Fortum Foundation’s Award Ceremony 2018

15.00 Welcome
Lars Peter Lindfors, Chief Technology Officer, Neste

15.05 Opening
Pekka Lundmark, Chairman of the Board of Fortum Foundation

15.15 It took 44 years from the idea to the Millenium prize – can we learn something about the process?
Tuomo Suntola, PhD, Winner of 2018 Millenium Technology Prize

16.15 Fortum Foundation’s Scholarships 2018

16.30 Buffet

It took 44 years from the idea to the Millenium prize – can we learn something about the process?

Tuomo Suntola

- Innovation behind Millenium 2018 prize: Atomic Layer Deposition (ALD) technology
- What makes ALD unique; what gives the special properties to the ALD material layers?
- How was ALD invented, how was everything started?
- Timeline of the ALD development and commercialization steps
- Hierarchy and timespan of developments

Innovation behind Millenium 2018 prize:

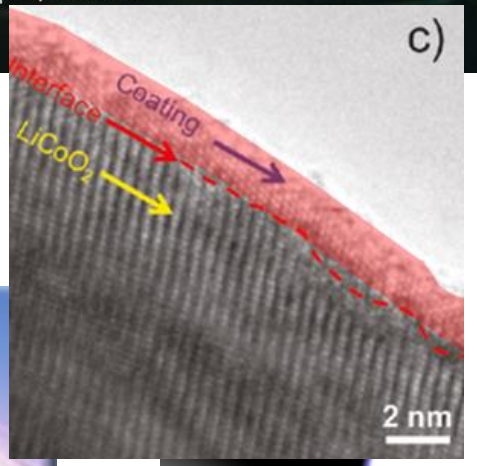
Atomic Layer Deposition (ALD) technology

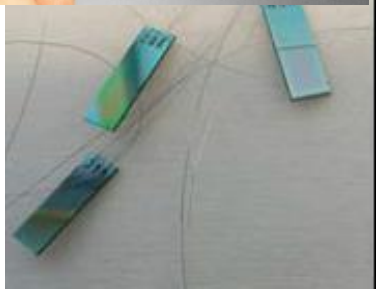
What is ALD, where and why is ALD needed?

ALD is a method for growing highly ordered material layers. ALD layers are built up sequentially, one atomic layer in a reaction cycle, which guaranties extreme uniformity even in layers of a few atomic layer thickness.

Highly ordered material layers are essential, e.g., in modern semiconductor devices needed in computers, mobile phones, and essentially in all electronic equipment.

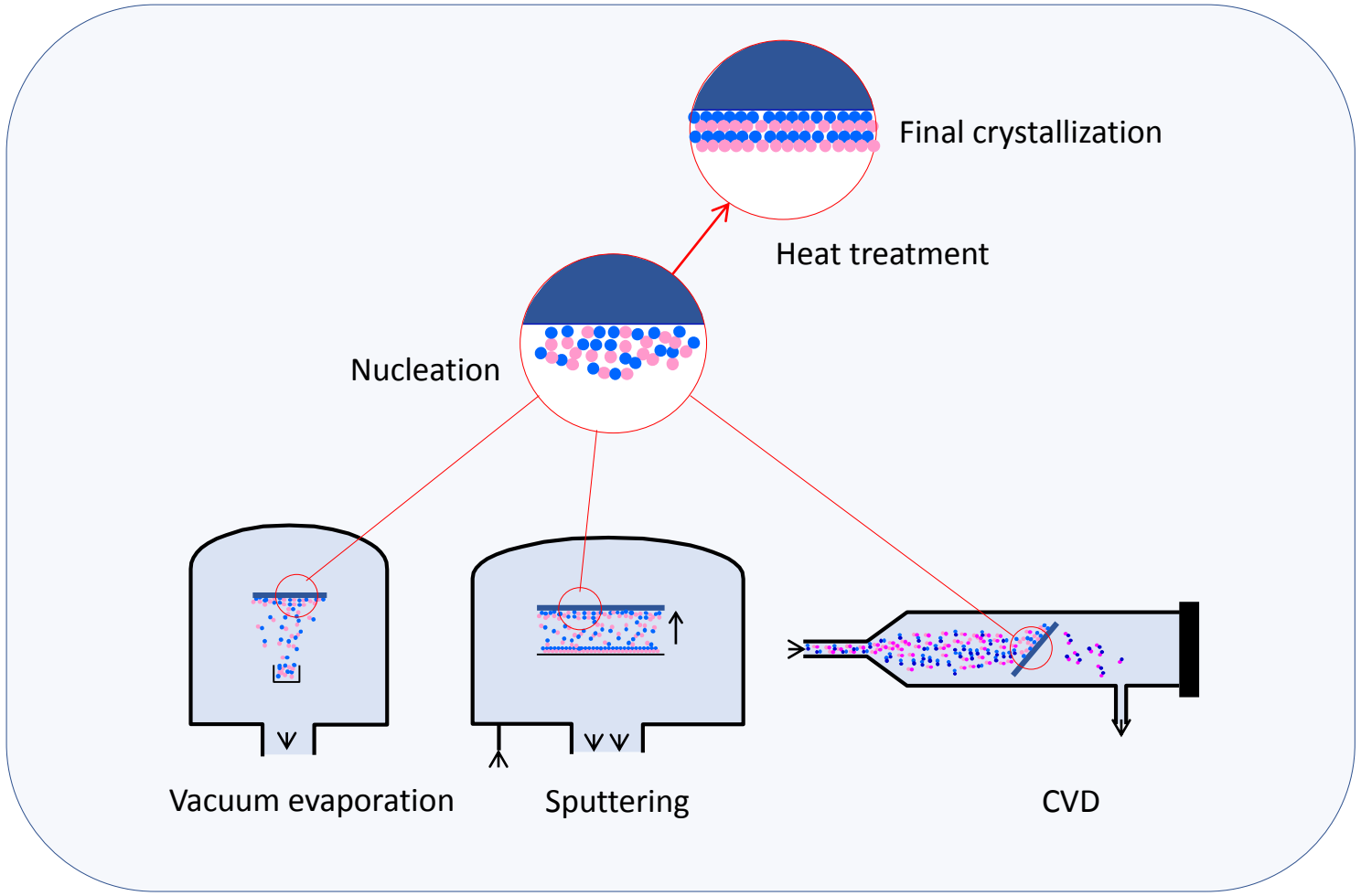
ALD layers can be used to enhance the properties of solar cells, Li-ion batteries and LED lights – also as protective layers in numerous products from implantable micromedical devices to quality watches, silver ornaments, and even telescope mirrors.



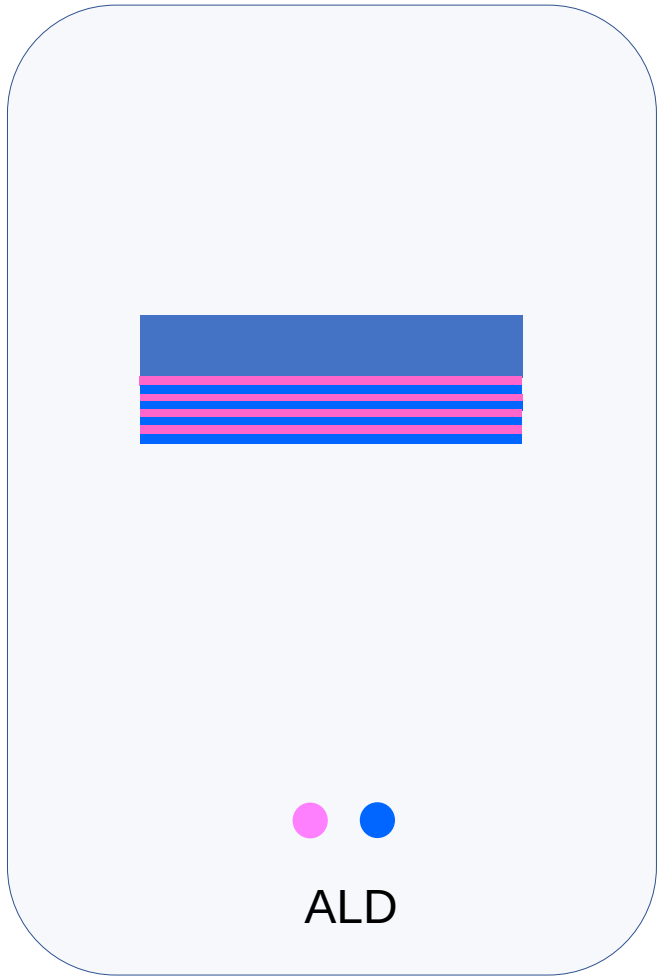


What makes ALD unique;
what gives the special properties to the ALD material layers?

