Preparation of two and three dimensional photonic crystals in Si and III-V semiconductors by pore etching

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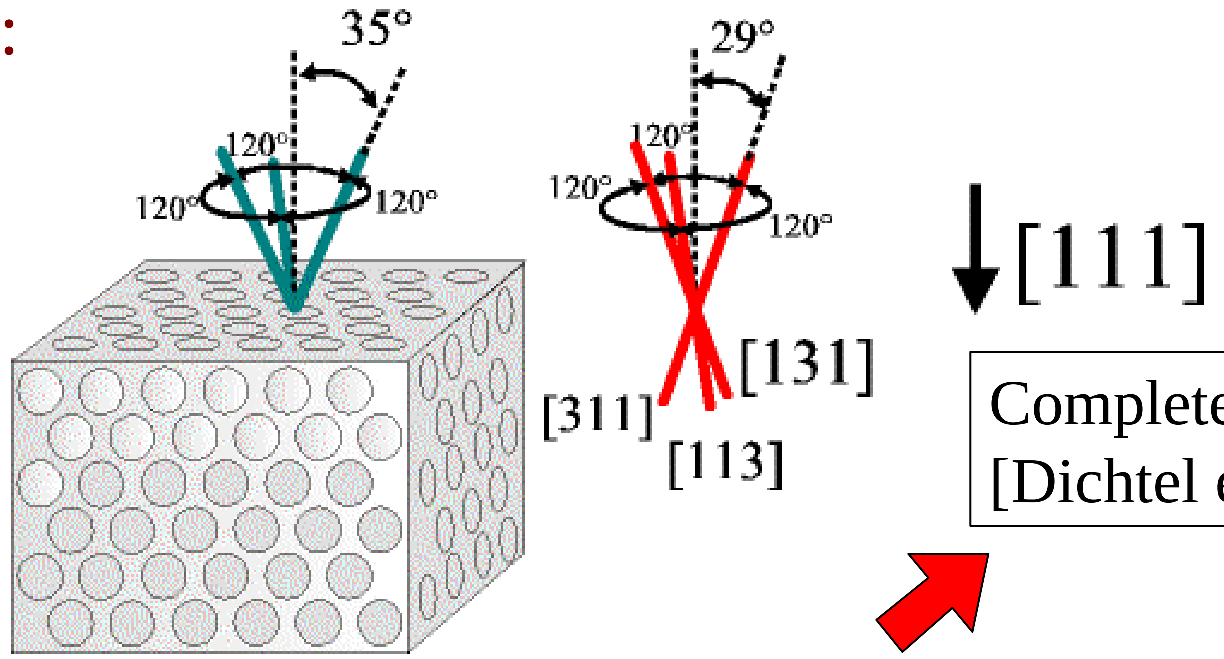
Introduction

- Key issues of project
- Experimental technique
- Experimental results
  - Sub-µm Si - Pores
  - Kielovite (3D Si)
  - InP
- Summary and outlook
- Acknowledgements

Major Goals

- ➢ New modes of pore etching in Si, esp. sub-µm structures
- ➢ 3D Photonic Crystal in Si

Kielovite:

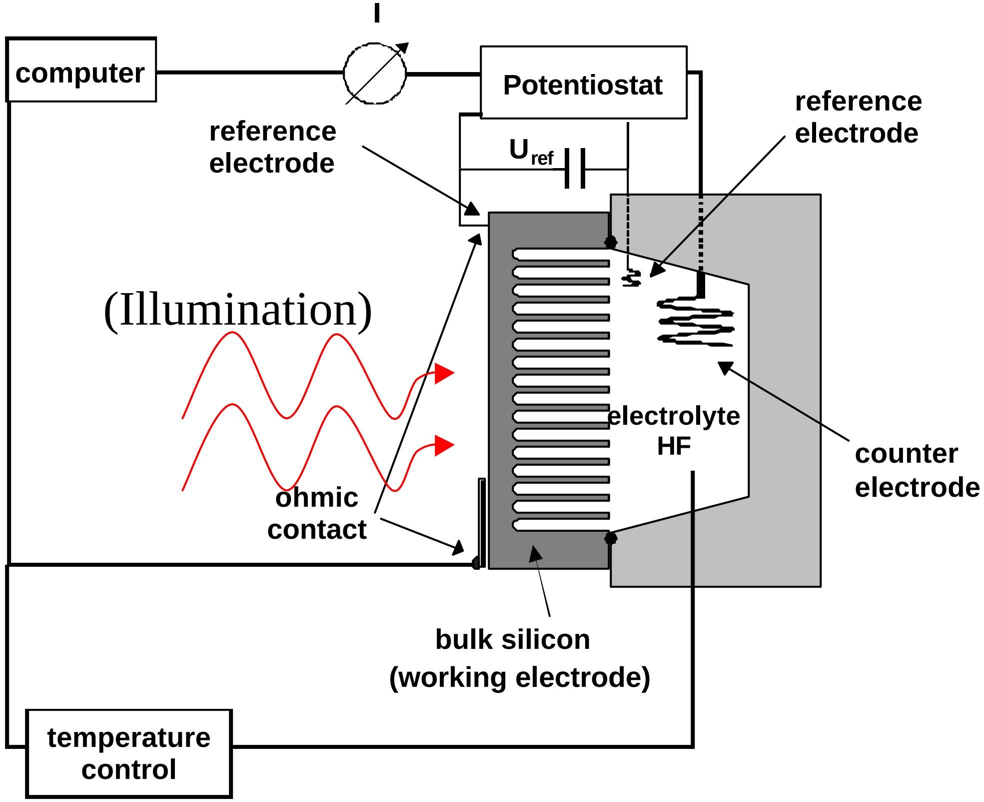


Complete 3D Gap !
[Dichtel et. al.]

- ➢ 2D PC in III-V-Compounds
- ➢ 3D PC in III-V-Compounds

Experimental setup

- PC controlled potentiostat/galvanostat
- Pt electrodes,
- Peristaltic pump,
- Teflon cell and Teflon electrolyte container
- NIR LED Illumination



Si: ~ 10^{15}-10^{17} cm^{-3}
I: ~ 0.1-10 mA/cm^2
U: ~0.5-4V (aq),0.5-20V(org.)
Etchant: HF

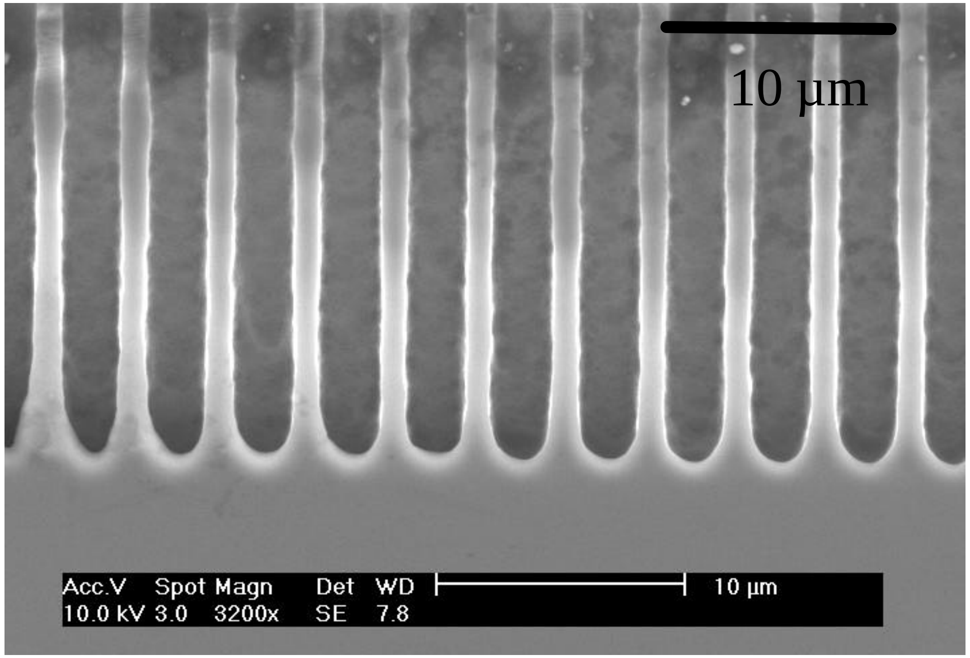
III-V: ~10^{17}-10^{18} cm^{-3}
I: ~ 1-60 mA/cm^2
U: ~1-10V
Etchant: H_2SO_4, HCl

