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U.S. Department of Energy

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A U.S. Department of Energy laboratory managed by The University of Chicago

1st Workshop on Photo-cathodes: 300-500nm

July 20-21, 2009: University of Chicago

Problems and Obstacles for Developing Nano-structured Photo-cathodes

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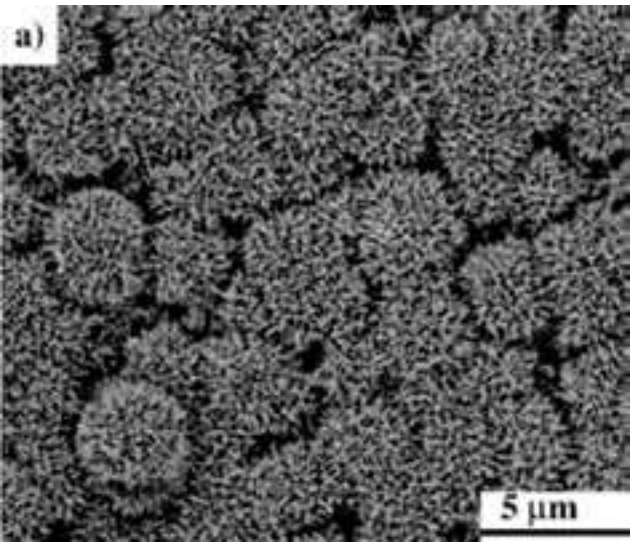
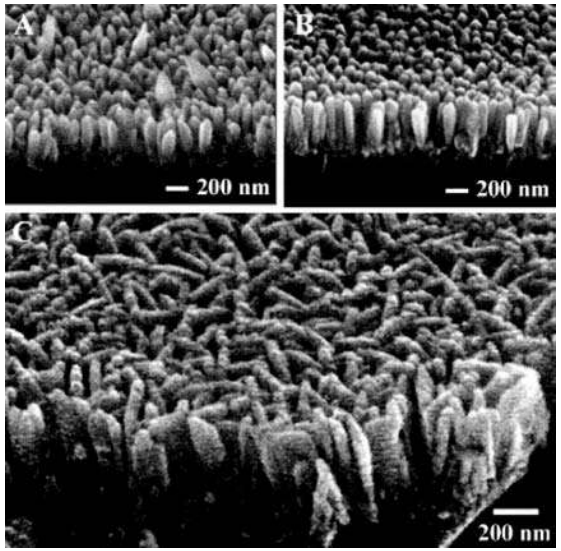
Overview

- What are the structures of interest
- What are the growth mechanisms
- Conformal/epitaxial growth
- Impurity and defects: source for thermal noise
- The role of the external electric field
- The optimization process: Need for new simulation tools

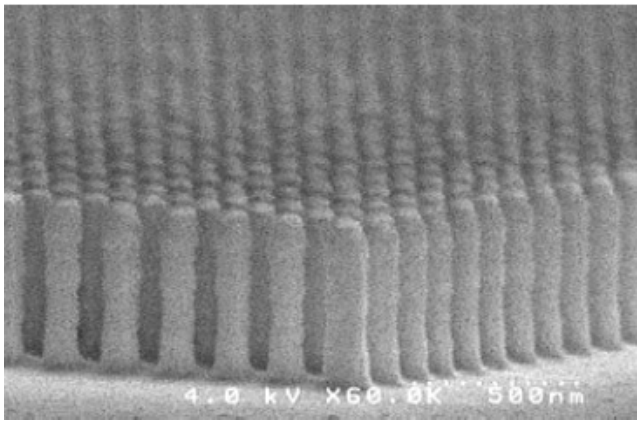
What is the best?