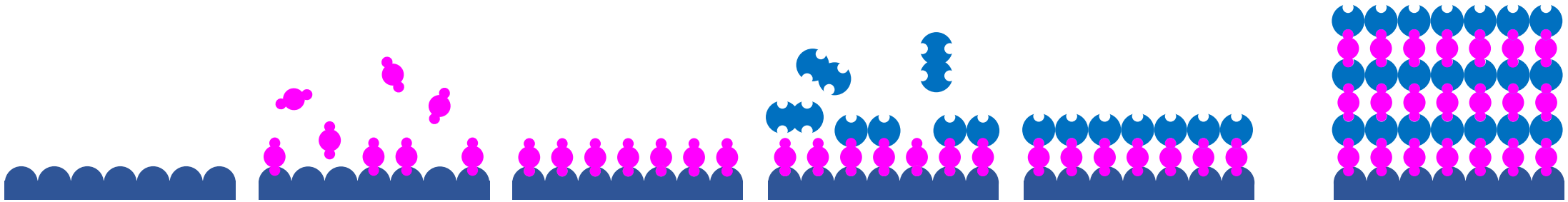
Conventional thin film technologies



Atomic Layer Deposition



ALD sequences for compound AB



Substrate surface

Introduction of precursor 1 supplying element A of compound AB

Completed monolayer of element A

Introduction of precursor 2 supplying element B of compound AB

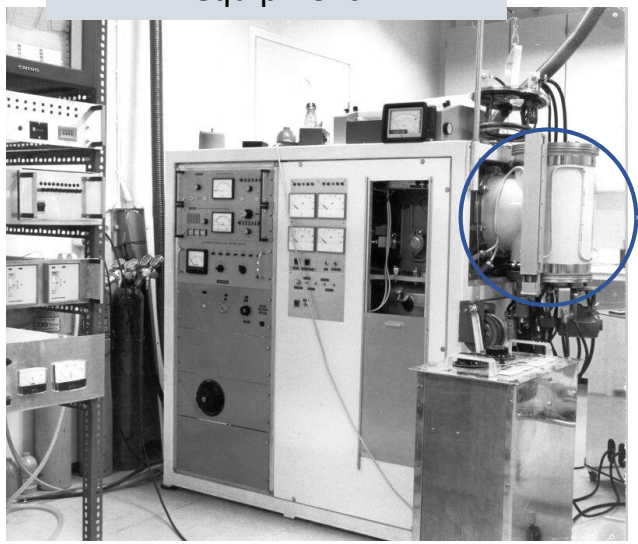
Completed monolayer of element B

Completed layers of AB

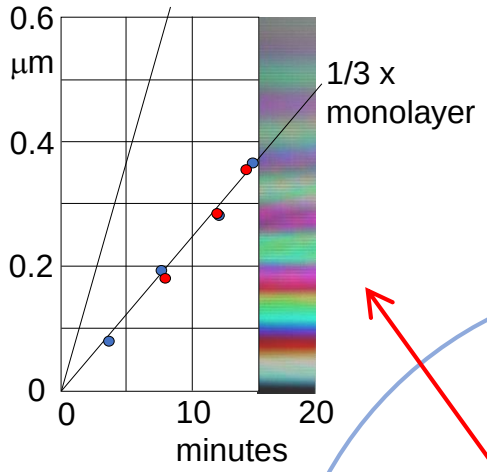
The 1st ALE process for ZnS, September 1974

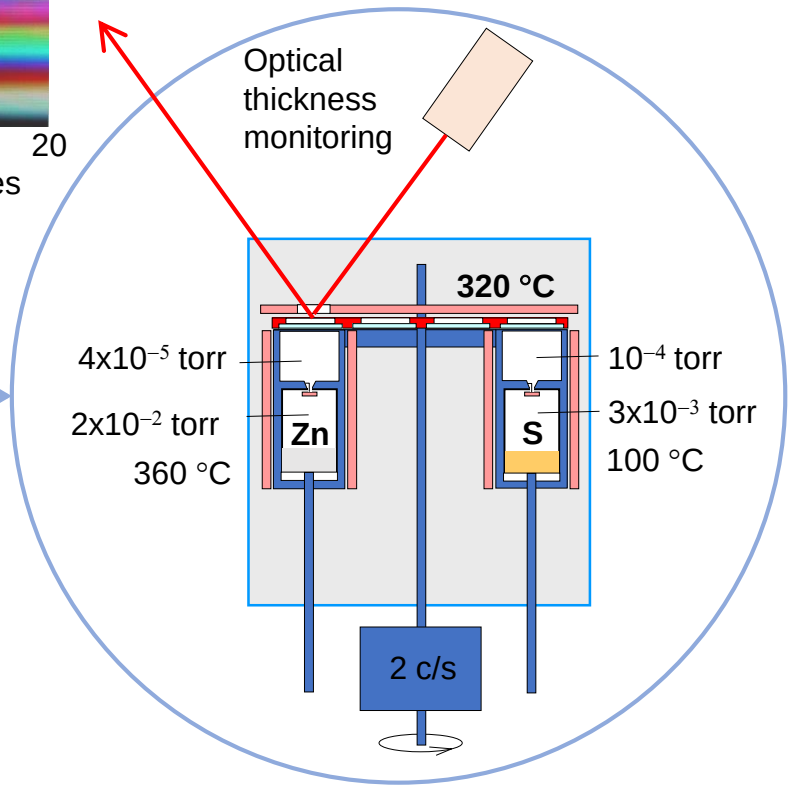
Idea of sequential buildup of compounds, June 1974

