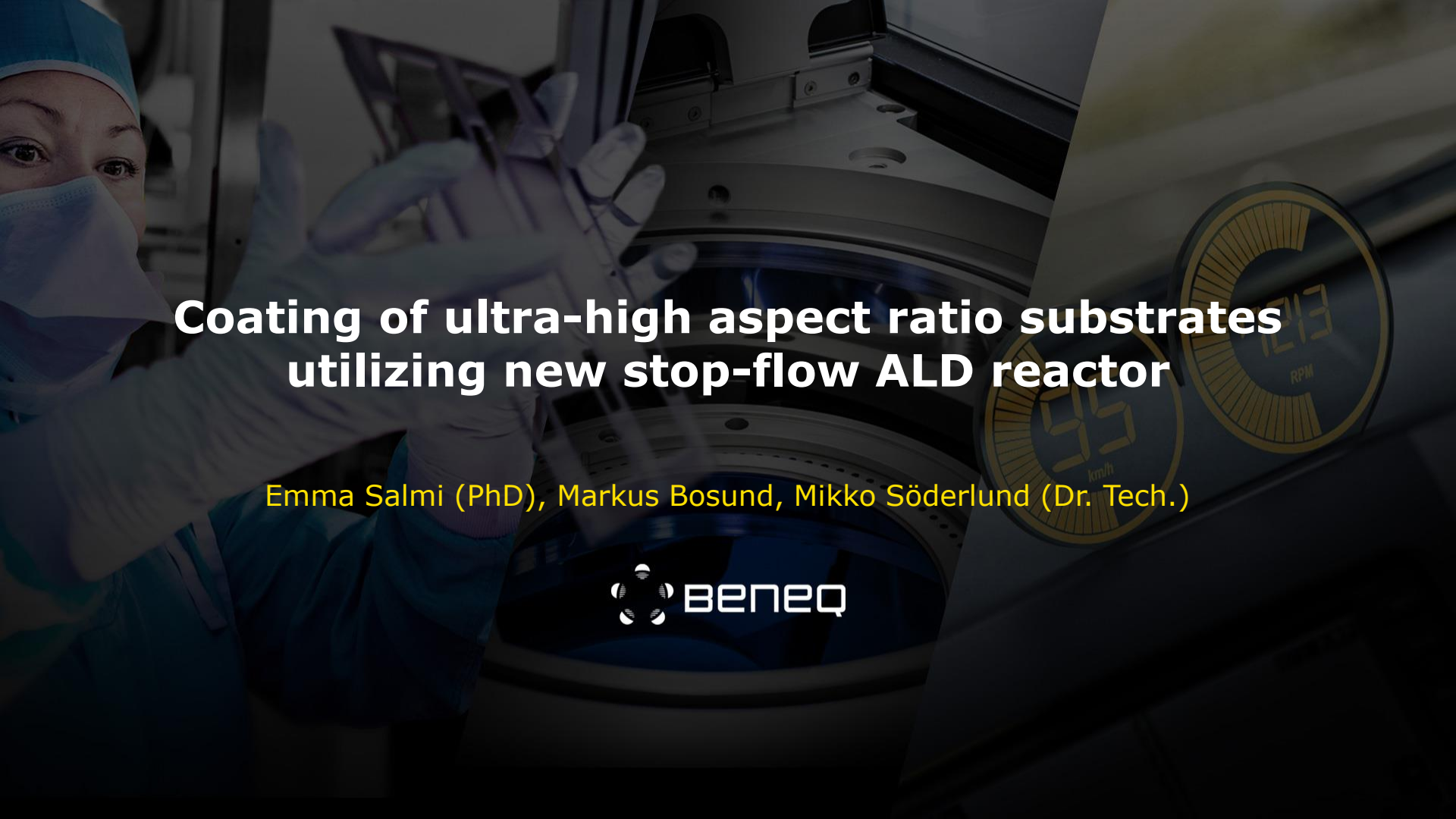


Coating of ultra-high aspect ratio substrates utilizing new stop-flow ALD reactor

Emma Salmi (PhD), Markus Bosund, Mikko Söderlund (Dr. Tech.)