X.Feng et al.,*Angew. Chem. Int. Ed. 44, 5115 (2005).© 2005*



J.J.W u and C.C.Y u, *J. Phys. Chem. B 108, 3377 (2004)*

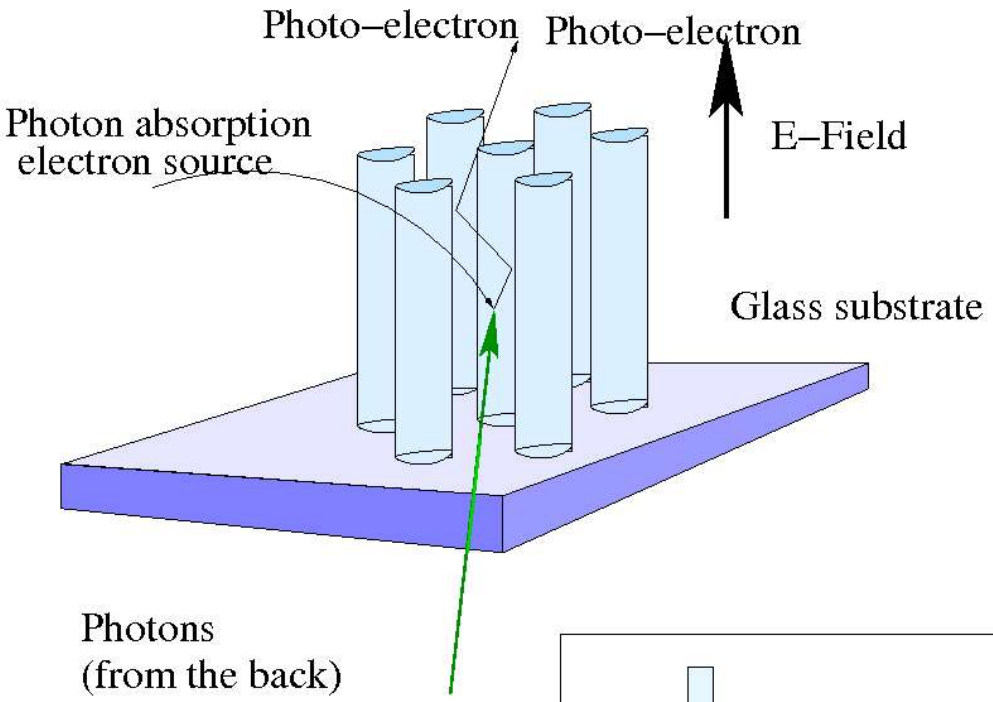


http://cqd.eecs.northwestern.edu/research/ebeam.php

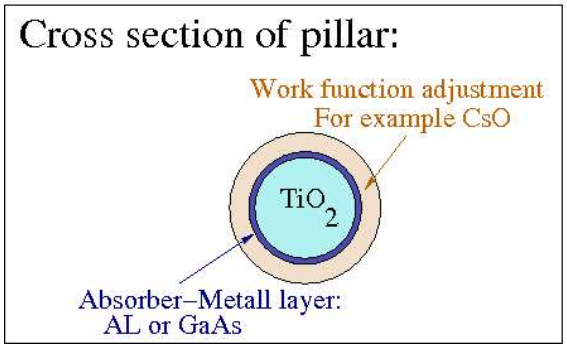
Cost →

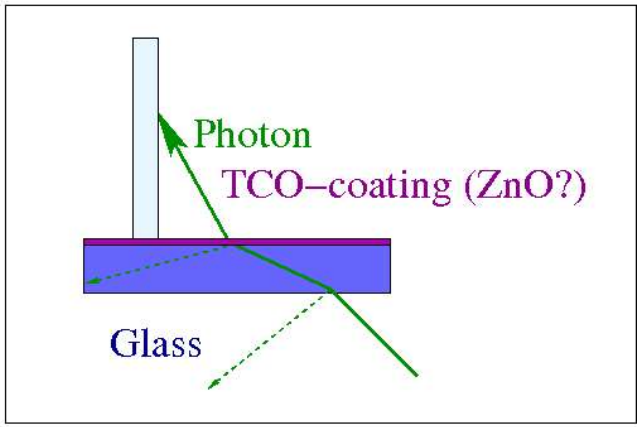
Defined material →

How May a Nano-Structured Cathode Look like



- Photon trap
- Refractive index matching
- Utilization of internal fields (PIN-structure)
- No ion etching
- Noise? (compare to APD)