Si meets HF

- w/o current: H-passivation of surface
- w/ current: holes can break up passivation!!

high current density j: electropolishing

low j: (macro)porous Si

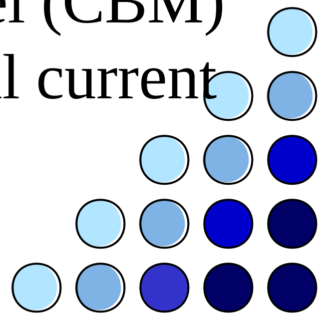


SEM micrograph
of prestructured macropores

- pref. growth directions (100, 113)
- branching
- intrinsic vs. extrinsic lengths
- Current Burst Model (CBM)

⇒no continuous local current
but local bursts

⇒dynamic system !

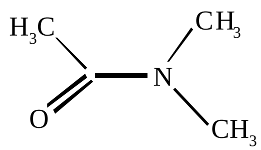
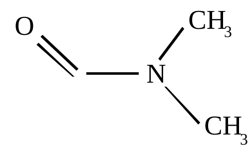
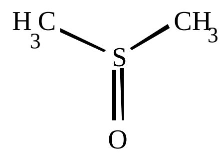


Sub-µm Si pores

normally: Backside illuminated n-Si with increased doping

- Problems: diffusion length, breakdown voltage comes closer
- intrinsic limit: 200 nm diameter (state-of-the-art: 500 nm)

Take other solvents than H_2O and p-Si!!

Dimethylacetamide	DMA	C_4H_9NO	
Dimethylformanide	DMF	C_3H_7NO	
Dimethylsulfoxide	DMSO	C_2H_6OS	

Tested and selected from a whole bunch of chems!

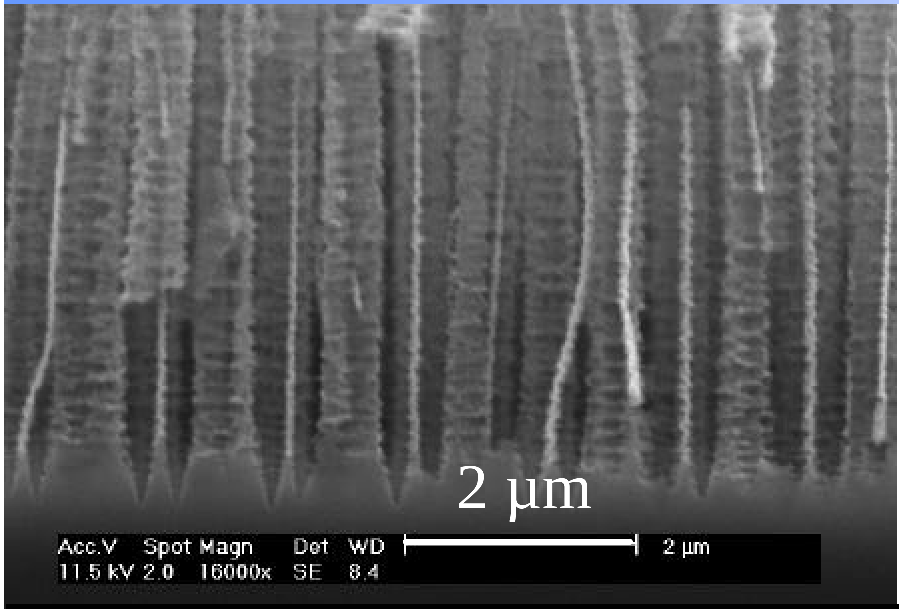
⇒lower tedency to form oxide at the Si interface