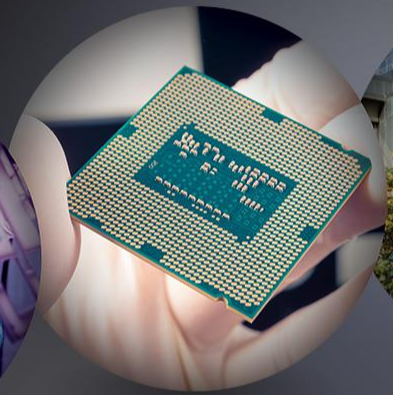
beneq


BENEQ
95
km/h
7213
RPM
Services
Equipment
Displays

One Stop for All ALD

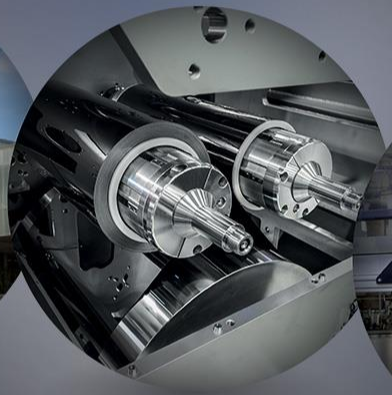
beneq

Research



Development Services

Coating Services



Industrial Equipment

Customer Services

Outline

- Introduction

- Results
  - In-house built test structure
  - Lateral high aspect ratio (LHAR) structure
  - Al_2O_3 on nanotubular TiO_2

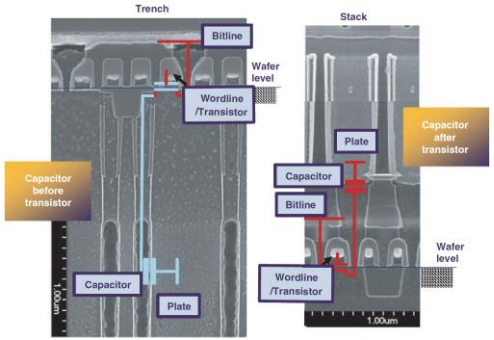
- Conclusions

Introduction – Motivation

- Conformal thin films in high aspect ratio (AR) structures
  → Atomic layer deposition
- Increasing demands
  – Higher AR
  – More challenging materials

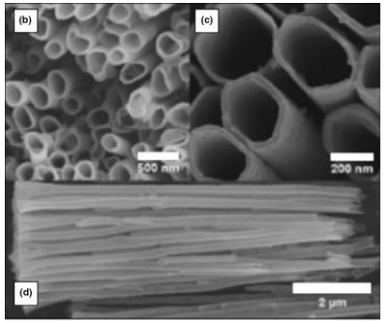
→ New technical solutions needed

Microelectronics



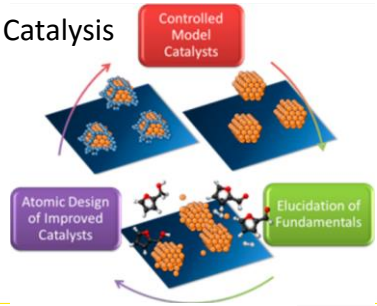
M. Ritala and J. Niinistö, Atomic layer deposition. In *Chemical Vapour Deposition: Precursors, Processes and Applications*, A. C. Jones, M. L. Hitchman, Eds.; Royal Society of Chemistry: Cambridge, U.K., 2009.

Nanofabrication



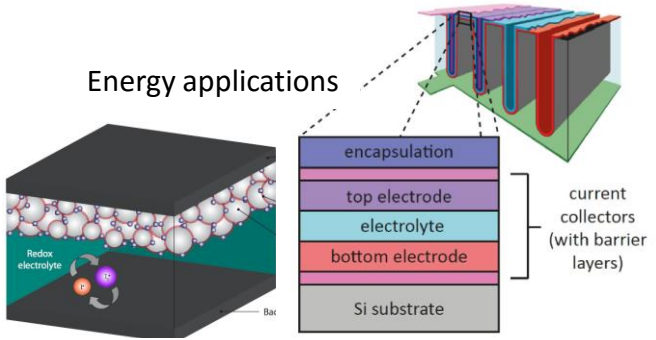
V. Pore et al., J. Am. Chem. Soc. **131** (2009) 3478

Catalysis



B. J. O´Neill et al. ACS Catel. 5 (2015) 1804-1825.

Energy applications



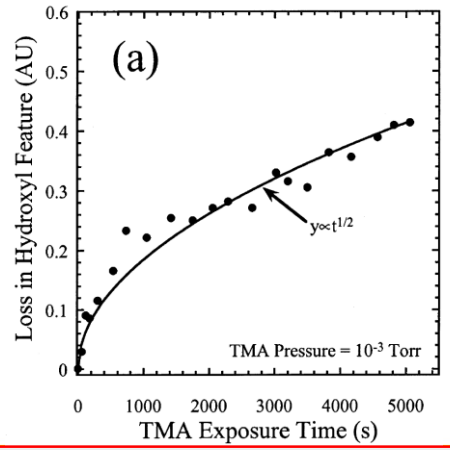
J. A. van Delft et al. Semicond. Sci. Technol. **27** (2012) 074002.