Construction of a test equipment

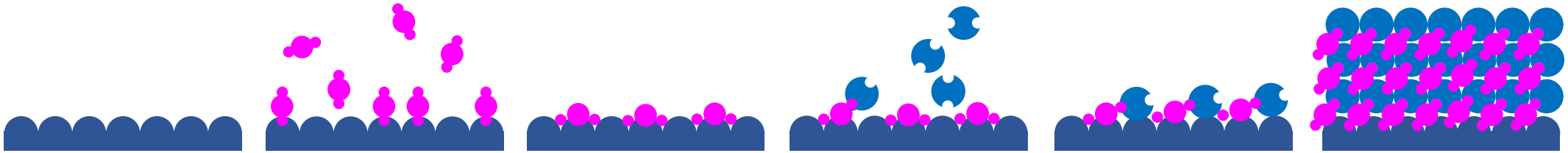


Hexagonal ZnS:
monolayer 3.13 Å
n=2.36





The ALD sequences for compound AB



Substrate surface

Introduction of precursor 1 supplying element A of compound AB

Completed monolayer of element A

-reduced monolayer density

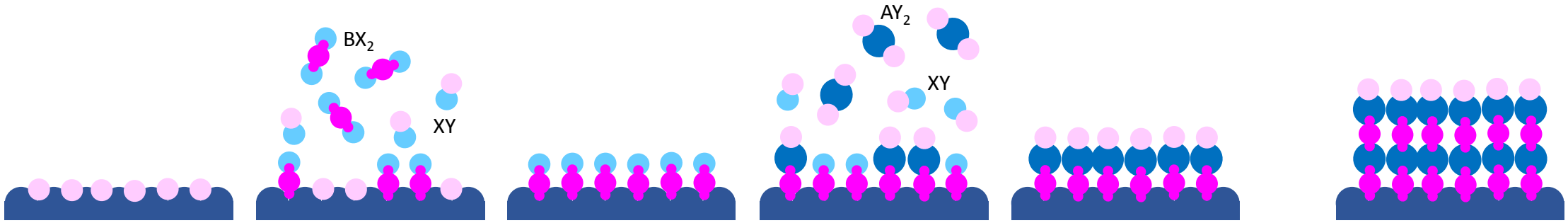
Introduction of precursor 2 supplying element B of compound AB

Completed monolayer of element B

-reduced monolayer density

Completed layers of AB

ALD sequences for compound AB using exchange reactions



Substrate surface AY

Introduction of precursor BX_2 for supplying element B of compound AB(X), removal of X as XY

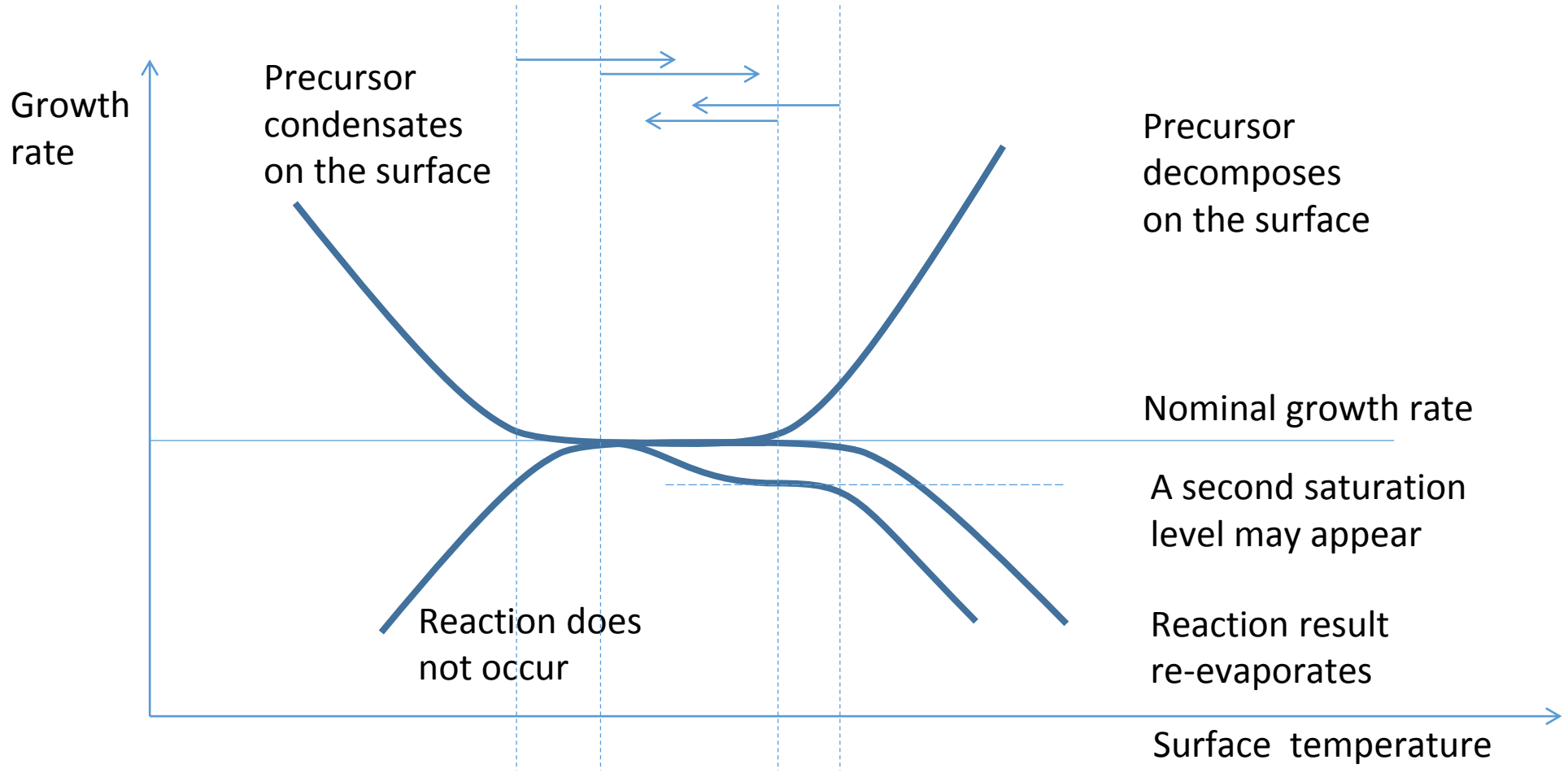
Completed AB(X) surface

Introduction of precursor AY_2 supplying element A of compound AB(Y), removal of Y as XY