⇒smaller pores possible

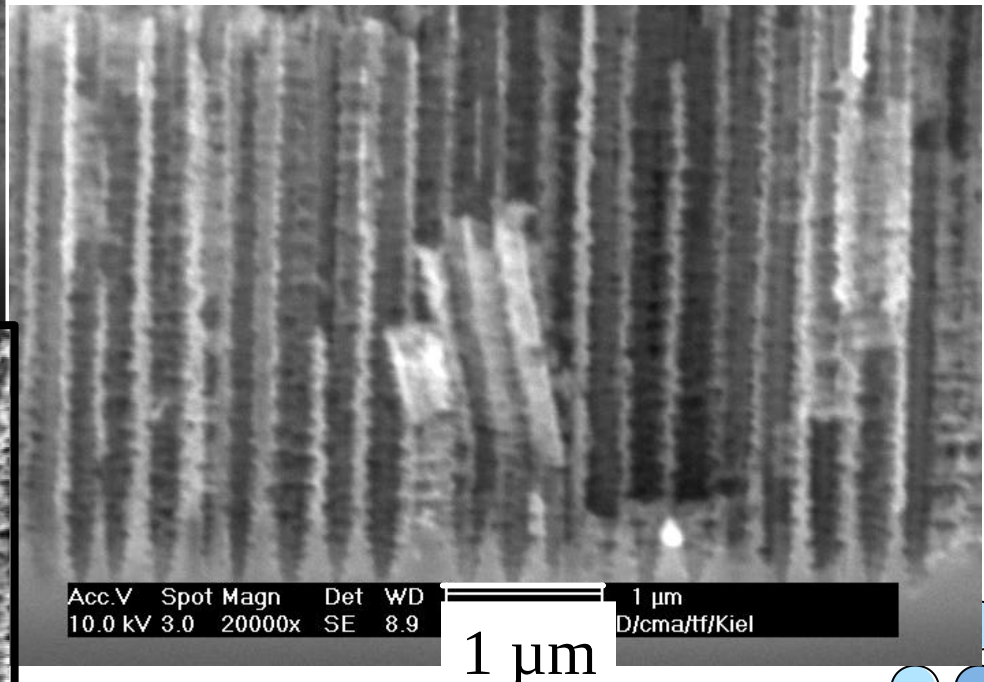
Sub-µm Si pores II

p-Si, 0.13 Ωcm,
DMSO, 2mA/cm^2

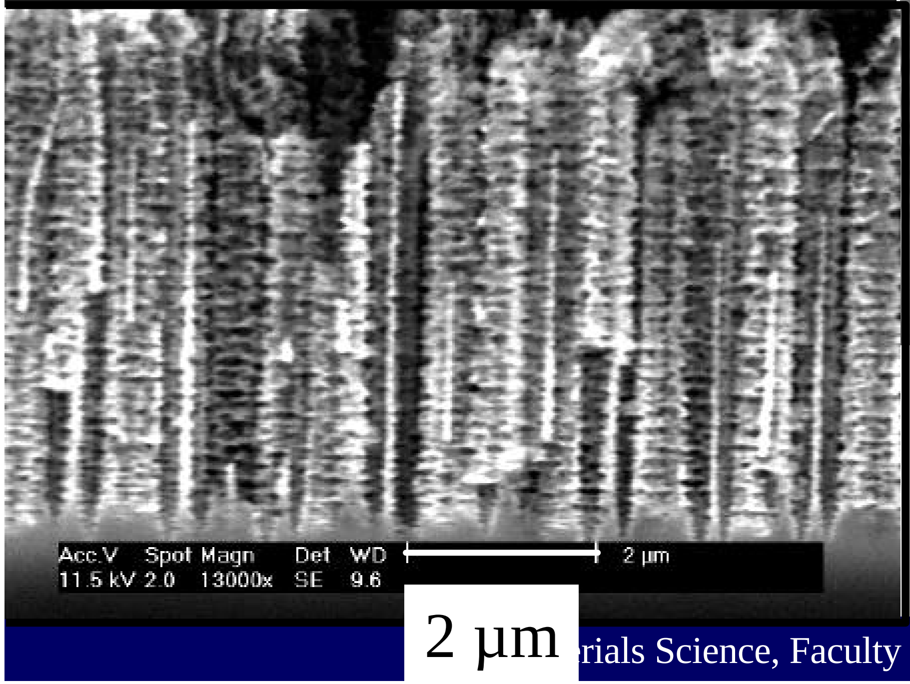
10 % HF



20 % HF, 100 Hz Mod.



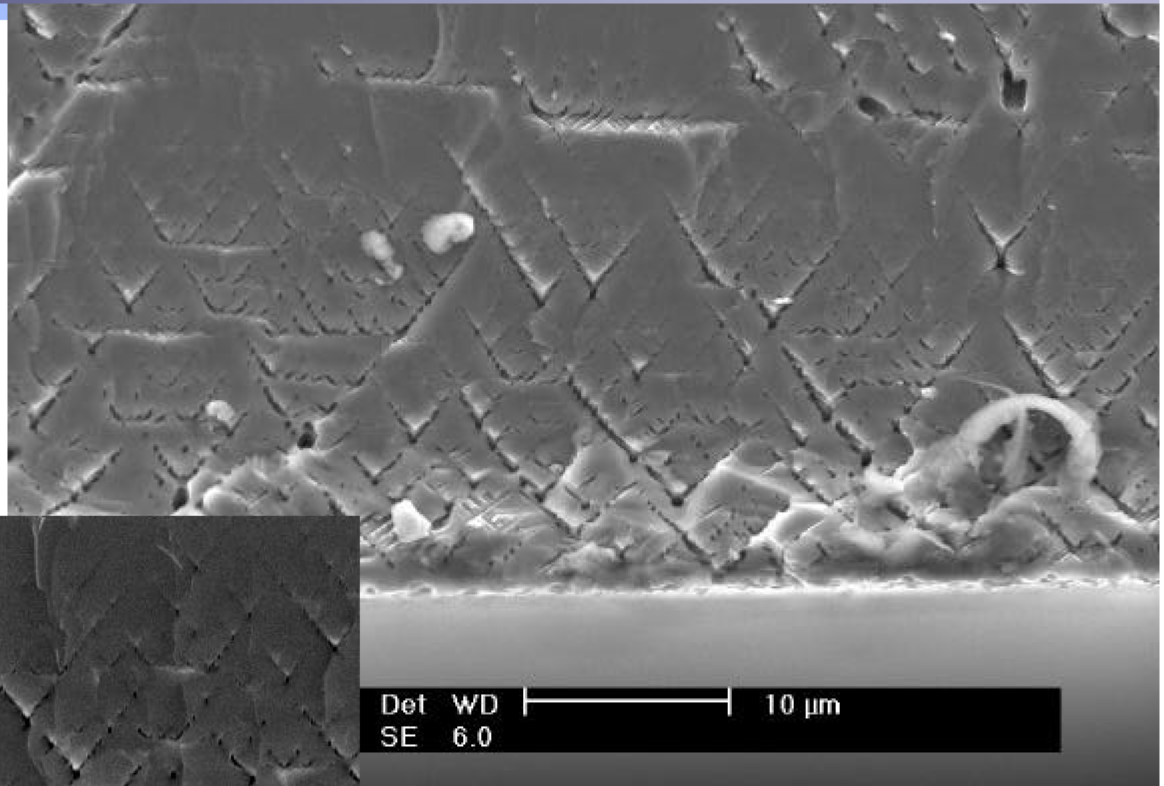
20 % HF



Problems:
- ➢ roughness

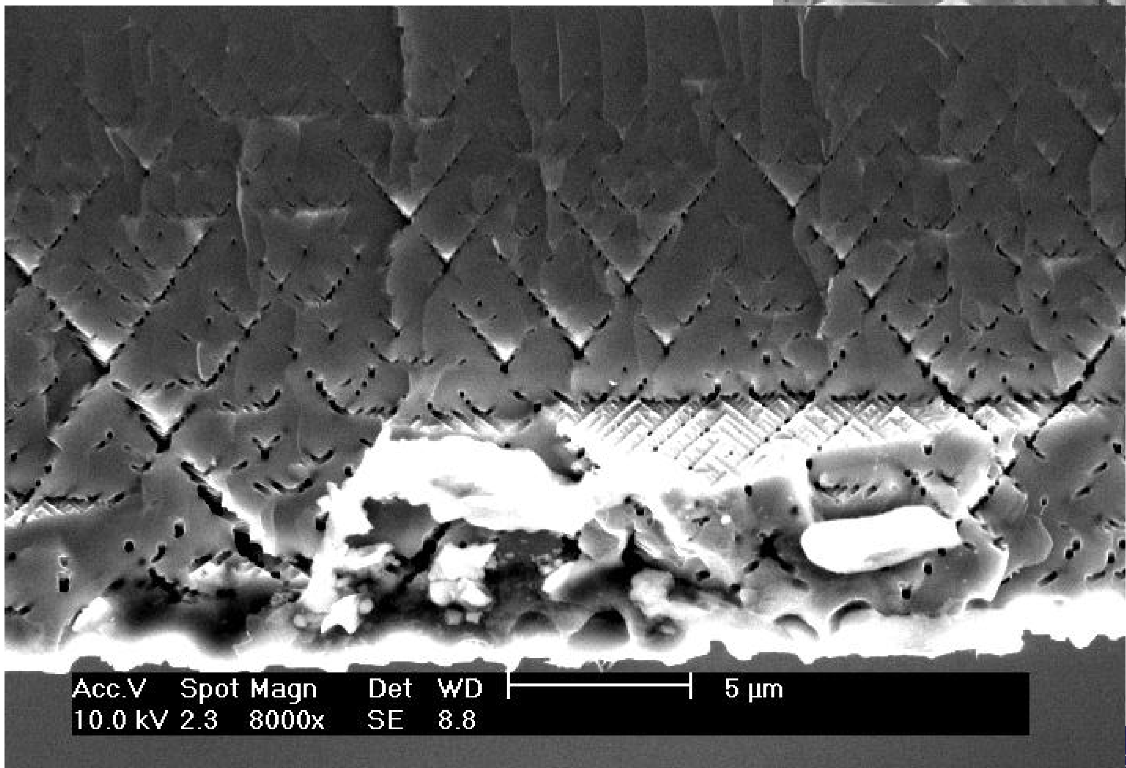
Kielovite with Lithography

random:



(n-Si, BSI, 4% HF aq., 3V, 1mA resp. 0.6 mAcm^{-2})

structured :

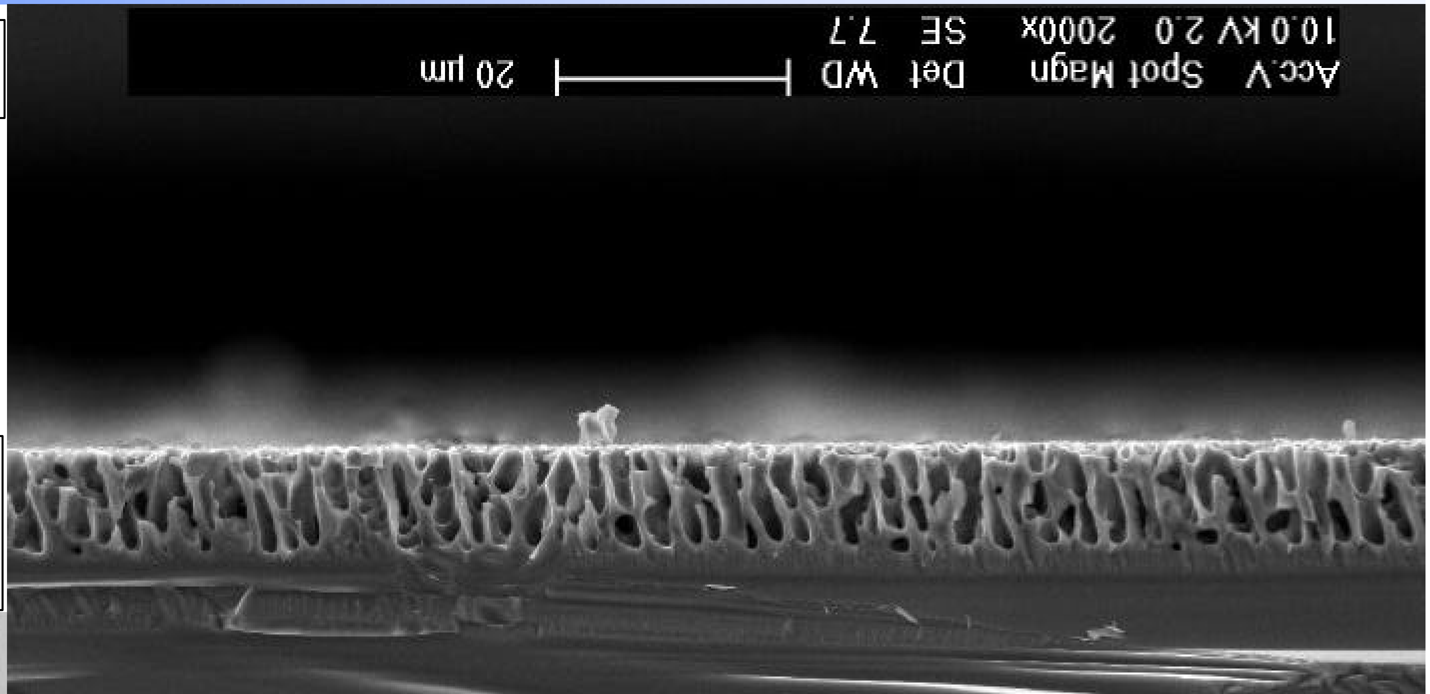


! enhance nucleation !
! smooth pores !
! Understand high Volt.

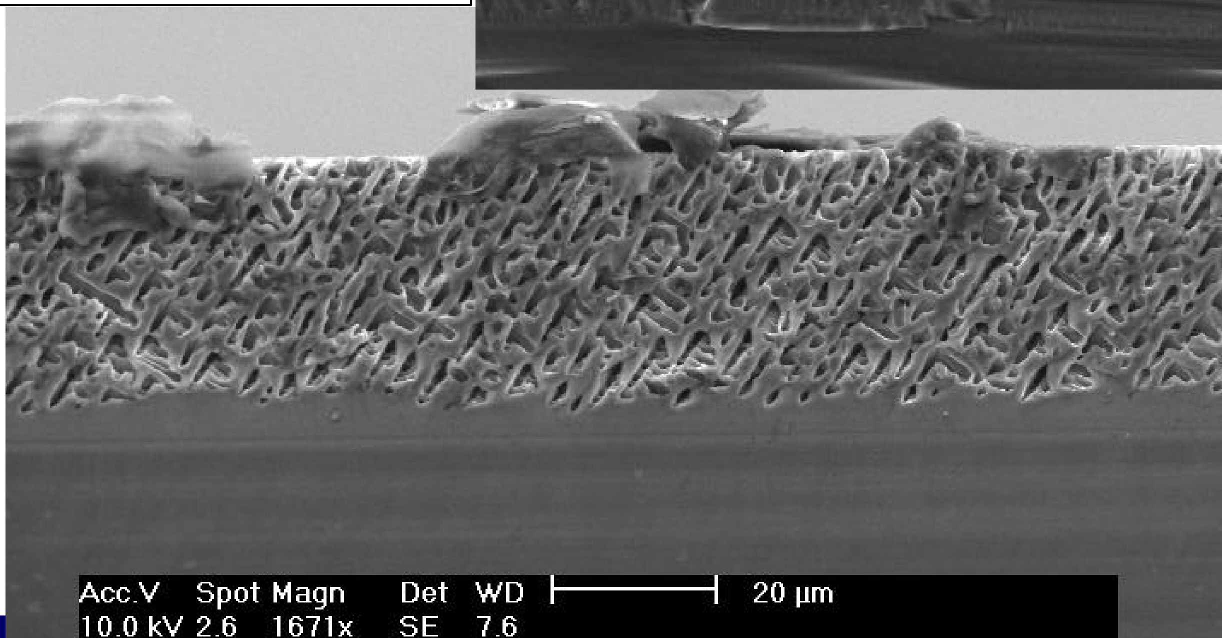
Kielovite with p-Si

Just try?:

(p-Si, 10-20 Ωcm, 4% HF DMF, galvanost. 2mA resp. 4 $mAcm^{-2}$)