H. Knoops, PhD Thesis, Eindhoven University of Tecnology, 2011.

Introduction – Theory

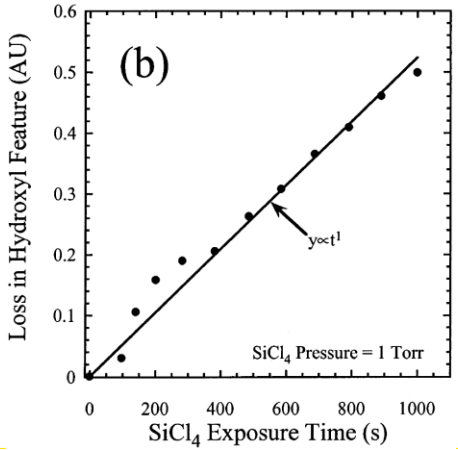
$$A \xrightarrow[diffusion]{H} B \xrightarrow[reaction]{S} C \qquad \left\| H = 16\left(\frac{d}{L}\right)^2 \right.$$

- Diffusion controlled $S \gg H$
  - Reactive sites fill approximately in order from the entrance



$$S_{TMA} = 1 \times 10^{-3}$$
$$H = 1.4 \times 10^{-5}$$

- Reaction controlled $S \ll H$
  - Precursors diffuse along the length of the tube prior to reaction

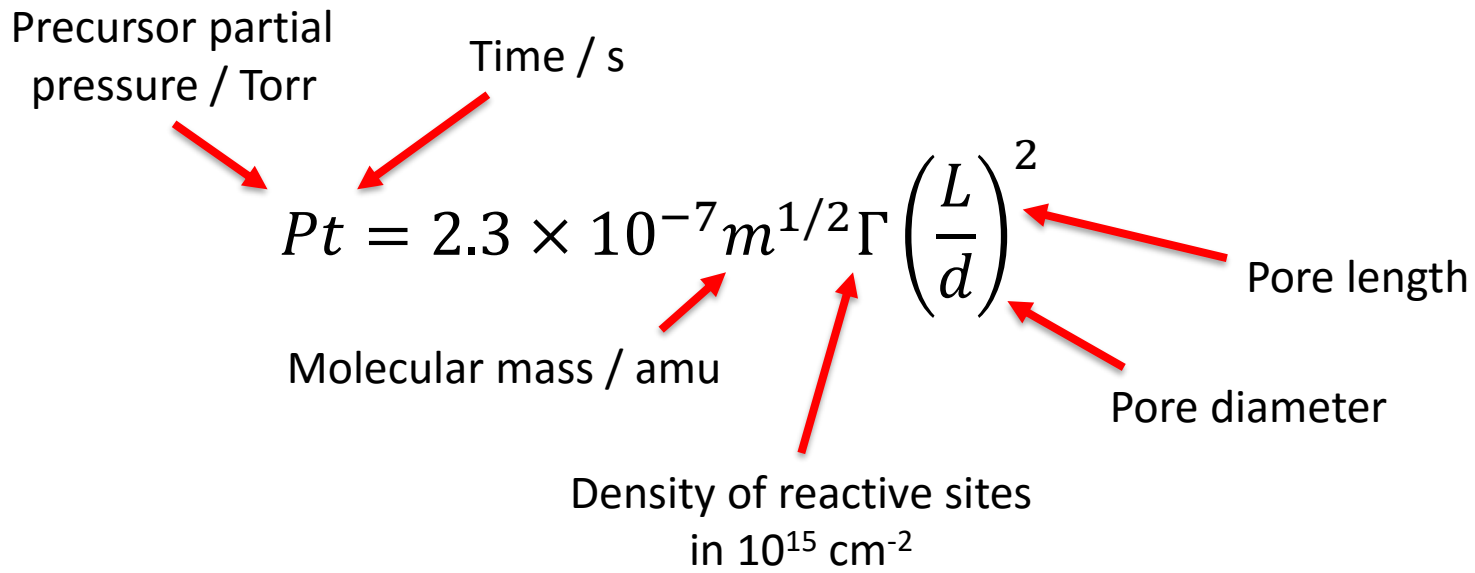


$$S_{SiCl_4} = 10^{-8}$$
$$H = 1.4 \times 10^{-5}$$

J.W. Elam et al., *Chem. Mater.* **15** (2003) 3507

Introduction – Theory

- When the system is diffusion controlled
  - Exposure required to conformally coat a HAR surface



