# Application of photonic crystals to gas analysis

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## Aim

**Exploitation of enhanced absorption in photonic crystals for detection of gases**

### Idea

If the absorption frequency of a gas filled into the pores of a macroporous Si photonic crystal is close to upper edge of the first band gap, two properties of light propagation through a photonic crystal can be exploited:

- Low group velocity near band edge results in an effective prolonged propagation time , i.e. enhanced interaction time of light with the gas
- Concentration of electromagnetic field of light in the gas-filled pores (air band)

→ **2001 - 2003 : Macroporous Si 3D PBGs as model system**
→ **2003 - 2005 : Macroporous Si 2D PBGs as realistic system**

### Team

*IPM:* Dr. A. Lambrecht, Dr. A. Feisst, P. Hahn (partly DFG-funded 2001), R. Glatthaar (partly DFG-funded 2002)

*MPI:* Dr. R. B. Wehrspohn, Dr. S. Schweizer, C. Jamois, Dr. J. Schilling, S. Matthias, T. Geppert, TA Andreas Herbst (partly DFG-funded)

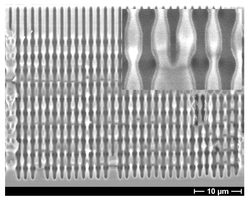
### Scientific Output

*Patent:* "Vorrichtung und Verfahren zur Analyse der qualitativen und / oder quantitativen Zusammensetzung von Fluiden", 10063151.7 (Aktenzeichen Dt. Patentamt) bzw. PCT/EP01/14802 (PCT-Nummer)

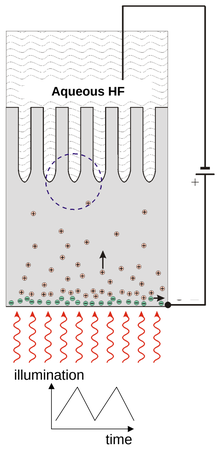
*Publications:* J. Schilling et al., Mater. Res. Soc. Proc. 722, L6.8 (2002)

*Talks:* La Roche Diagnostic internal seminar (2001), Dräger AG internal seminar (2002), EH Conducta AG internal seminar (2002)

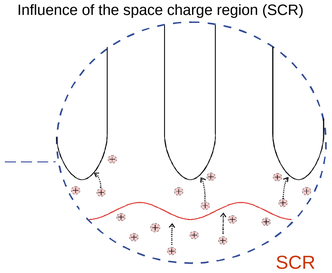
## Modulated macropores - Fabrications issues




*Problems encountered:*
Pores die or merge during high-carrier concentration pulse.

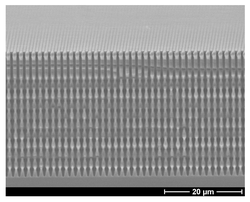



Influence of the space charge region (SCR)



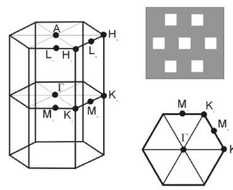

$v_{etch} \sim kT\, c^{3/2}$

*Reason*: Focussing effect of the SCR is reduced during high-carrier concentration pulse
*Solution*: Increase of etching velocity
- increase of T
- increase of HF concentration
Higher-quality samples achieved




## Optical properties of 3D-macroporous silicon photonic crystals

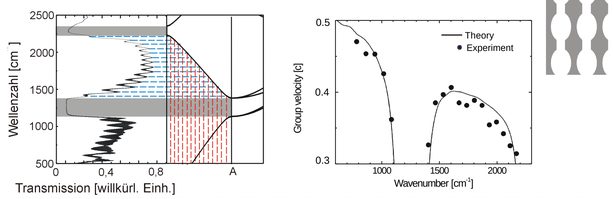
*Crystal properties*




3D-crystal symmetry:
**base-centered orthorhombic**

Properties:
- No complete 3D band gap, but stop-gaps in all 3 directions
- Polarization dependent band gap

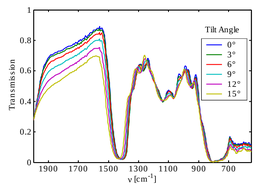
*Optical properties in G-A direction*

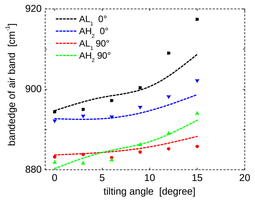



For 15 modulation periods, $v_g = c/3$ is optically determined.

J. Schilling et al., Mater. Res. Soc. Proc. 722, L6.8 (2002)

*Band edge tuning by tilting*

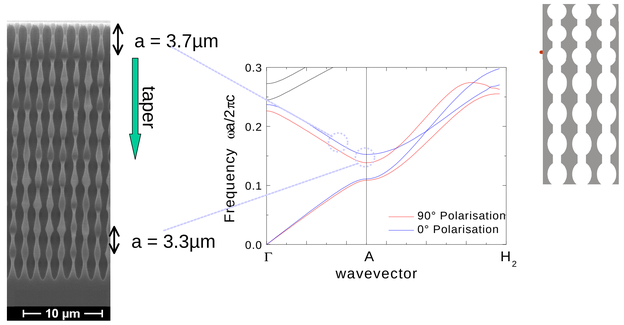



Lines: theory (shifted)
Dots: experiment

The easiest way to tune the 3D-crystal is by tilting. An absolute shift of 35 $cm^{-1}$ is observed. This corresponds to a relative band edge shift of 3.5% and can compensate for fabrication tolerances which are in the range of a few percent for the optimized process.