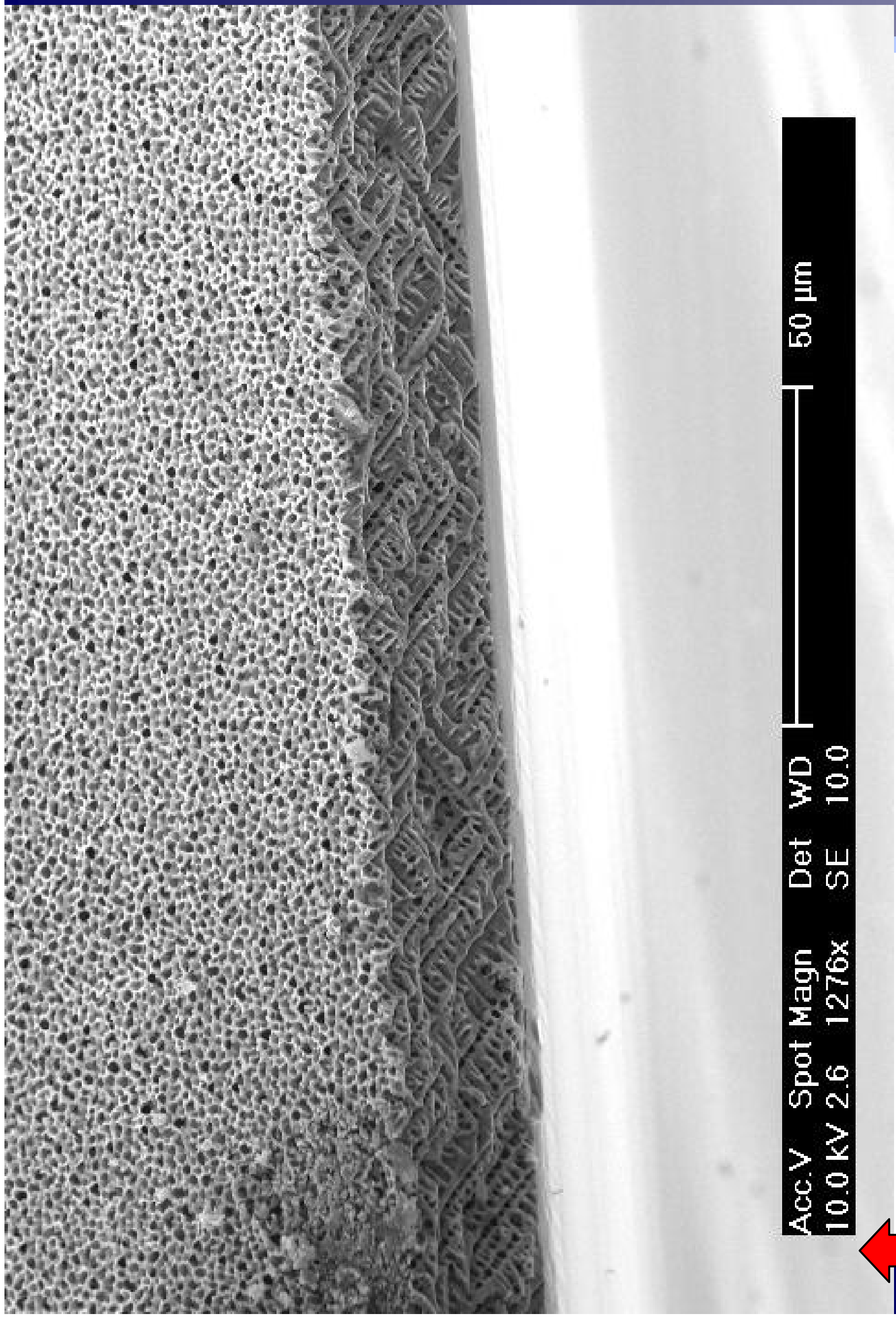


W/ TBAP (Levy-Clement et al.):

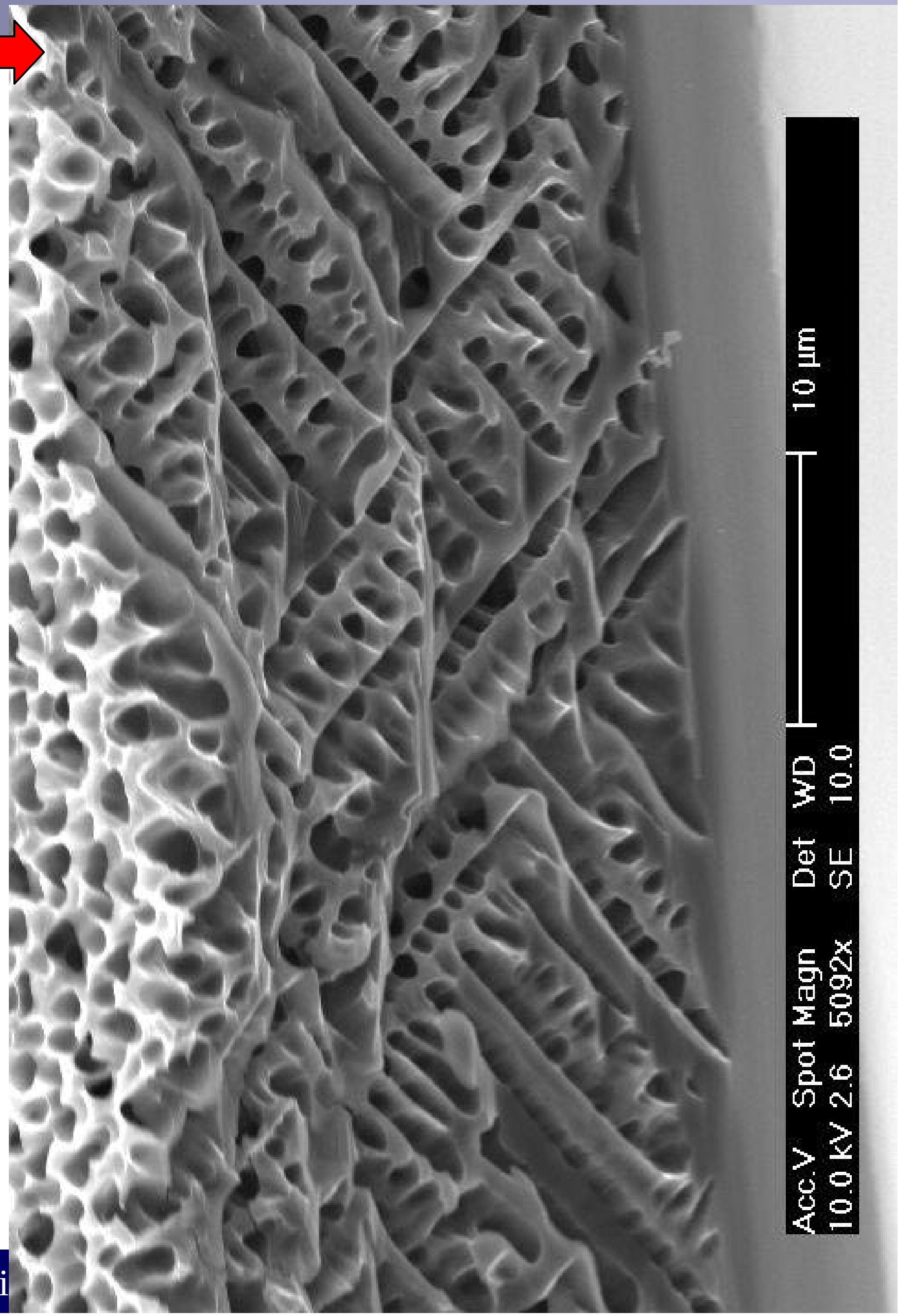


- Up to 140 µm thick layer!
- Much more homogenous

High density of pores



Overview DMF/TBAP 4 mA/cm^2 detail



PhoCs out of III-V-compounds

Different behaviour than Si:

•Crystallographically oriented pores form at low j

•Current line oriented pores form at high j

Advantages to Si:

• sometimes bigger E_{gap} (in the visible)

