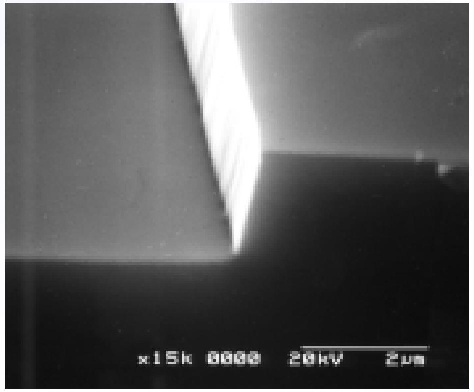
Ar: 20 sccm
CH_4: 20 sccm
CH_4/H_2: 20 sccm/70 sccm

pressure: 26 µbar
temp.: 20 °C

Results: SEM / AFM

SEM

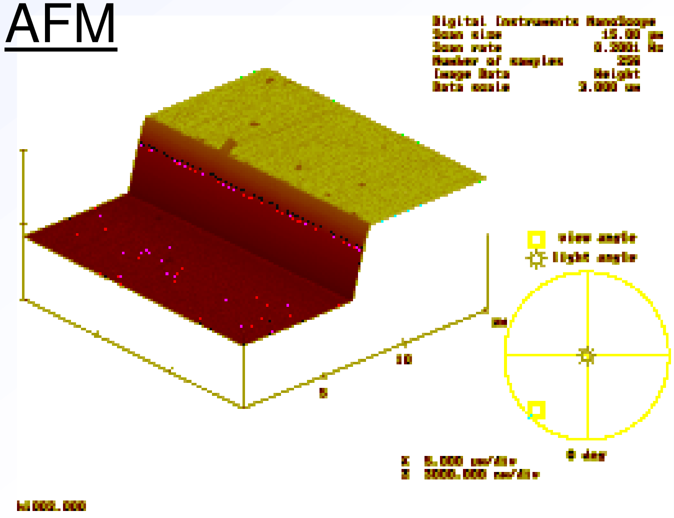




Etching using Si_3N_4 mask:

CH_4 [20 sccm],
H_2 [70 sccm],
press.: 26 µbar,
temp.: 20°C,
time: 15 min
power: 250W