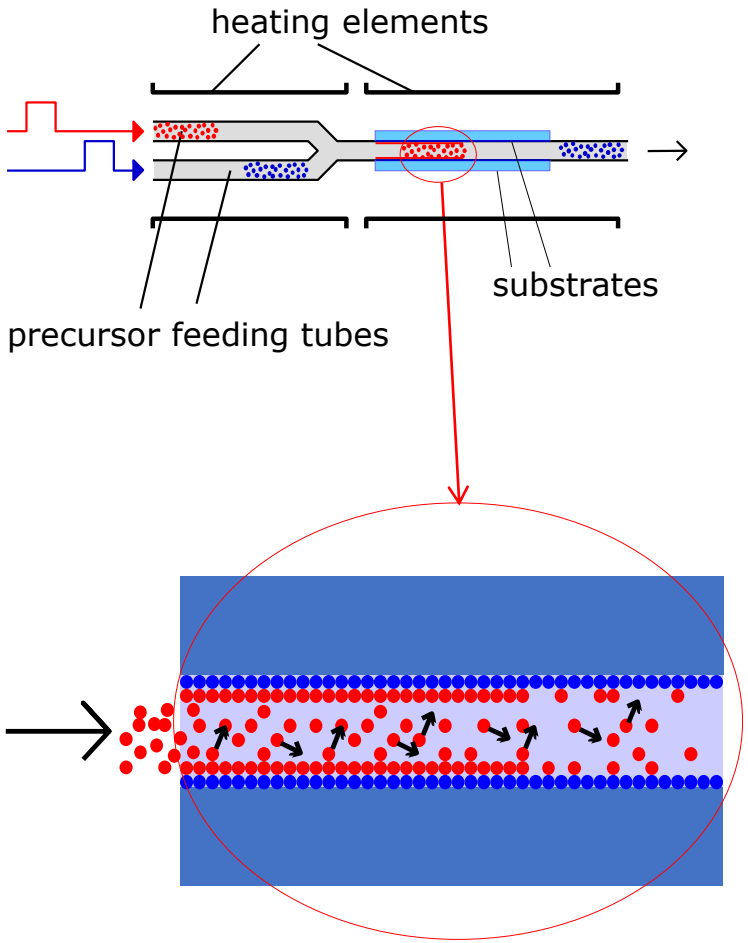
Completed compound AB(Y) monolayer

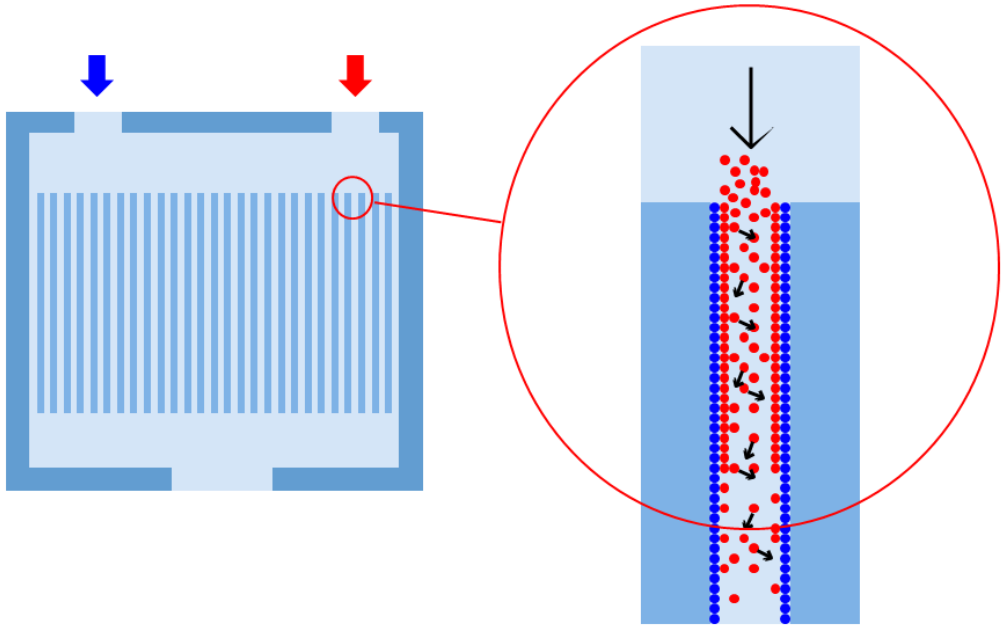
Completed layers of compound AB

ALD processing window

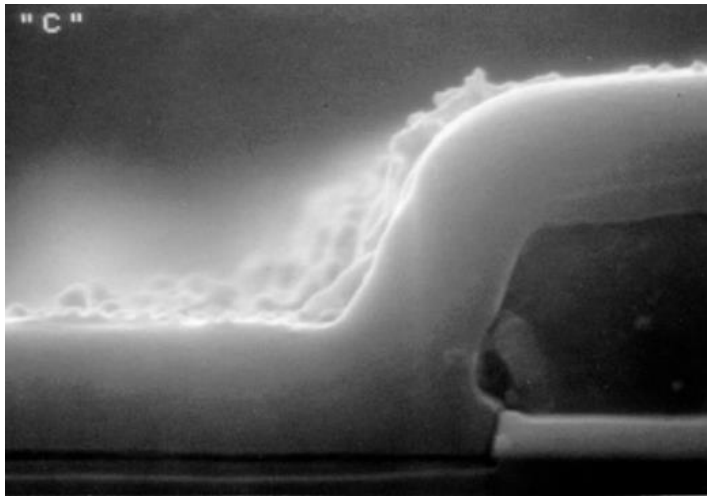


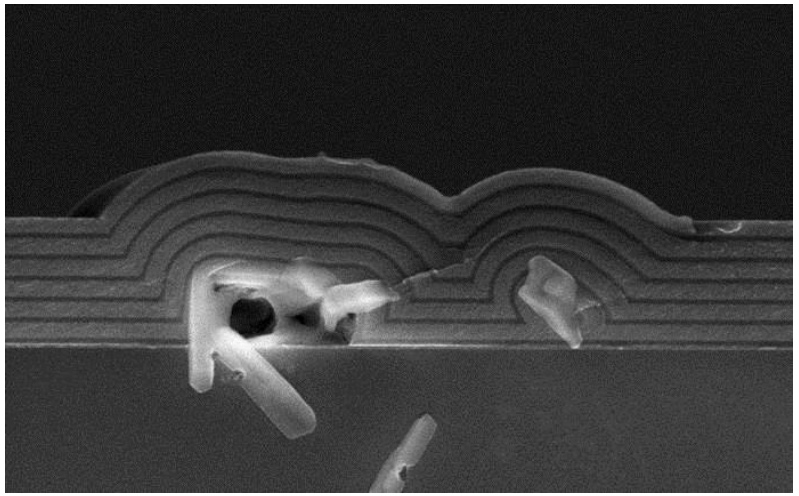
Atomic Layer Deposition

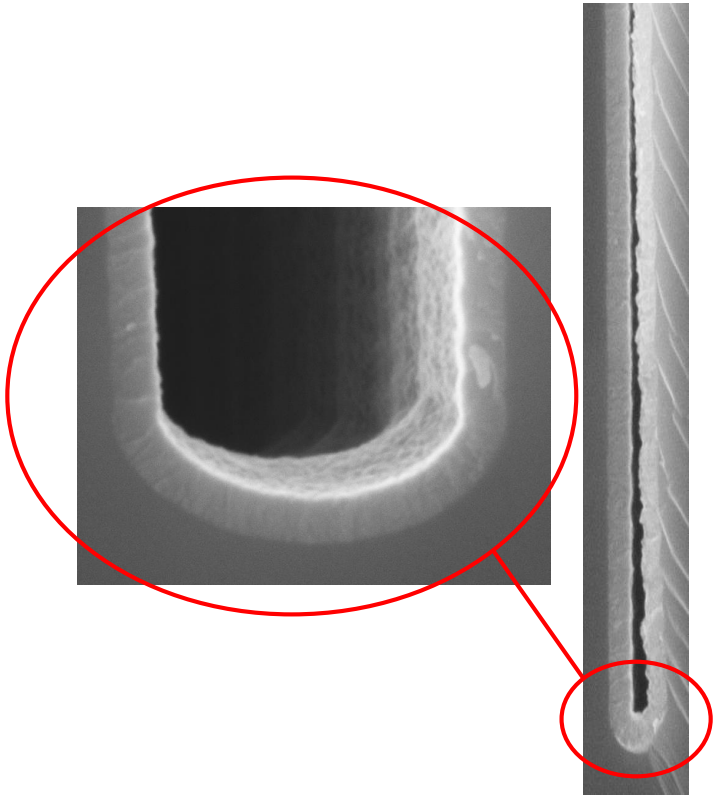