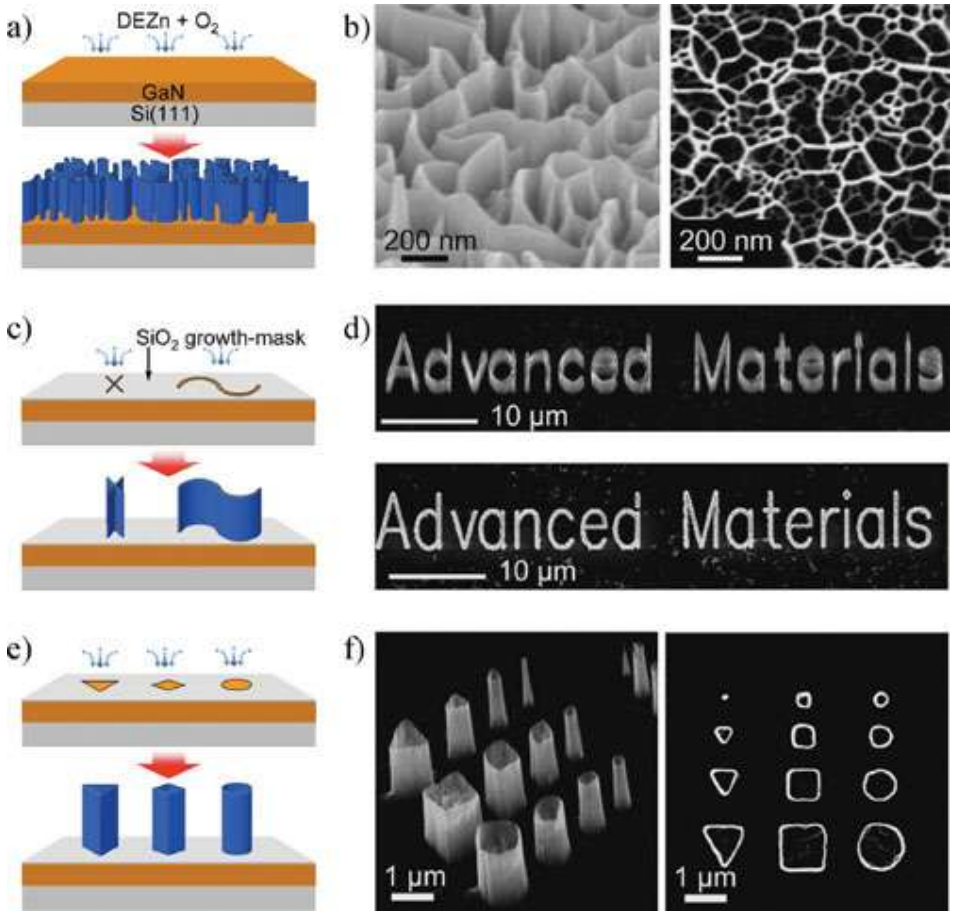
The Way from the Cartoon to Reality
How to choose the right fabrication process

- There are many ways to Rome! Many fabrication processes exist
- Typically the most defined structures cost most!
- Which effort is essential (for example noise) and what is unimportant to the functionality.
  (shape, defect concentration)
- How to decide which structure is the best

What is Nano-Technology?
The Two Design Principles

Bottom-up approach
(molecular self-assembly)

Top-down approach
(conventional lithographic way)



Bottom-up

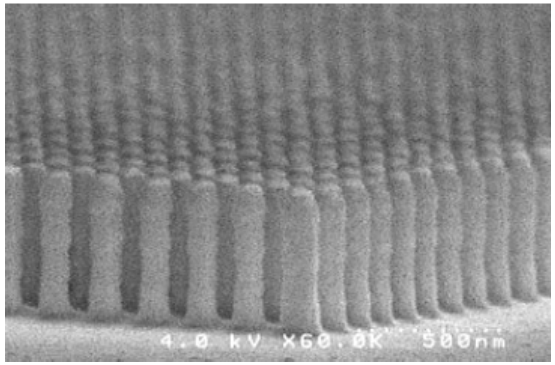
- Bottom-up approach is very cost efficient
- Typically not easy to change growth result
- Often not good long range order

Top-down

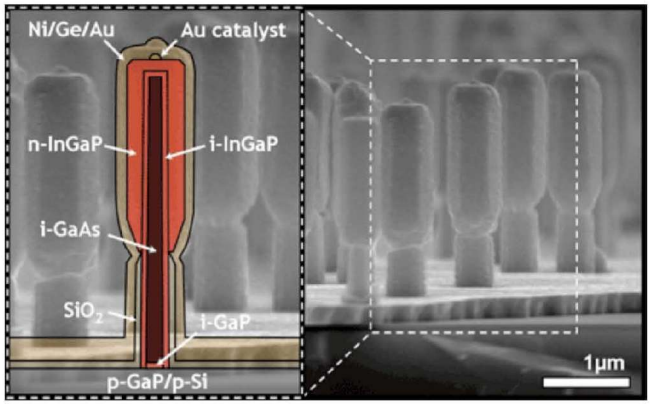
- Good reproducibility
- Well defined structure
- Large variety of shapes available
- Expensive for large areas
- Already used for IR detectors