AFM



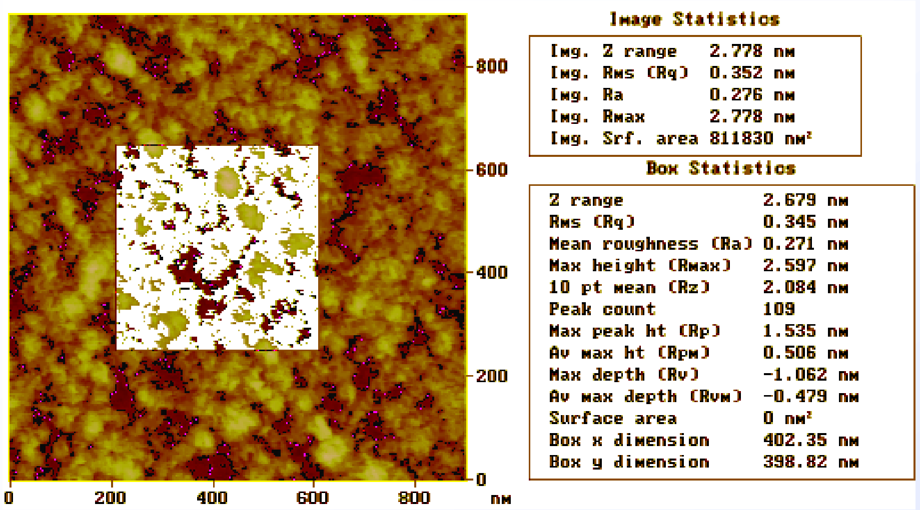


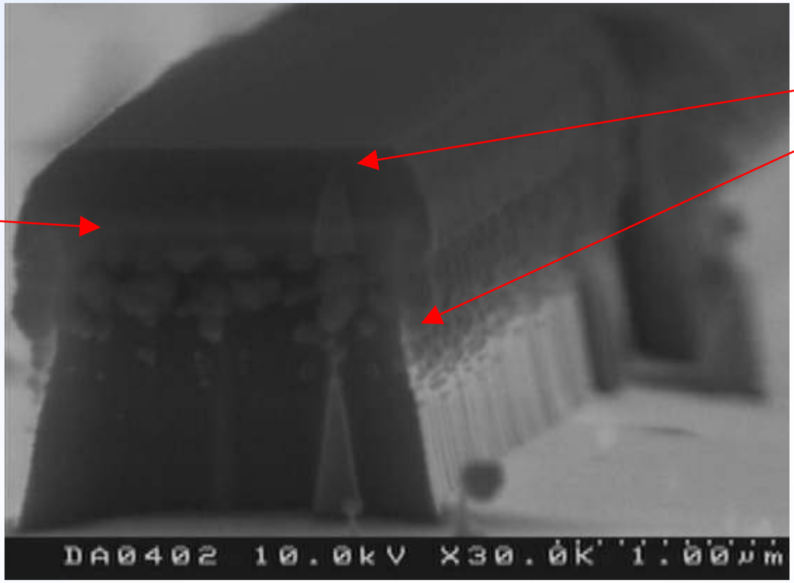
Image Statistics

Img. Z range	2.778 nm
Img. Rms (Rq)	0.352 nm
Img. Ra	0.276 nm
Img. Rmax	2.778 nm
Img. Srf. area	811830 nm²

Box Statistics

Z range	2.679 nm
Rms (Rq)	0.345 nm
Mean roughness (Ra)	0.271 nm
Max height (Rmax)	2.597 nm
10 pt mean (Rz)	2.084 nm
Peak count	109
Max peak ht (Rp)	1.535 nm
Av max ht (Rpm)	0.506 nm
Max depth (Rv)	-1.062 nm
Av max depth (Rvm)	-0.479 nm
Surface area	0 nm²
Box x dimension	402.35 nm
Box y dimension	398.82 nm

Filter fabrication – critical process steps



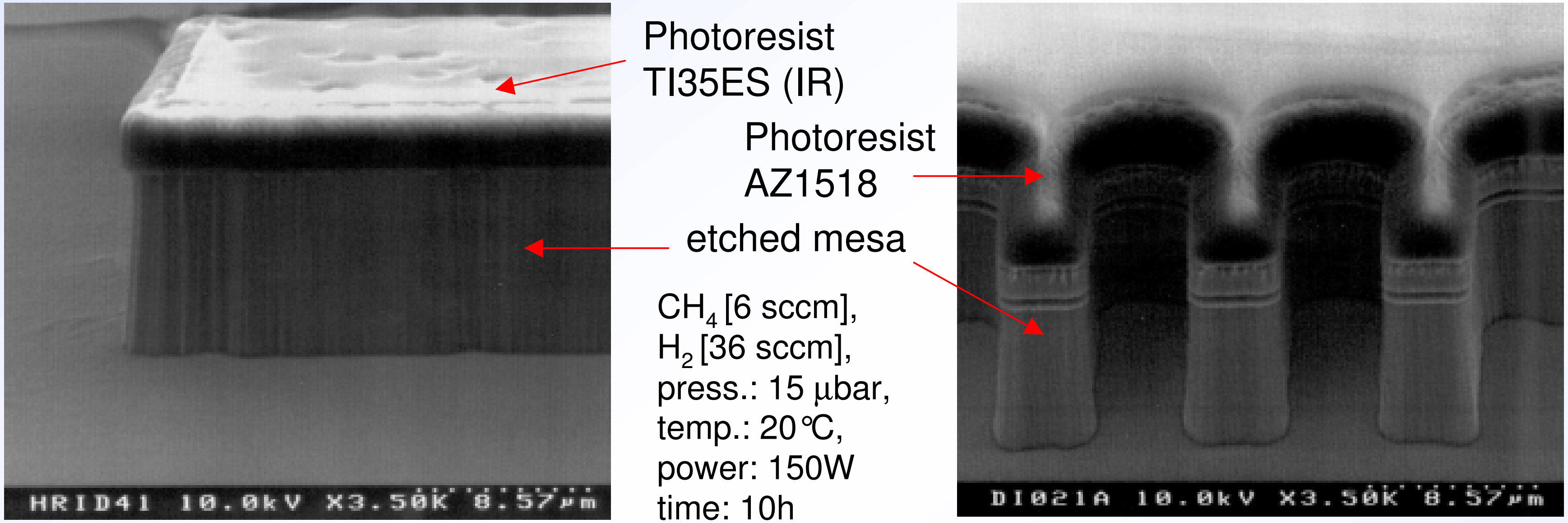
Si_3N_4

Formation of polymer layer (~200-300nm) on top of mask and at sidewalls

- problem: removal of mask
  - =>usually: - aceton+ultrasonic / O_2-ashing
    - - HF
  - =>but: - O_2 ashing -> high power=contacts removed
    - - HF -> etching of Ti
    - - ultrasonic -> destruction of small MEMS
- problem: underetching (deposition at sidewalls)

possible but:
difficult + small yield
↓
optimization ?!