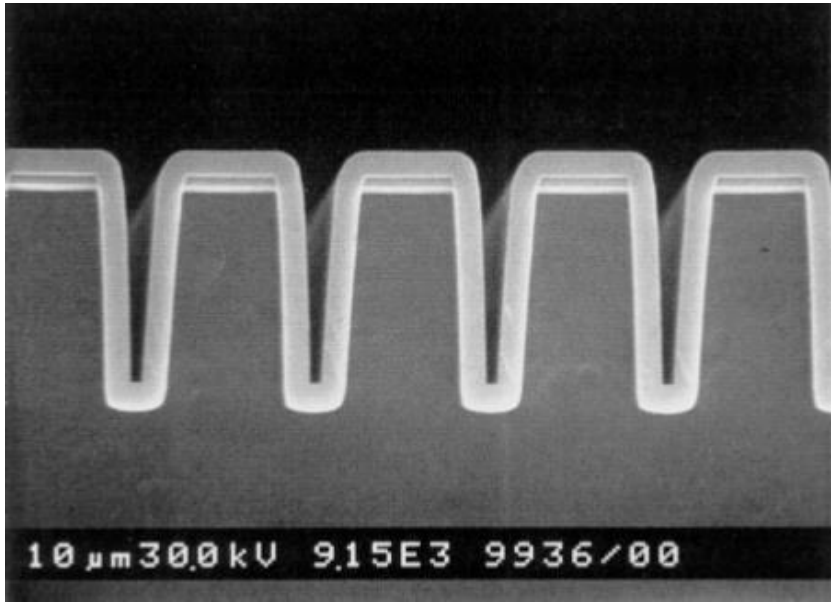


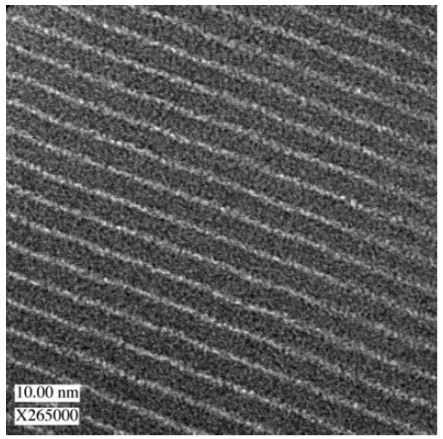
Conformal layers by ALD

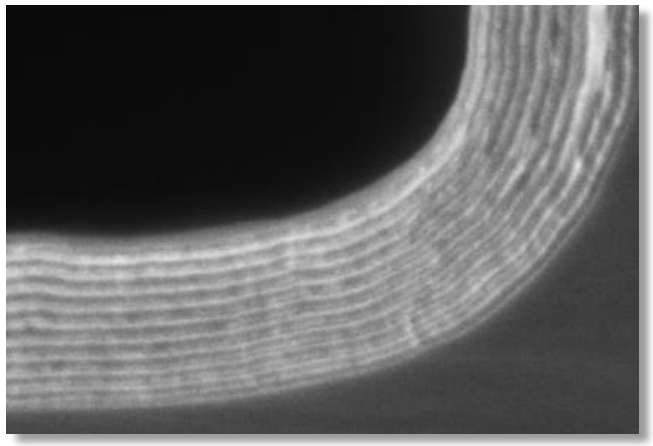






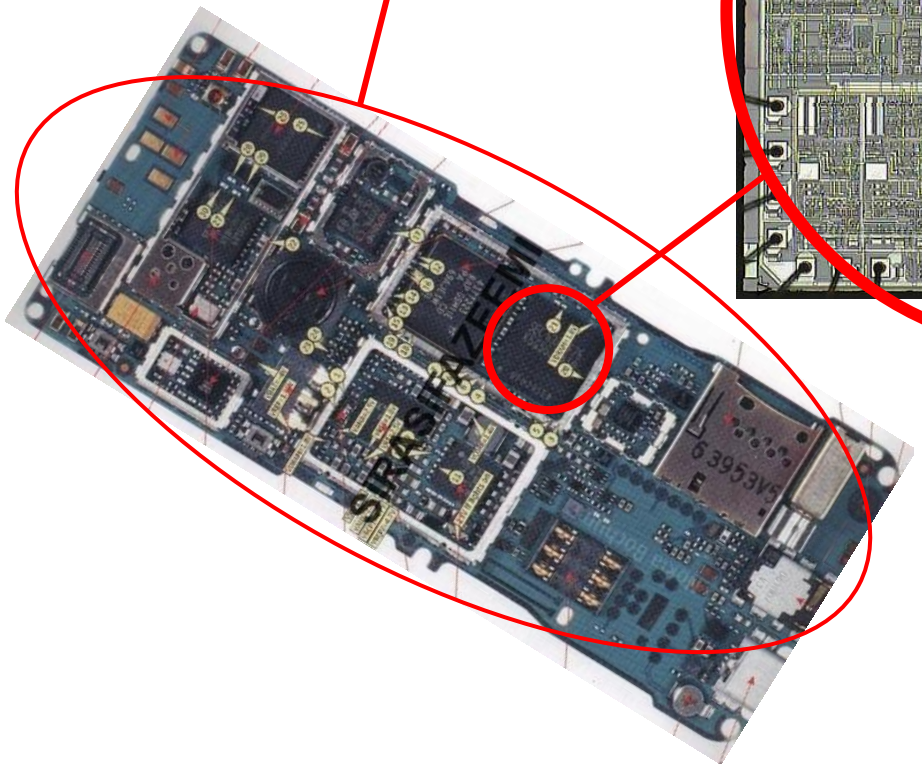


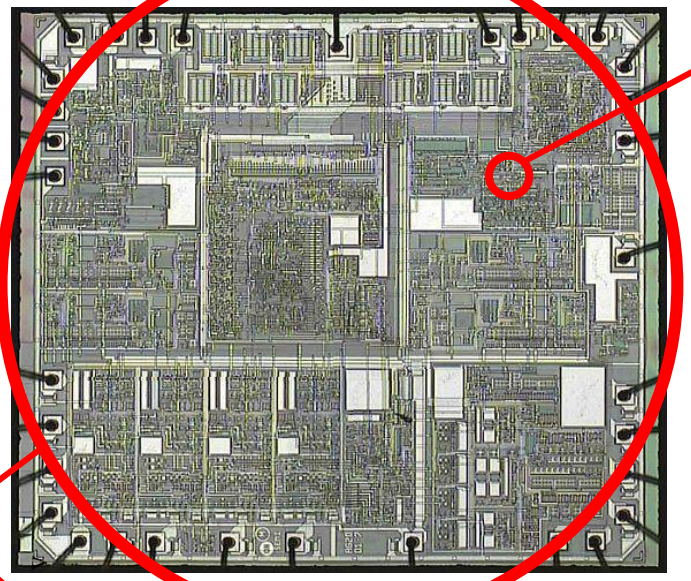


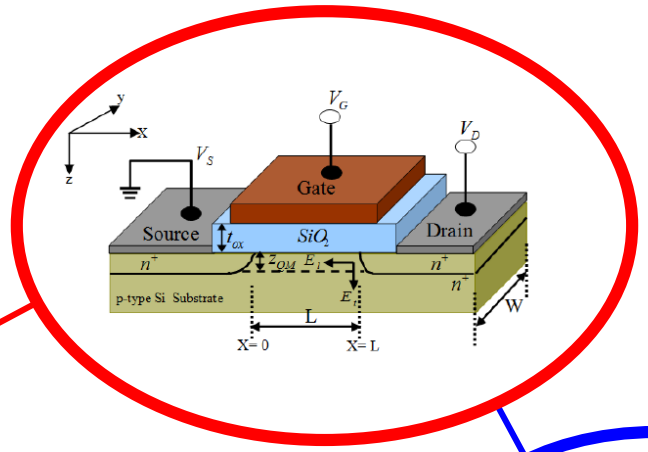


Where can we find ALD layers?