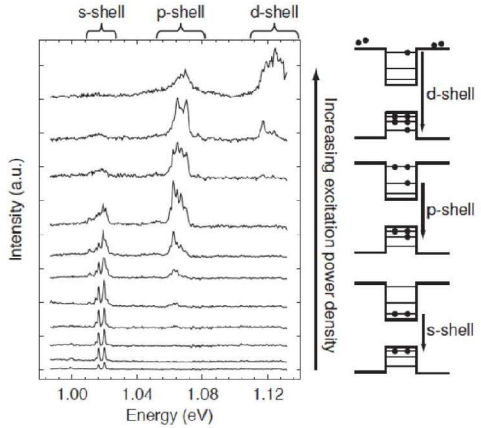
http://www.nanowerk.com/spotlight/spotid=9020.php

Fabrication Mthodse: How to Choose

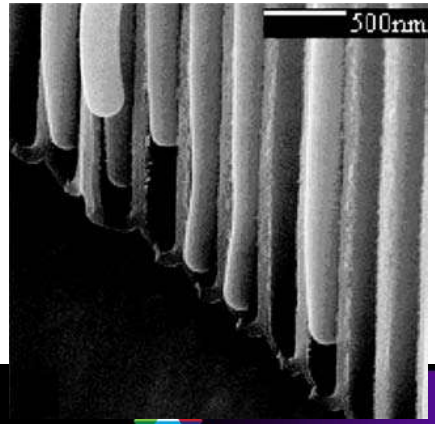


Nano-pilars etched out of multilayer:
For example 20nm diameter and 200nm high
Materials: GaSb, InAs/GaSb, GaInAs
and GaInP, GaN, InGaN and AlGaN
Work: Center for quantum devices/ **Prof Manijeh Razeghi**
Northwestern University
http://cqd.eecs.northwestern.edu/research/ebeam.php