Filter fabrication - process optimization



CH_4 [6 sccm],
H_2 [36 sccm],
press.: 15 µbar,
temp.: 20°C,
power: 150W
time: 10h

Reduction of gas flows / pressure / RF power

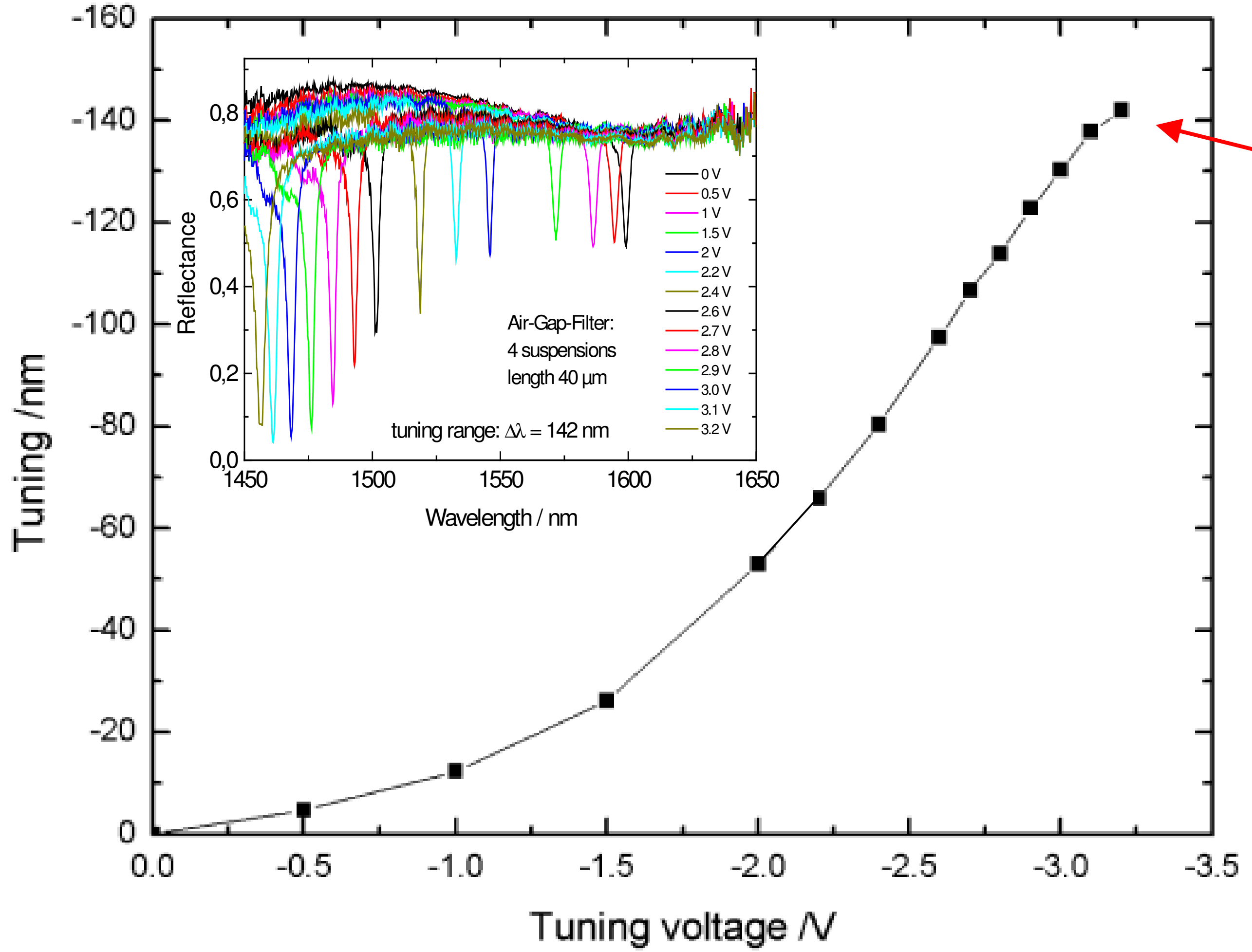
- reduced polymer formation
- only PR necessary
  (reduction of process steps)
- simple removal of PR by
  aceton

⟷

small etch rate
(15nm/min)