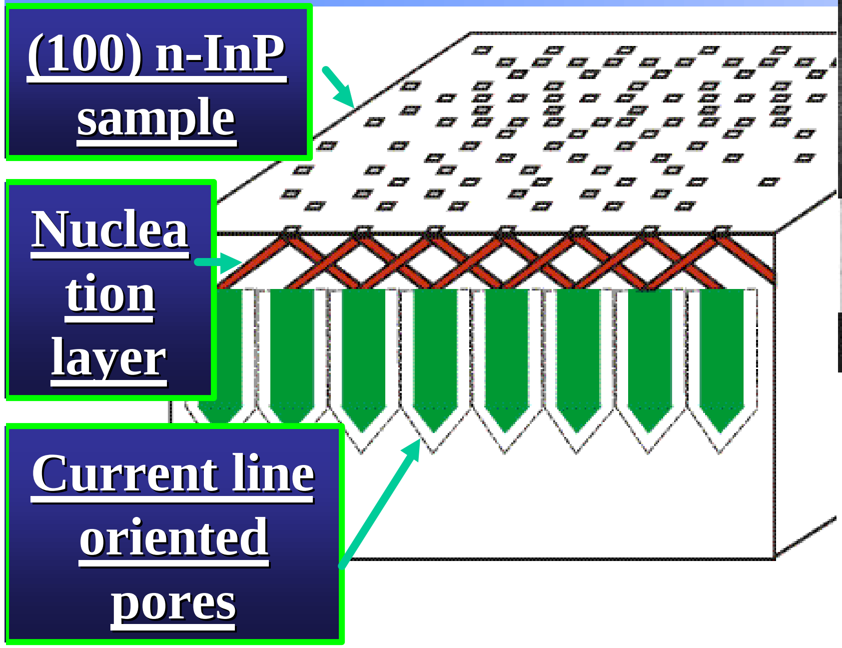
• Luminescence

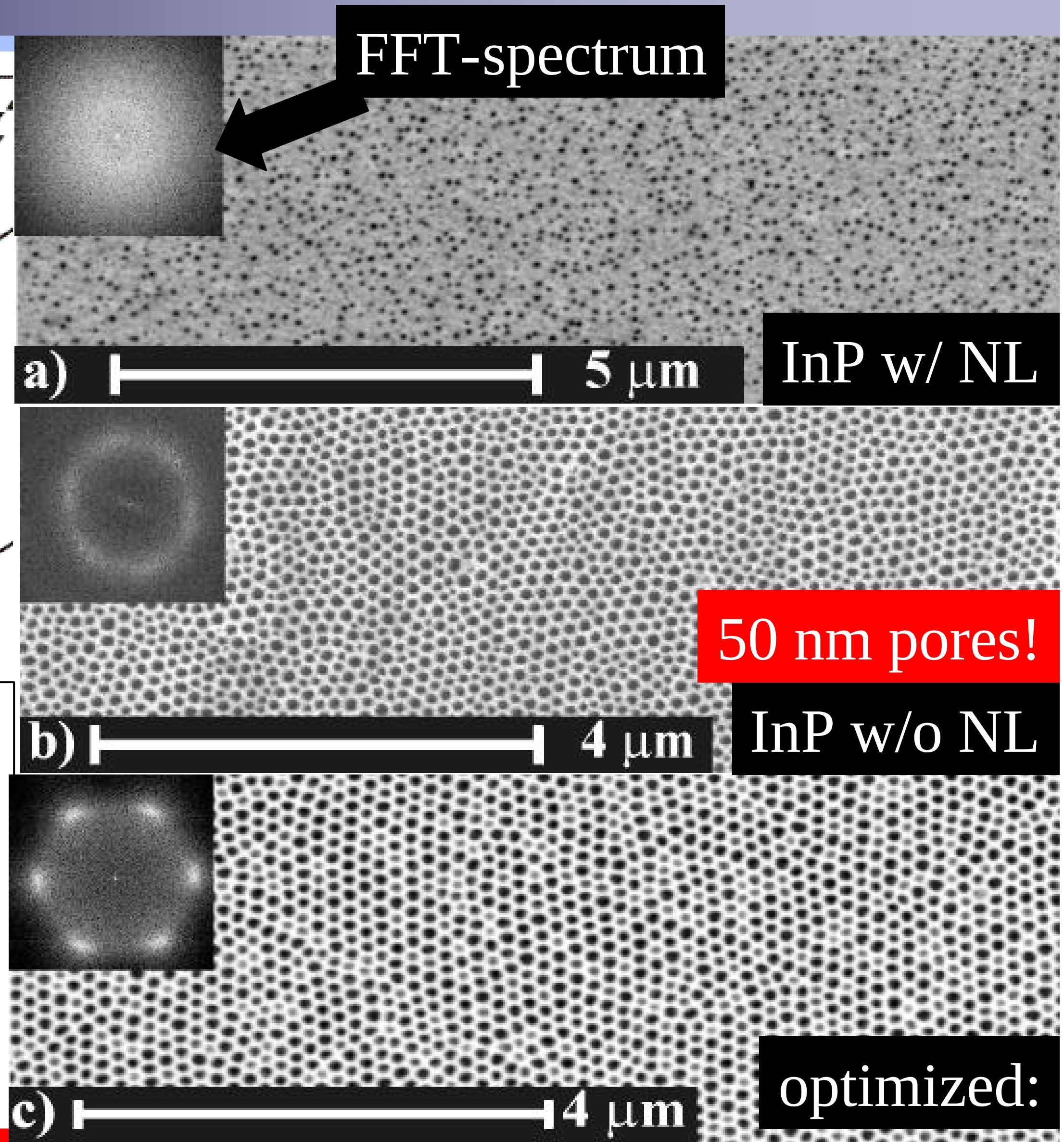
• sometimes larger ε

III-V problem: Lithography doesn‘t work well

➡ Try without!

Selforganization in InP





Long range order:
interplay between
- Nucleation layer NL)
- Interaction of neighboring pores

First monocrystalline self-ordered 2D PC in InP ever!!

Summary and Outlook

Essential to understand pore formation mechanisms in order to:

- further shrink pore dimensions
- build complex 3D PC structures like the Kielovite
- benefit from self-organisation mechanisms like in InP

We showed you:

- First examples of 200 nm macropores (best with DMSO)
- 3D Kielovite-structures
- 2D single-crystalline self-organized PC in InP

We'd like to show you next time:

- Ordered (esp. p-Si) 3D Kielovite PC
- 3D single-crystalline self-organized PC in InP
- Further optimization of pore growth in resp. to PC
- Optical measurements