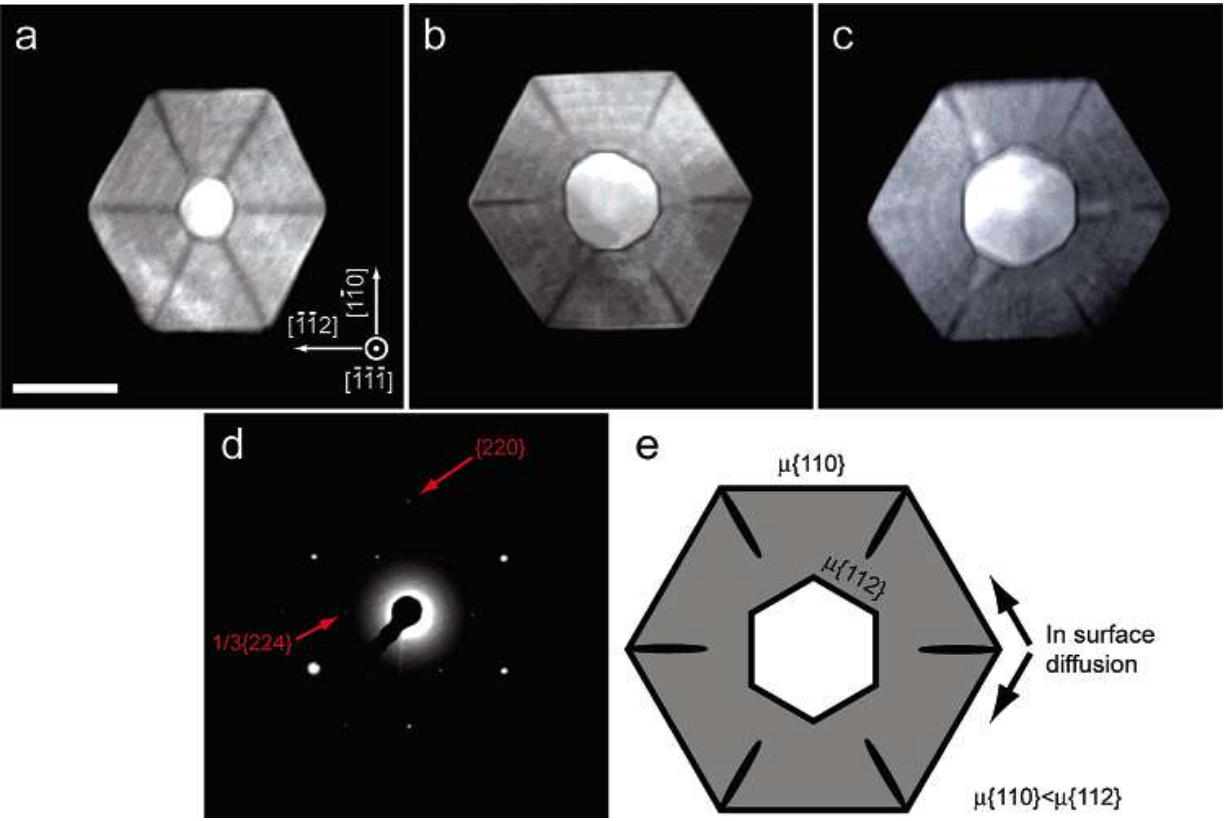


Catalytic growth:
Heterostructures for light emitters
Work: The Nanometer Structure Consortium at Lund University
http://www.nano.lth.se/research/nano-electronics/project-2-1



Template growth: TiO2 in AAO
S.Liu and K.Huang, *Solar Energy Mater. Solar Cells 85, 125 (2004).© 2004,* Elsevier

Materials Properties Depend on Fabrication Process
What is a dopant?



- Conformal versus epitaxial growth
- Residual from wet or gas chemistry
- Strain and lattice miss-match have different effects
- Many different approaches available (cheap versus defined?)

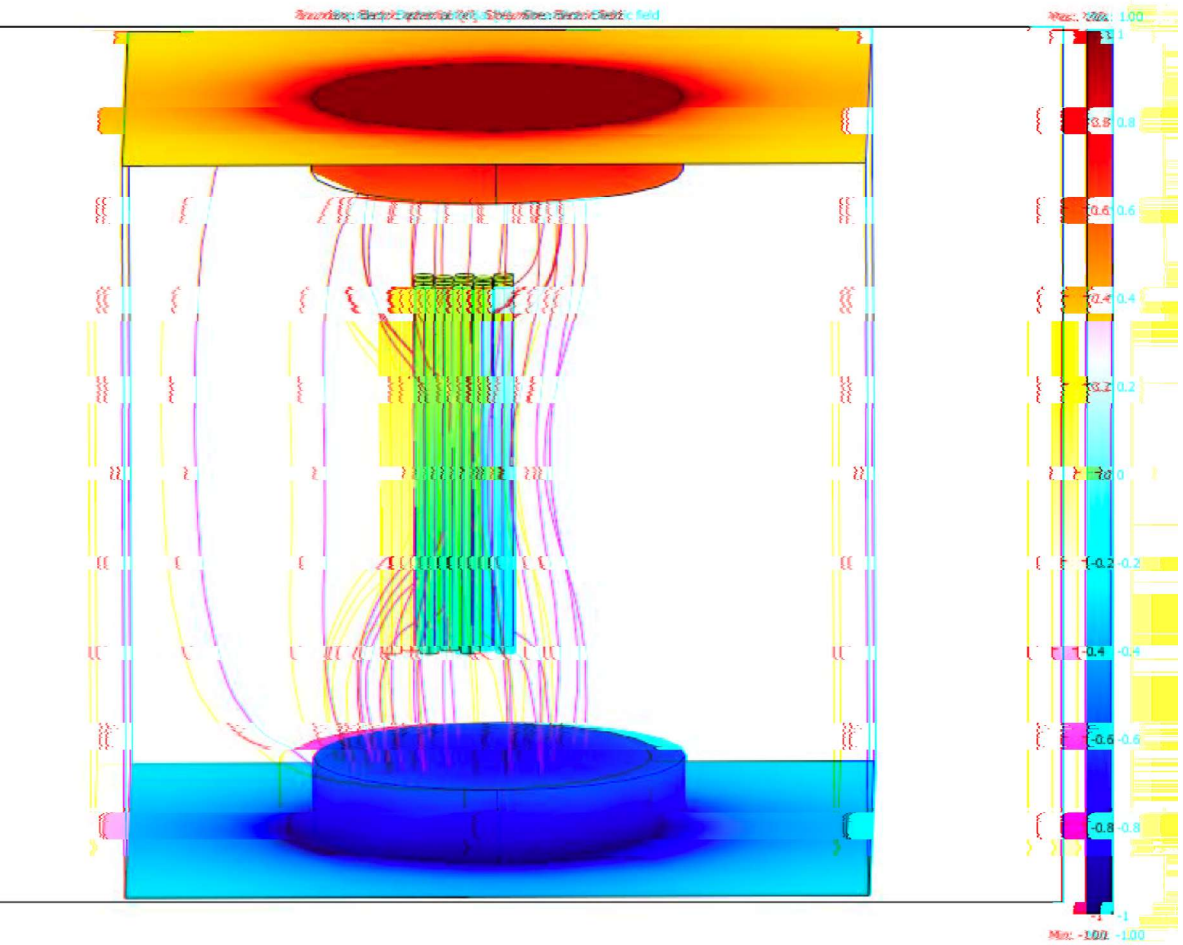
"Phase segregation in AlInP shells on *GaAs nanowires", N. Sköld, J.B. Wagner, G. Karlsson, et al., nano Lett. 6, 12 (2006), 2743-2747 DOI:10.1021/nl061692d*