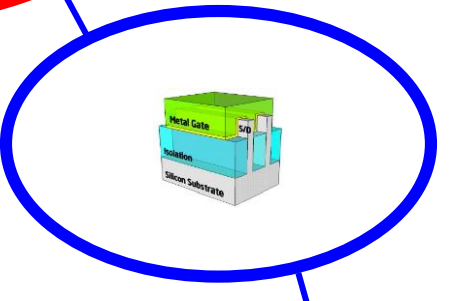
Towards < 10 000 000 000 transistors / chip

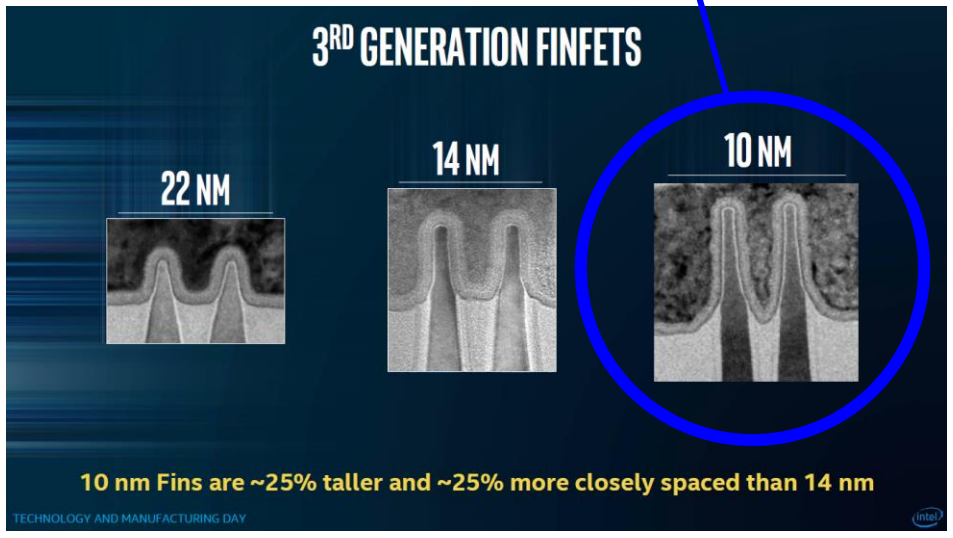




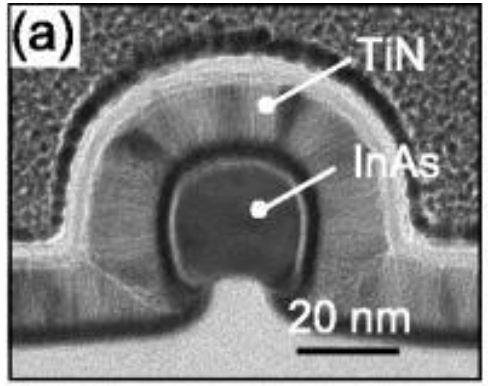


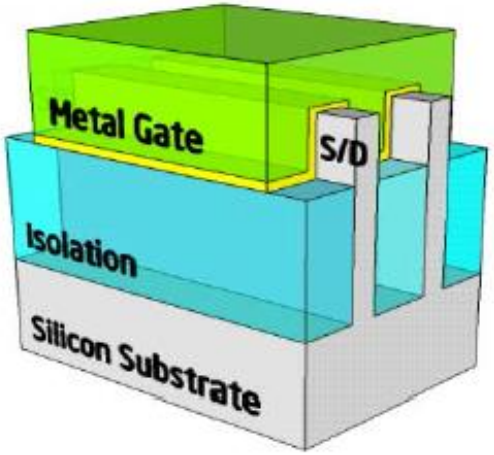
ALD





Atomic Layer Deposition





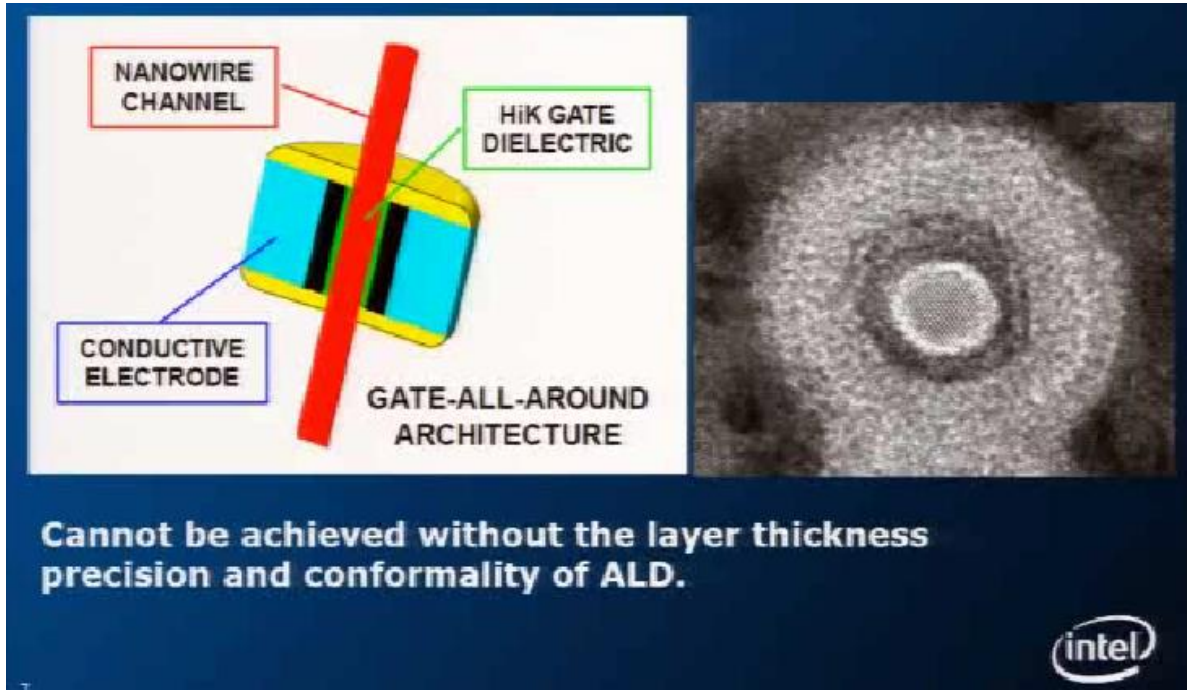
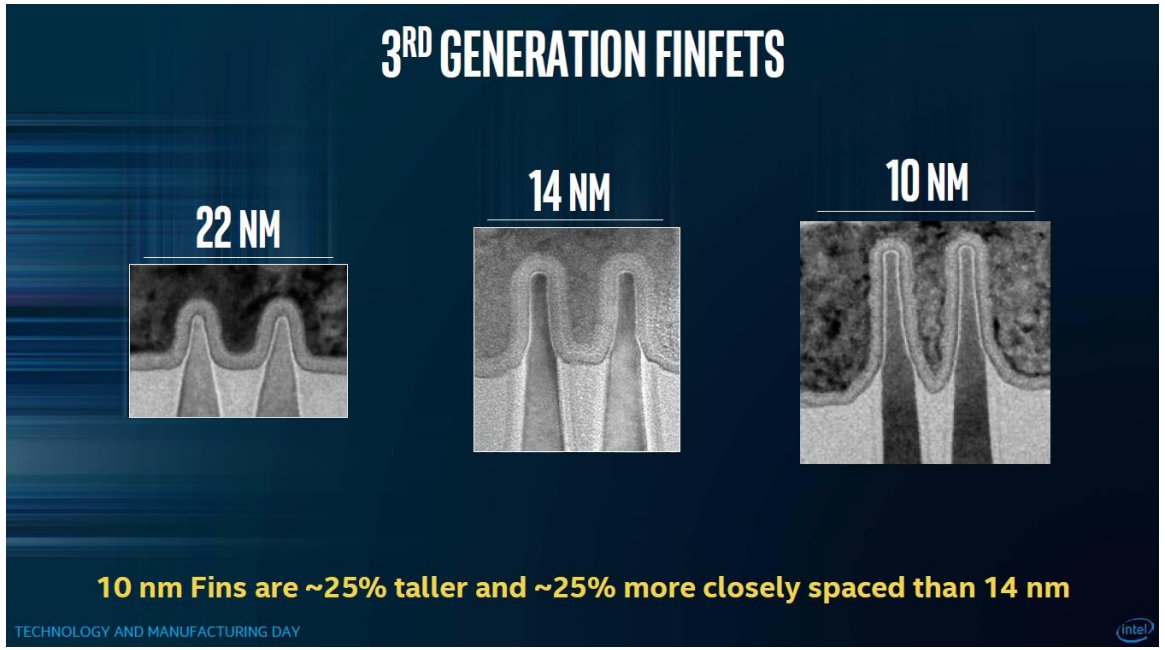