J.W. Elam et al., *Chem. Mater.* **15** (2003) 3507

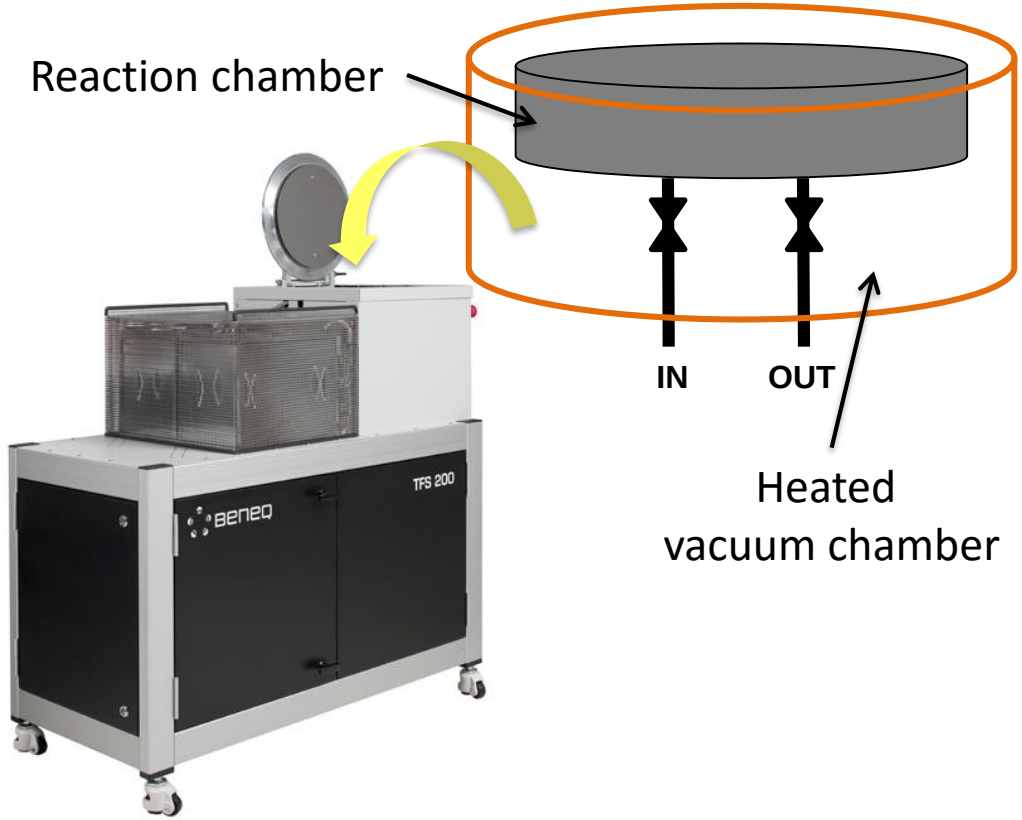
Introduction – Methods

- Comparison of methods used for conformal deposition onto HAR structures

	Constant flow	Reduced flow	Stop-flow
Precursor consumption	**High**	Intermediate	**Low**
Conformality in ultra-high AR	**Challenging**	**Enabled**	**Enabled**
Conformality with low sticking coefficient precursors	**Challenging**	**Enabled**	**Enabled**
Control of allowed diffusion time	**Challenging**	Prolonged, with risk of back diffusion	**Full**
Pressure	Constant	**Increasing**	**Adjustable**

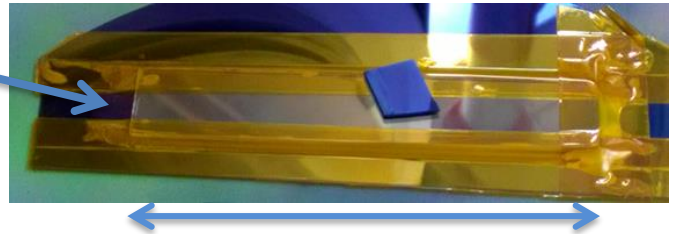
Introduction – The Beneq solution

- Beneq HAR module
  - Available for existing and new TFS 200 systems
  - Isothermal conditions
    - Minimum risk of
      - Condensation
      - Powder
      - Leaking valves
  - Temperature specs up to 300 °C
    - Near future upgrade for 450 °C
  - Diffusion (/reaction) time not restricted