Impurity and Defects: Source for Thermal noise?

- Can models for APD's be applied?
- What energy levels of dopents contribute to thermal noise?
- Is the internal electric field removing all charge ate the beginning?

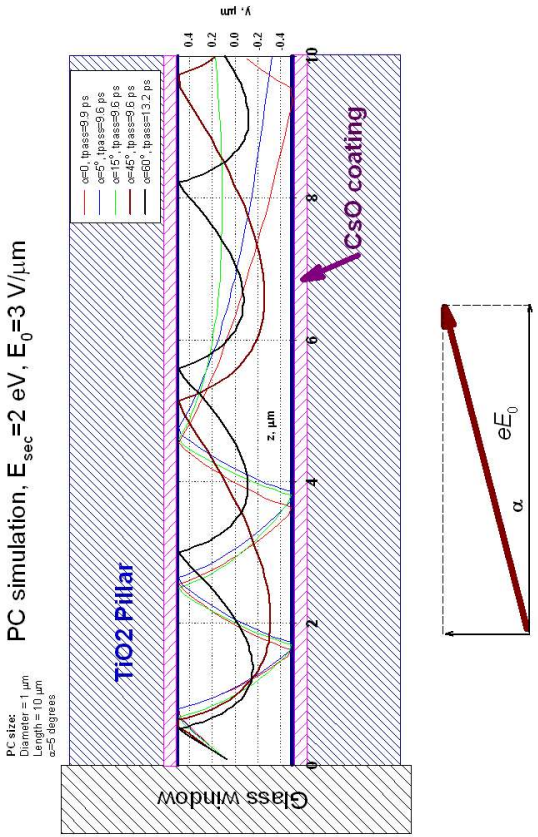
Where is a quantitative description?

Electric Field in Nano-Structures



- Field emission depends on:
  - Carrier density inside the cathode materials
  - Dielectric constant of the material (focusing effects)
- Extraction Field has to be internal (by doping)
- Many materials parameter are unknown
- Difficult to simulate (large and small dimensions)

Tunable Materials-Parameter and Shapes Require Good Simulation Tools



- Simulation has to include photon, electron, and internal/external electric fields
- Materials parameters are more ore less known dependent on process technologies
- Simulations have to cover many orders of magnitude in space
- Resulting electronic properties of a given defect is often unknown

Summary

- There are many excellent growth tools available
- Each of the techniques requires hard work to do it right
- Growth mechanism vary from very cheap to very expensive (per square meter)
- At present there is no way to define the “specs”
- Basic understanding in defects, structure design, and noise is necessary

However: The gain will be huge

- Low reflection losses (opaque/front-back illumination doesn’t play a role)
- Potentially very cost efficient
- Large energy tunability and high QE