Characterisation: Tuning, Reflexion

InP/Air - Filter



Δλ = 142 nm
@ 3.2 V

IMA

Institute of
Microstructure Technologies and
Analytics

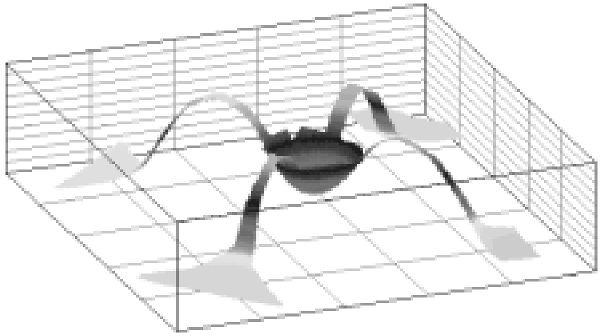
Technological Electronics
University of Kassel
Germany

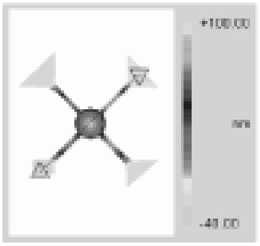
2004-03 Muehlleithen

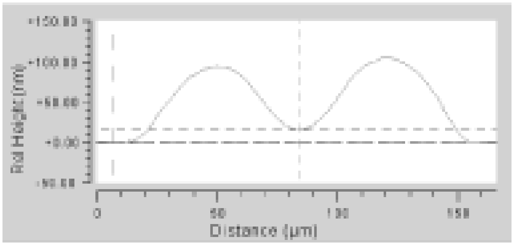
Characterisation: WLI, SEM

InP/Air - Filter

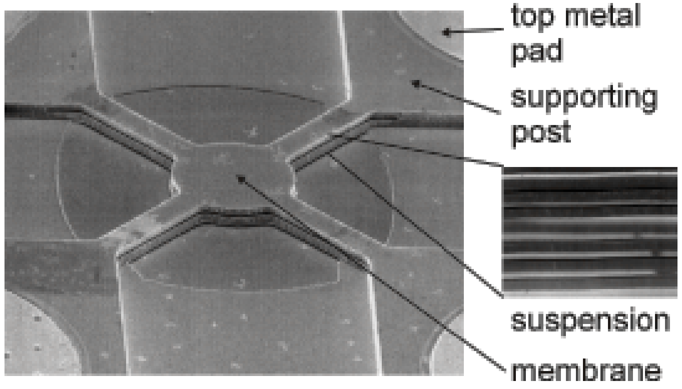
- scanning white light interferometry (WLI) (200µm x 200µm x 100nm)
- evaluation of strain in top layer
- approx. flat membrane (ROC 5mm)
- unfortunately instable resonator

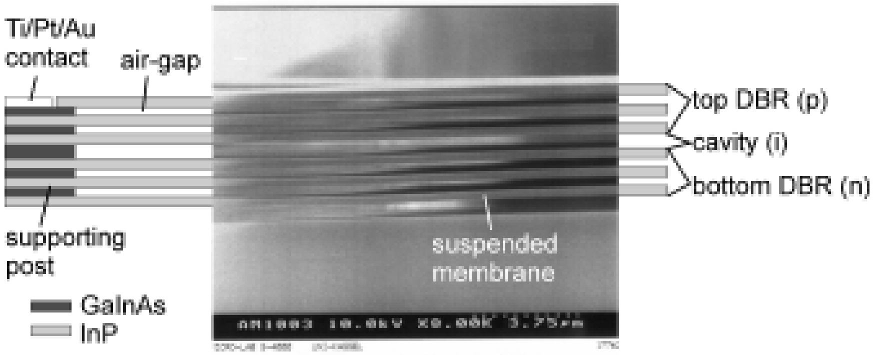






SEMs of filter with protection mask





Zusammenfassung / Ausblick

Herstellung eines vertikalen, mikromechanisch aktuierbaren, optischen Bauelements (Fabry-Pérot-Filter) vorgestellt

- Materialsystem InP/Luft
- Herstellungsschritte
  - Trockenchemisches Ätzen von InP
  - Optimierung des Herstellungsprozesses
- Ergebnisse

Ausblick:

- Weitere Verbesserungen der Filtereigenschaften
- Integration von aktiven Materialien (Photodetektor, VCSEL)
- Filter im Materialsystem Si_3N_4/Luft
  - Trockenchemisches Ätzen von Si_3N_4/Si mit PR-Maske
  - PECVD von Si

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