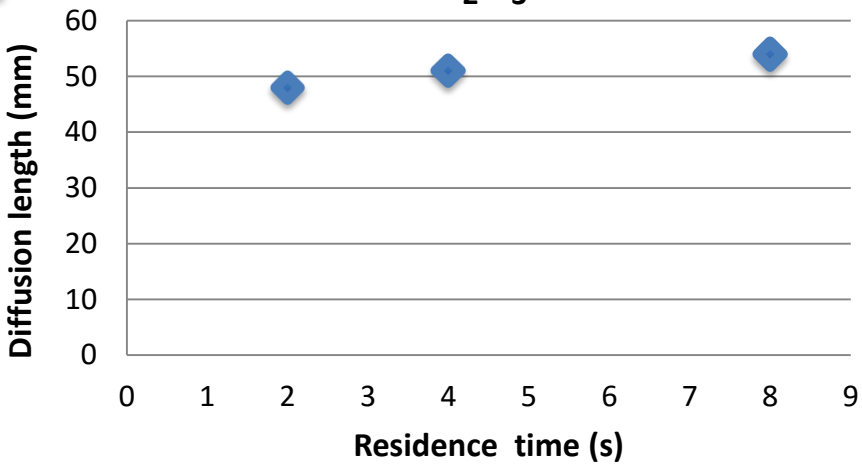
Results – In-house built test structure

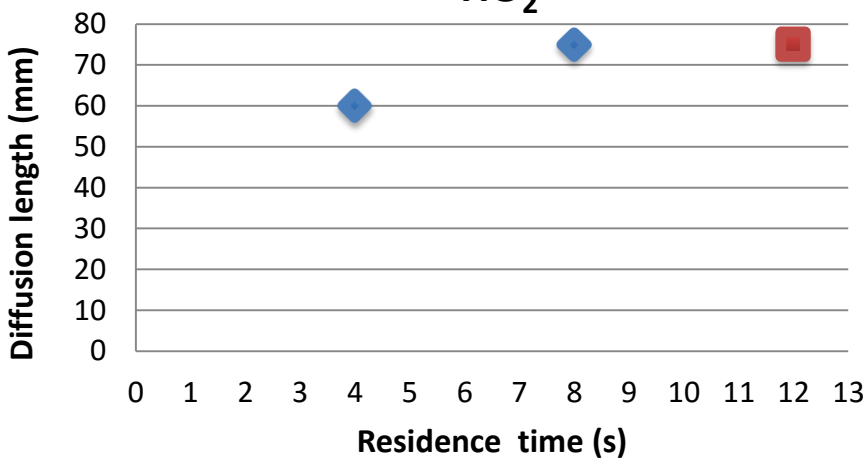
62.6 x 1000 µm opening



~100 mm length

Increasing aspect ratio

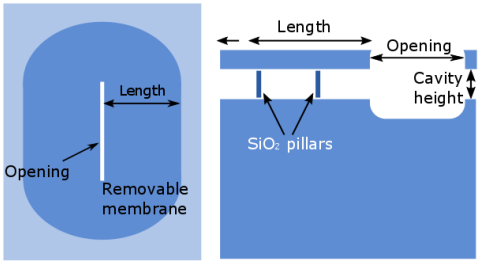


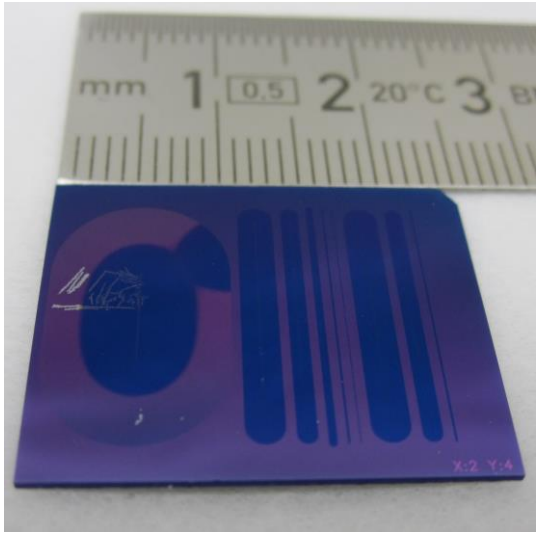


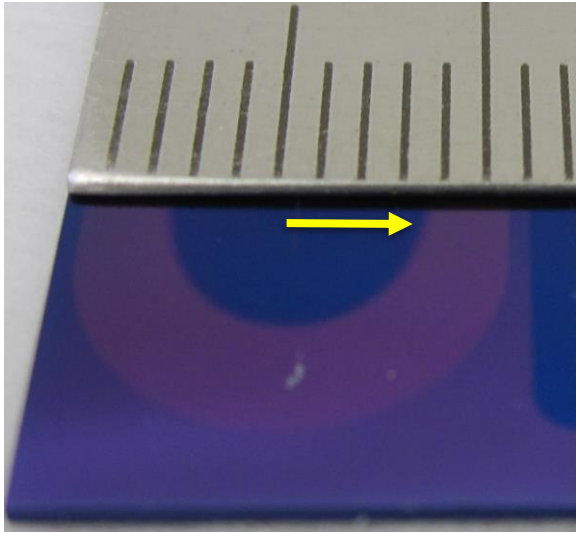
Results – LHAR structure

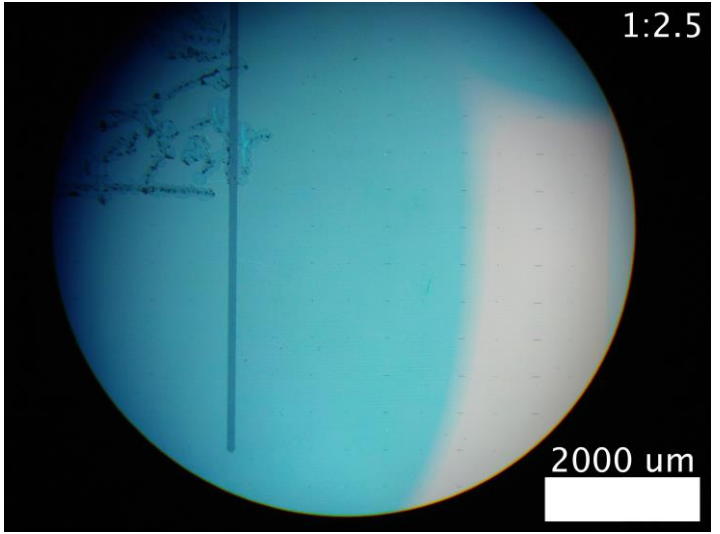
- Al_2O_3
  - Growth up to 3000 µm length