Acknowledgements

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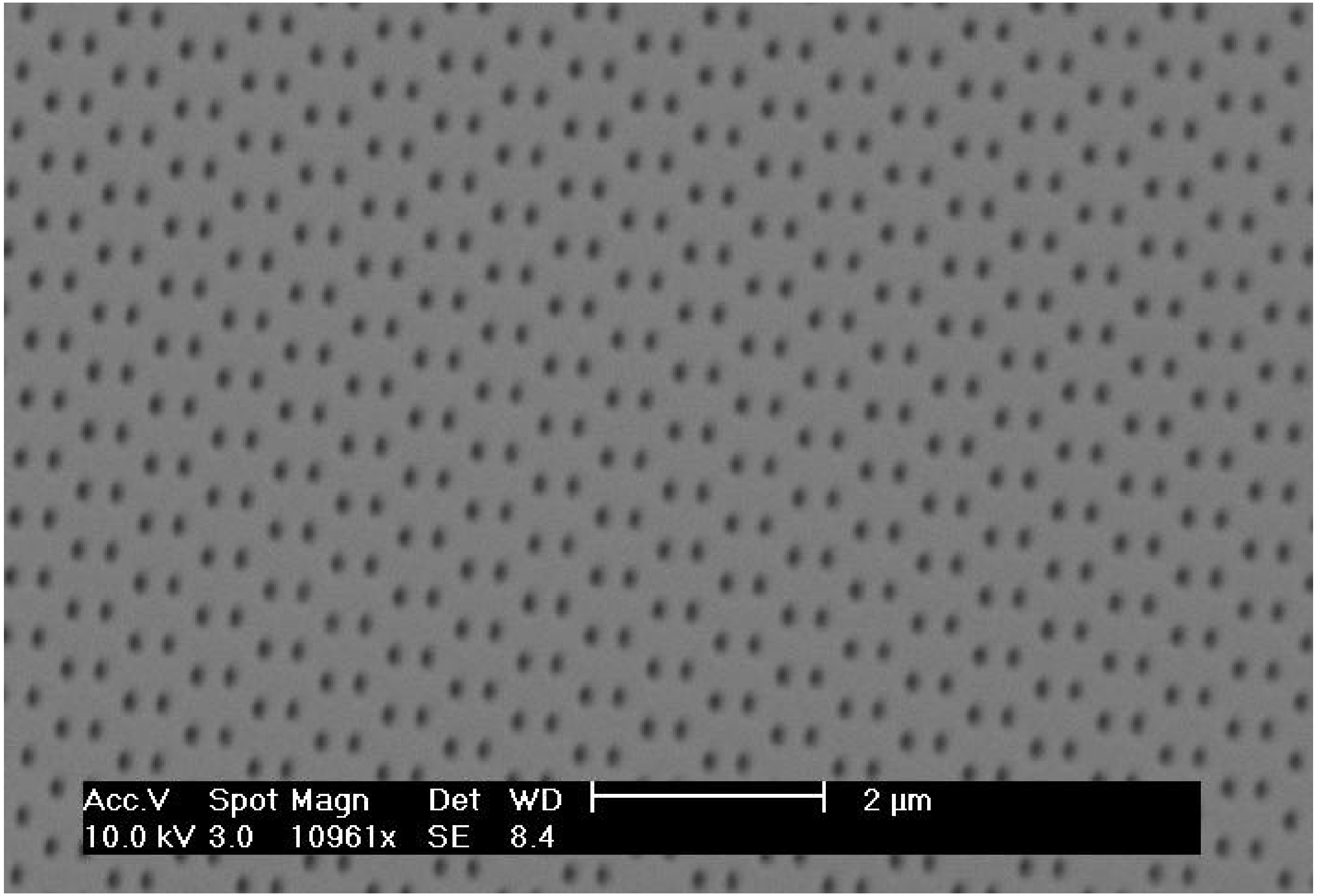
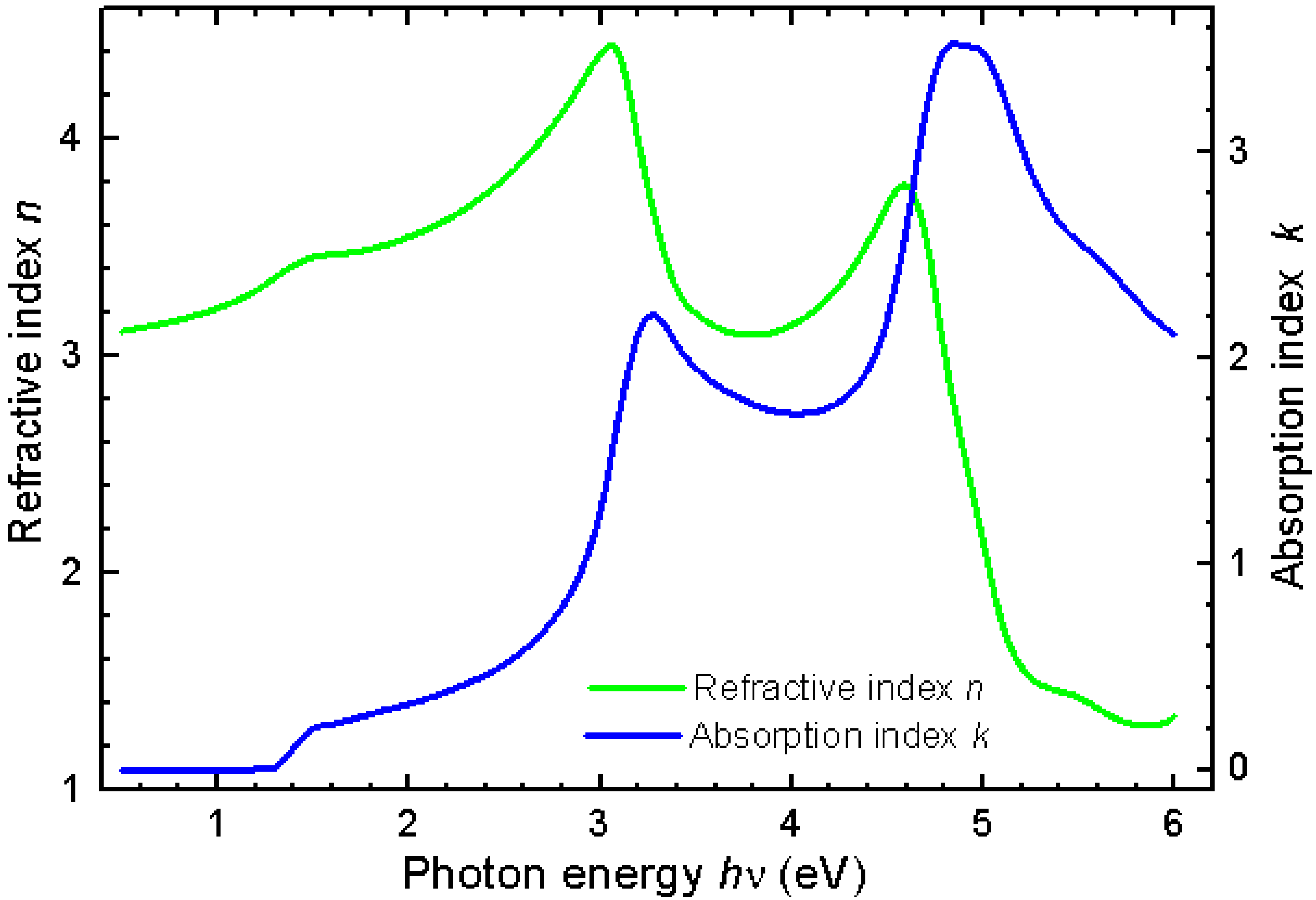
Thank You for your attention !