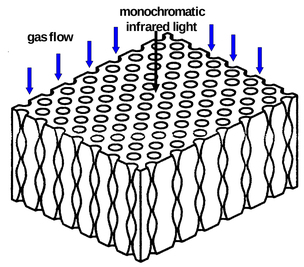
*Tapering*

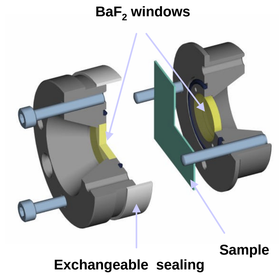




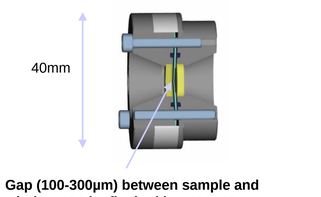

Tapering / Chirping allows to couple to low-$v_g$ bands, variation of the modulation period with depth can be easily realized by designing an appropriate illumination profile.

## Measurement setup



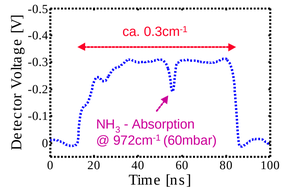

Cell

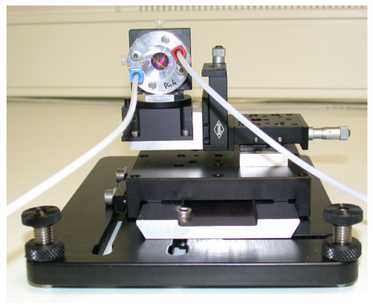


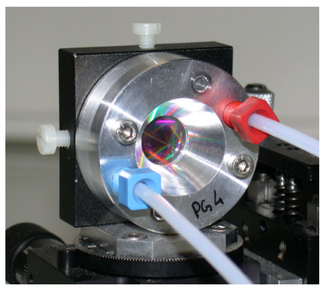

Gap (100-300µm) between sample and window can be flushed by test gas.

Optical measurements in Bruker IFS 66 v/S. In future with Quantum Cascade Laser

**QCL-test**

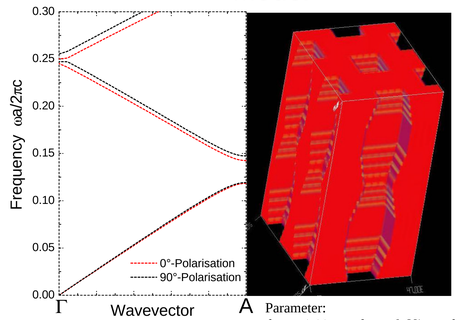




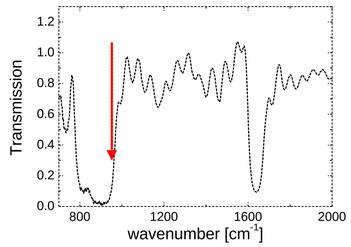
## First optical measurements of 3D-PBG with $SF_6$ (@948 $cm^{-1}$)

Model

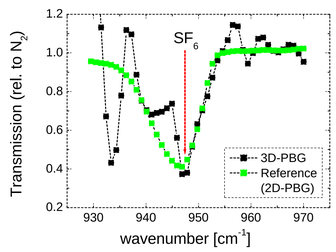



Parameter:
$d_{max}$ = 1.11 µm, $d_{min}$ = 0.68\ µm, h = 2.56 µm and a = 1.5 µm.

Without $SF_6$



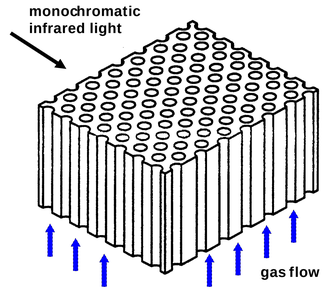

With $SF_6$

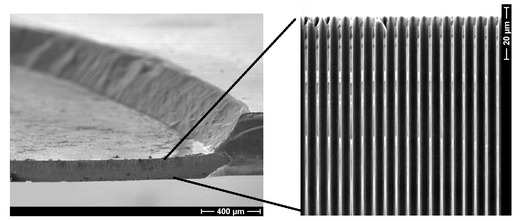



Absorption of $SF_6$ in 3D-PBG clearly observable! However, due to low coupling efficiency and small number of modulation periods, no enhancement observable.
*Next step*: Taper + 30-40 modulation periods.

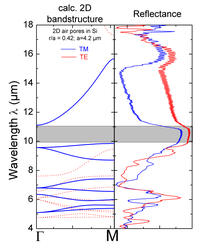
## Work ahead (2003-2005)

- Verification of enhanced absorption
- Change to 2D-PCs with air band edge at 948 $cm^{-1}$.

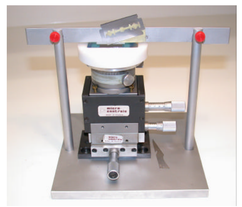



First realizations with a = 4.2 µm




First optical characterizations, the band gap is clearly observable



Micro-cutter (IPM)