    →Aspect ratio 1:3000





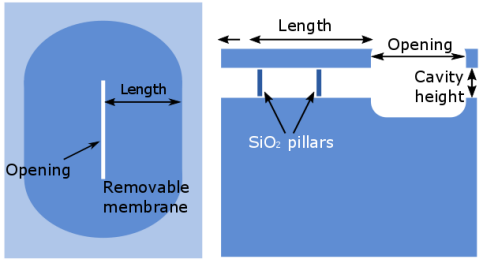


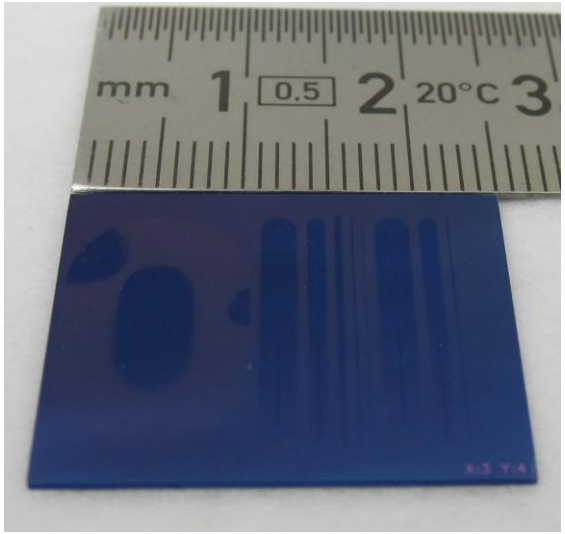


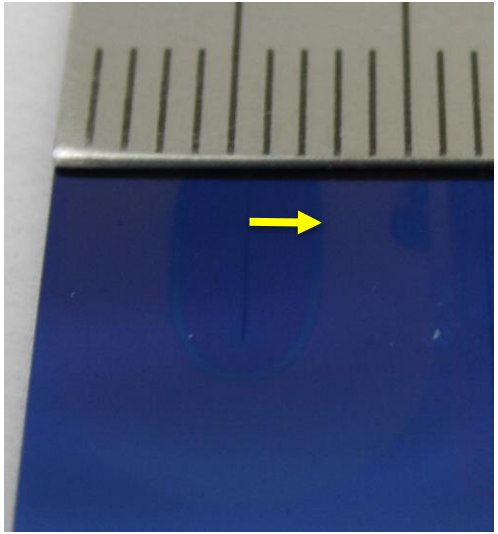
Results – LHAR structure

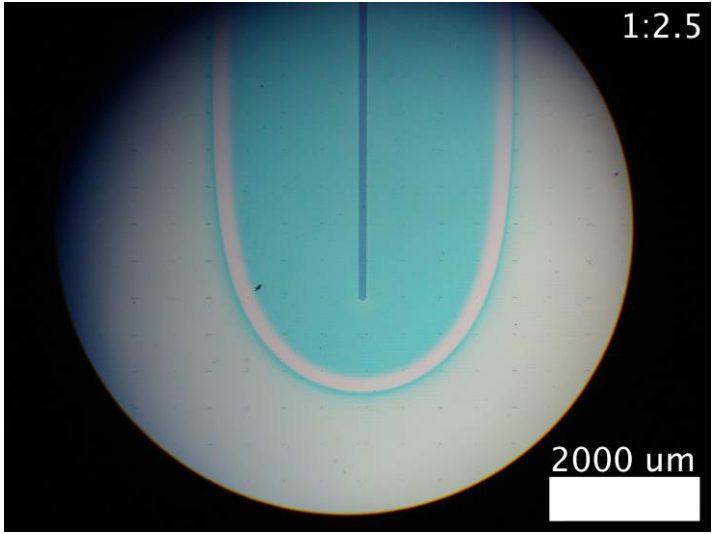
- TiO_2
  - Growth up to 2000 µm length

    →Aspect ratio 1:2000

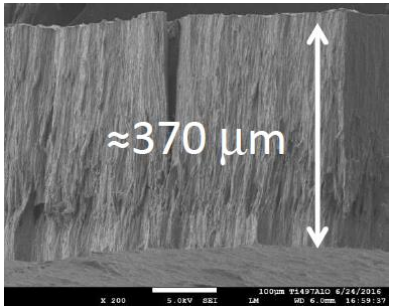


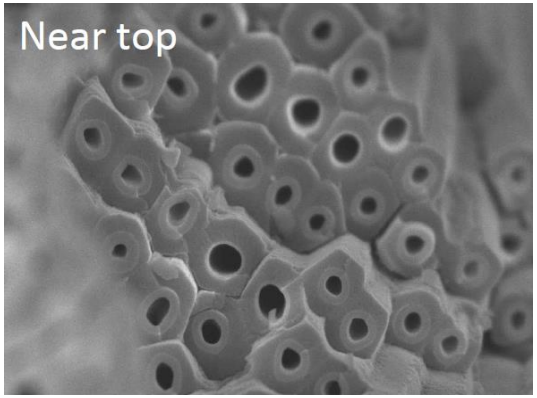


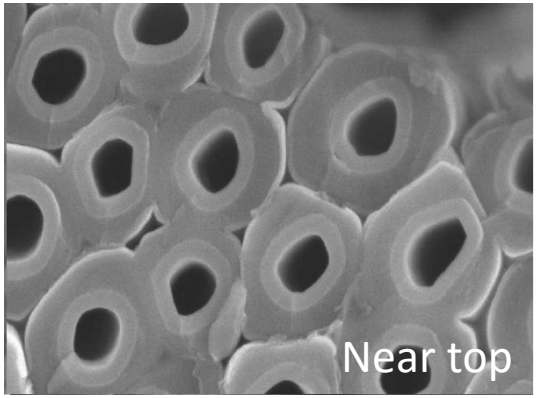




Results –Al_2O_3 on nanotubular TiO_2