„Free pores!“ (German advertisement)

Mask for sub-µm



InP refractive index



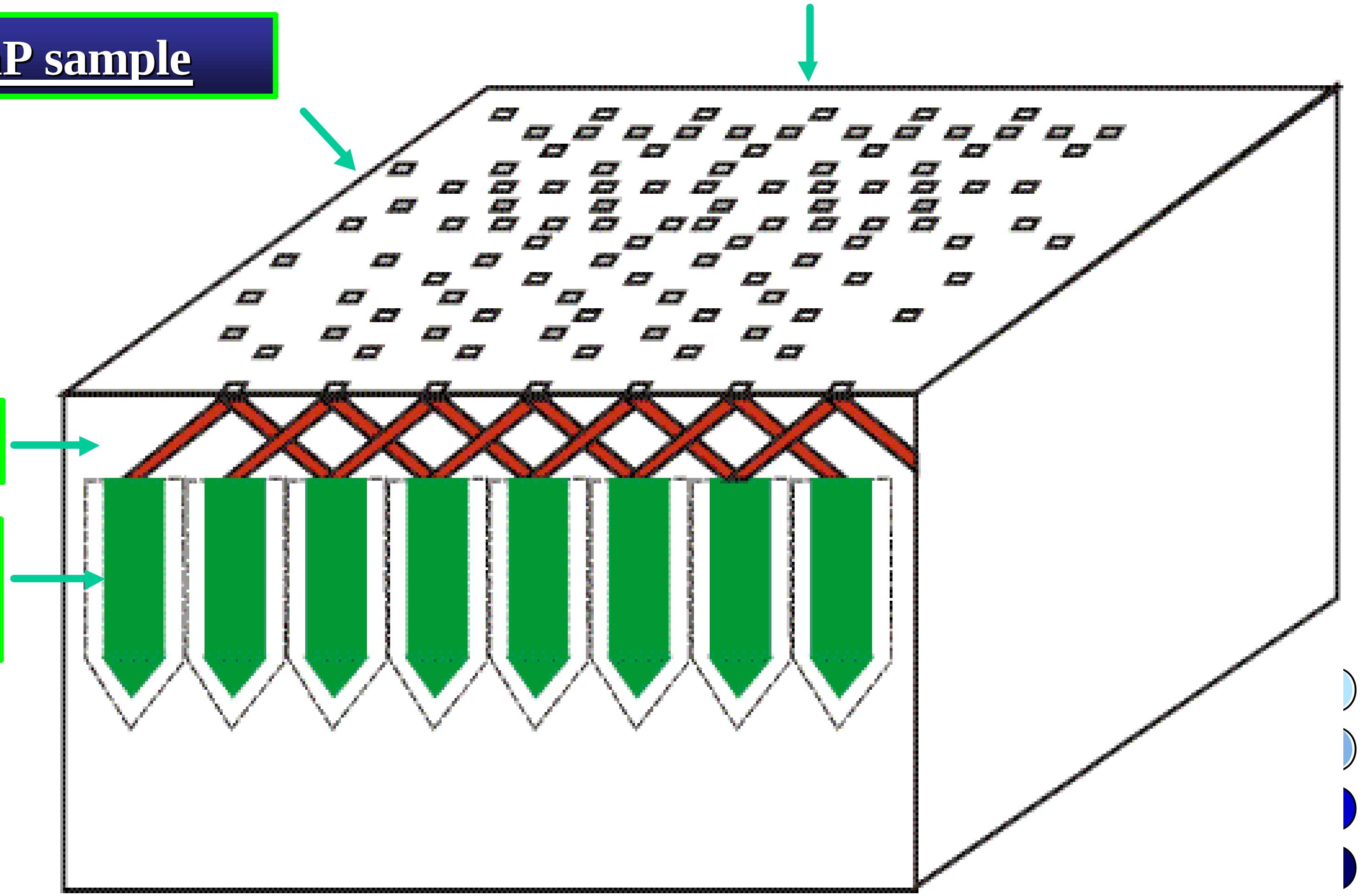
Conclusion

Monocrystaline 2D porous arrays have been obtained for the FIRST time by means of self-organisation without any lithographic prepatterning!!!

2D Crystal = { **Closed packed arrangement !** + **Crystallographic nucleation layer!** }

Low voltages :	K	**No Closed packet arrangement**
High voltages :	K	**No Nucleation layer**
Optimum :	K	**Both**

InP in detail



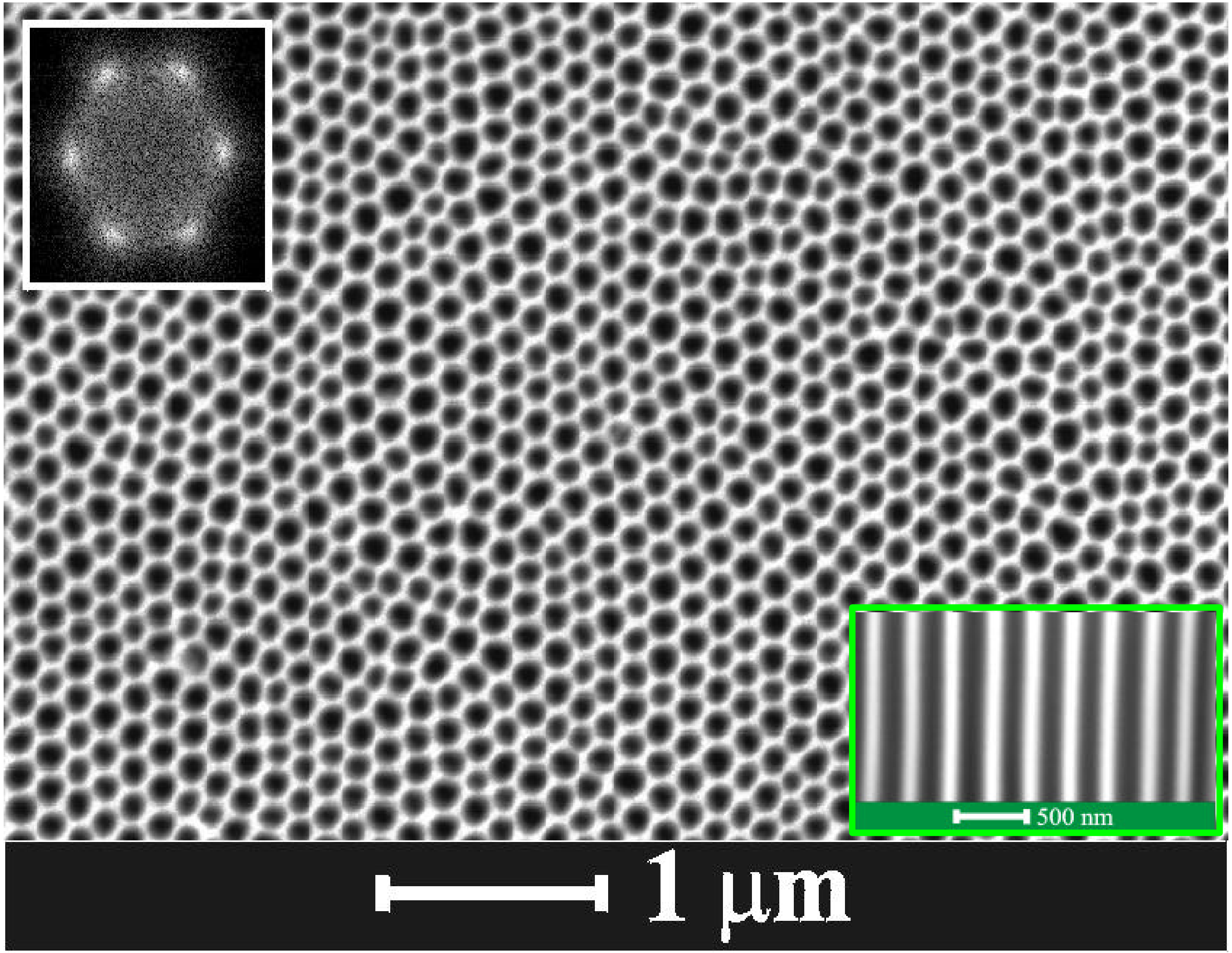
Anodization surface

(100) n-InP sample

Nucleation layer

Current line oriented pores

Long range order: interplay between NL and SL



InP

Nucleation layer on (111) samples