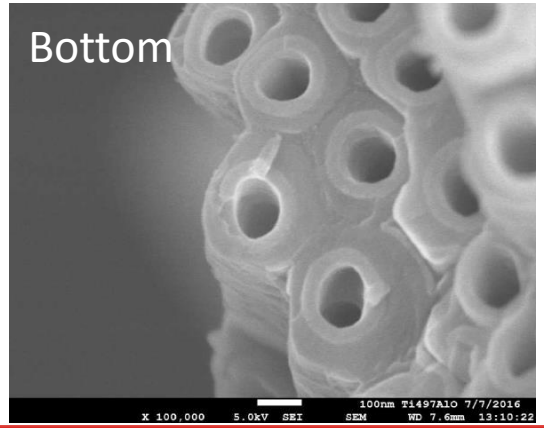




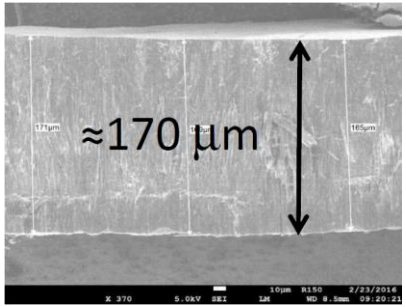
Bottom diameter
170.7 ± 27.8 nm

Aspect ratio 1:1088

Thickness
- Middle 38.8 ± 4.0 nm
- Bottom 39.8 ± 5.7 nm



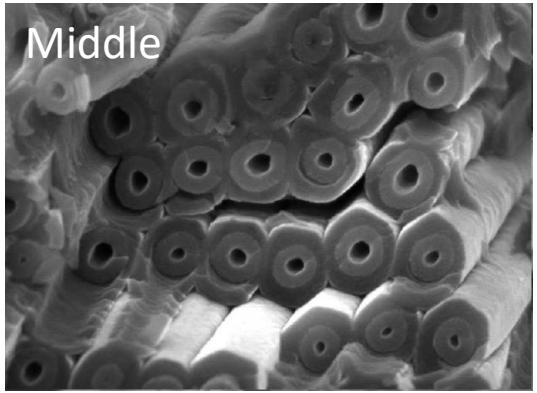
Results –Al_2O_3 on nanotubular TiO_2

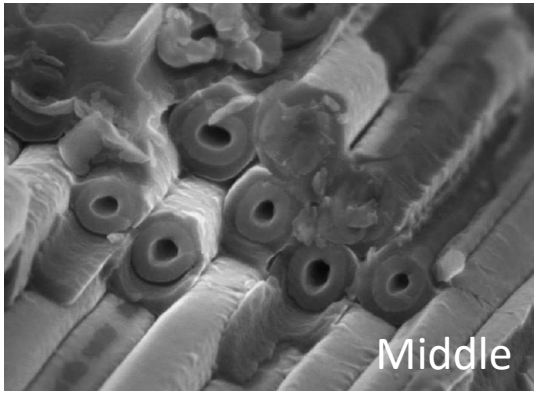


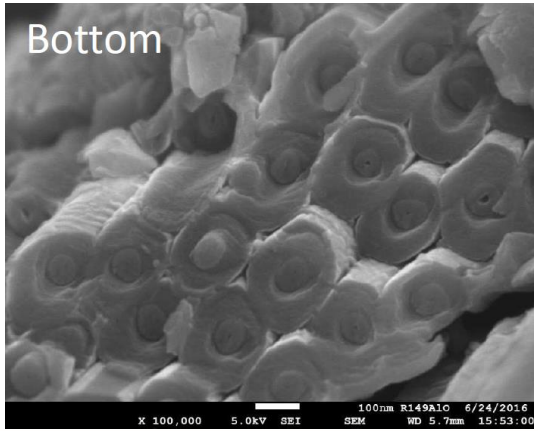
Bottom diameter
76.9 ± 5.2 nm

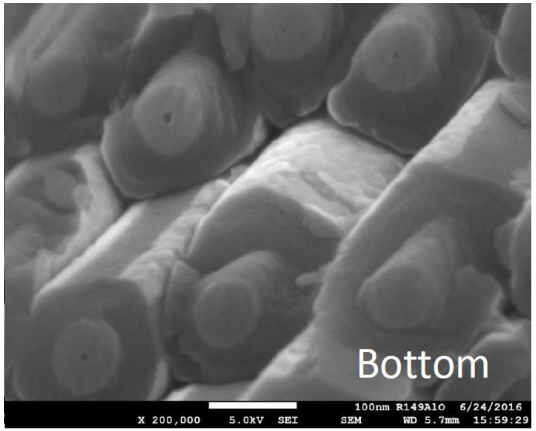
Aspect ratio 1:1105

Thickness
- Middle 34.2 ± 3.6 nm
- Bottom 35.5 ± 2.5 nm



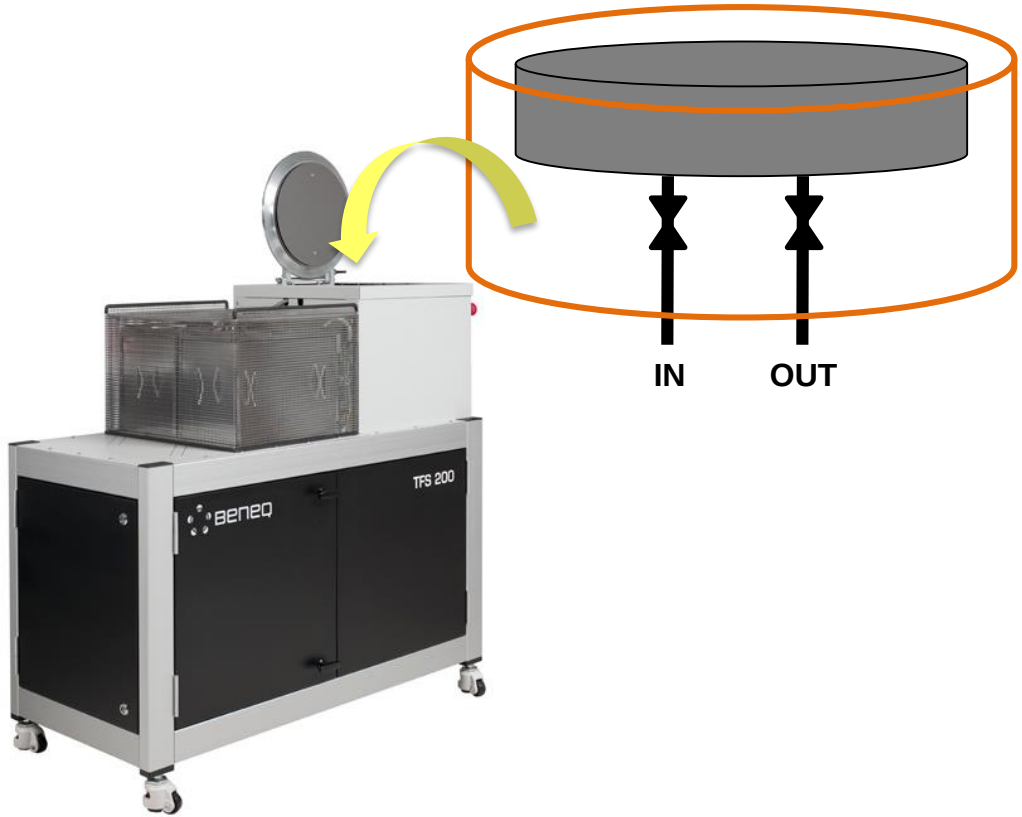






Conclusions

- Stop-flow
  - Conformal ALD enabled into ultra-high AR structures
  - Problems with continuos flow and reduced flow solved
- Beneq HAR module available for existing and new TFS 200 systems
  - Isothermal conditions
  - Temp up to 300 °C
  - Proven performance to AR 1:3000



Thank you

www.beneq.com
emma.salmi@beneq.com

beneq