FIG. 4. Structural and electrical characterization of InAs MuG-FETs fabricated by TASE. (a) TEM cross-section image of the smallest device fabricated showing one out of ten parallel nanowire channels. (b) TEM cross-section image along the gated area of a 55 nm wide nanowire channel. Stacking faults inclined and perpendicular to the channel are visible. (c) output, (d) transfer and transconduction characteristics of a 55 nm wide MuG-FET.
Citation: Appl. Phys. Lett. 106, 233101 (2015);
http://dx.doi.org/10.1063/1.4921962



Tokyo Electron reports on patterning technology for advancements in scaling

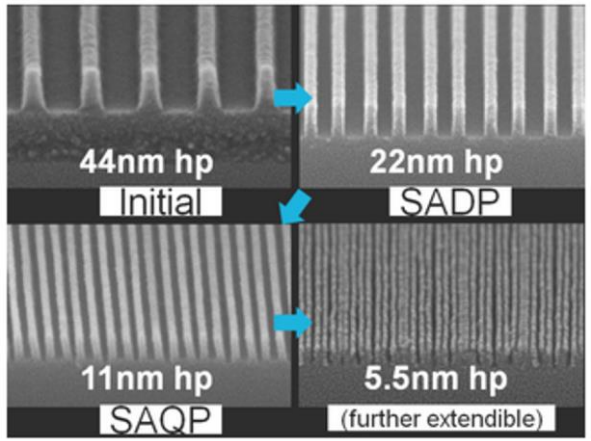


Fig. 4 Self-aligned multiple patterning

How was ALD invented, how was everything started?

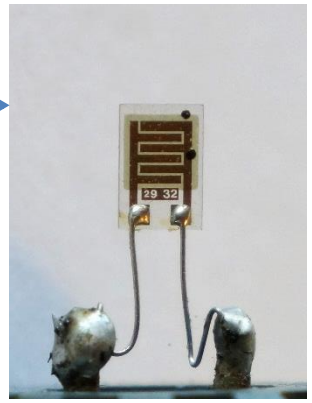
From humidity sensor to EL-panels and ALD

Instrumentarium Oy (Medical instruments)
Search for new challenges
Late 1973

1.1.1974
Research unit

Request for proposals for new products

1967-1973
Helsinki University of Technology (Aalto University)
VTT Semiconductor Lab
- thin film technologies
- semiconductor devices



”Humicap” humidity sensor to Vaisala Oy, 1971-73

Vaisala: Meteorological instruments

The proposal

Request for proposals for new products

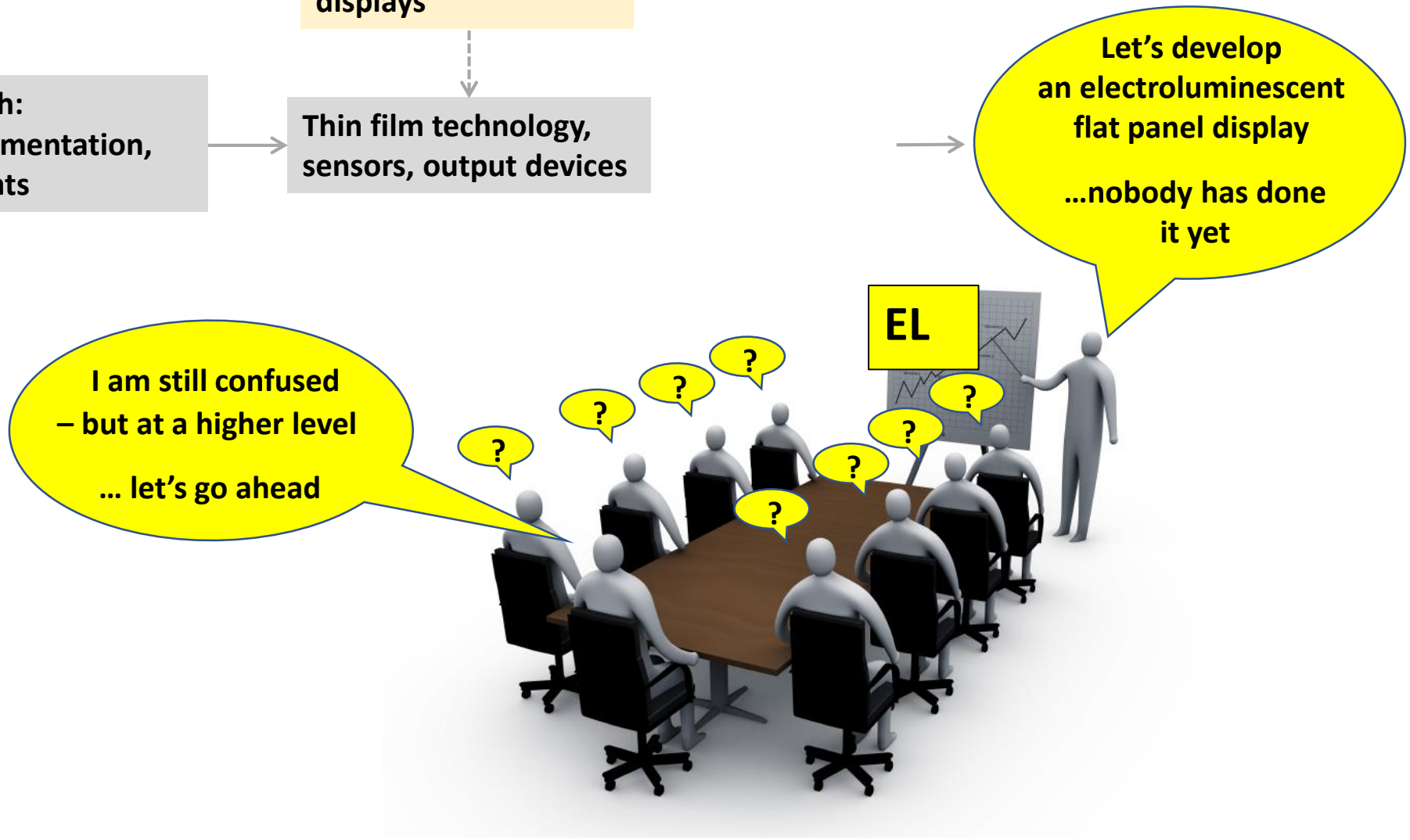
TS lectures on future displays

Market research:
- medical instrumentation, key components

Thin film technology, sensors, output devices

Let's develop an electroluminescent flat panel display

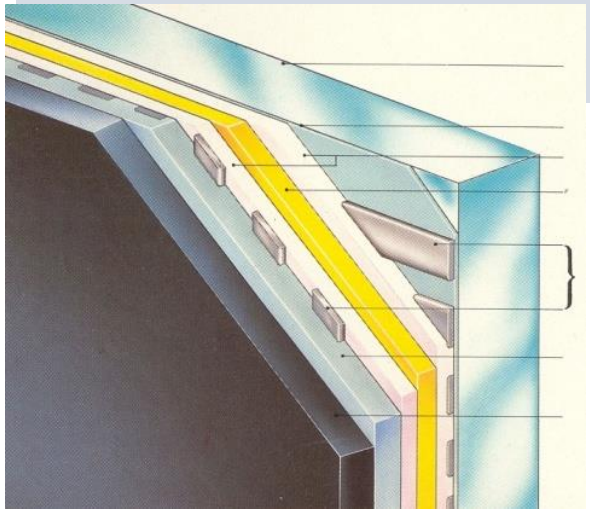
…nobody has done it yet



The problem and the solution

State of the art in 1974:

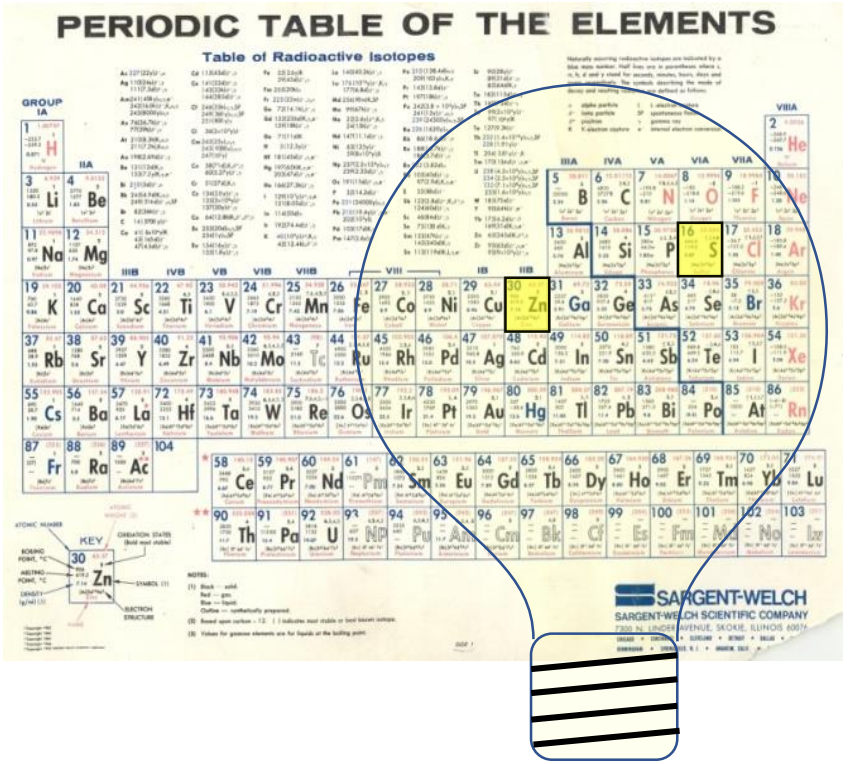
- **High performance demonstrated**
- **Major problems with stability due to the high operational voltage**



Well controlled electronic properties require well ordered material

Well order material requires well ordered processing conditions

Novel thin film processing technique is needed

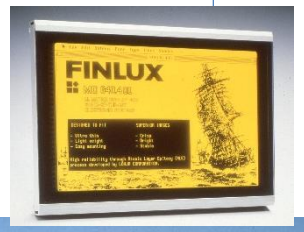


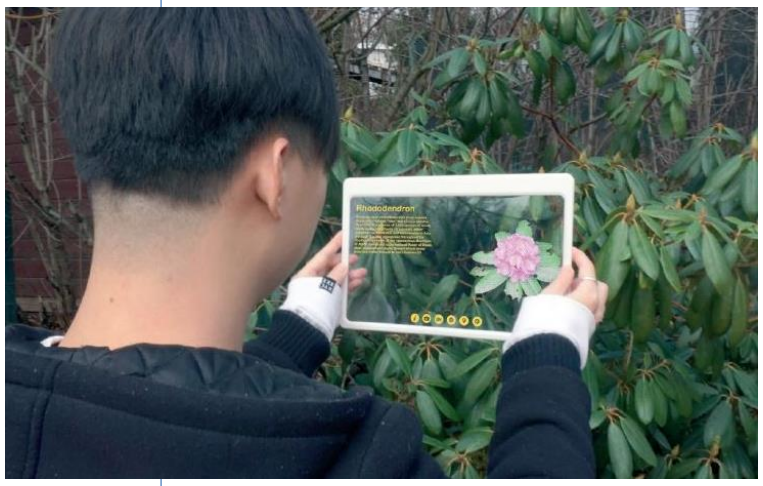
How about sequential buildup of compounds? May - June 1974

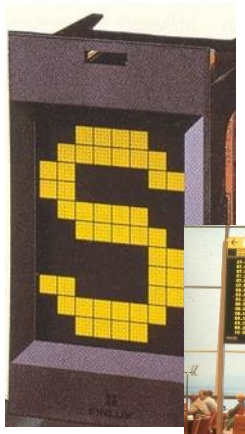
Timeline of the EL-display development, commercialization steps

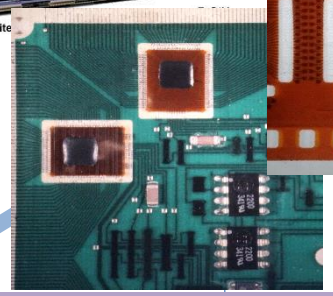
Timeline of the electroluminescent displays

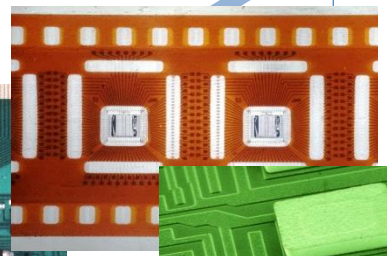
1970 1980 1990 2000











Picopack

Elcoteq

Production of EL panels

Pilot production of EL panels

EL demos

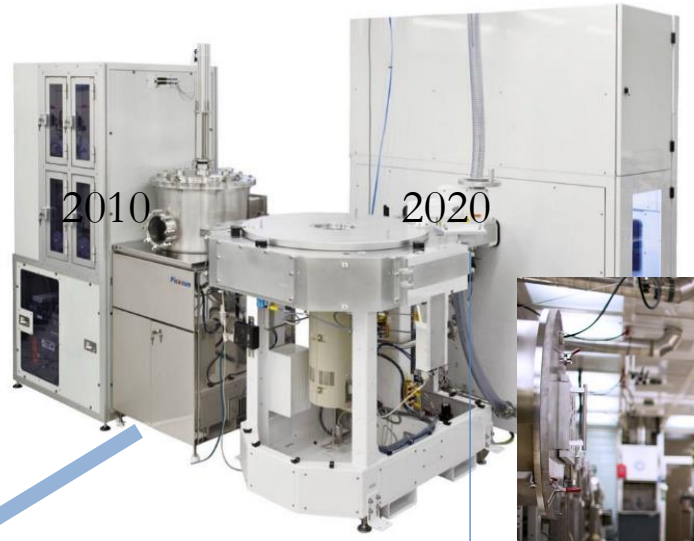
Need, ideas, solution, demonstration, basic patents

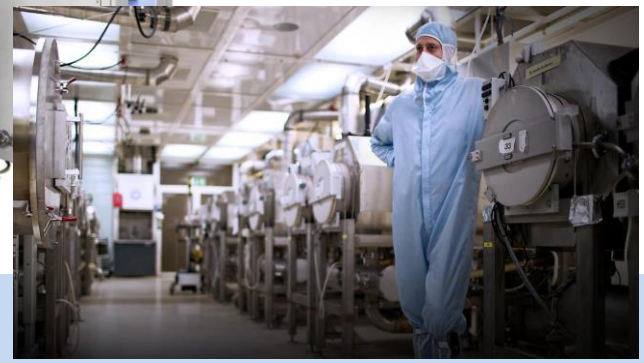
Instru Lohja Oy 1990 Planar International 2007 Beneq

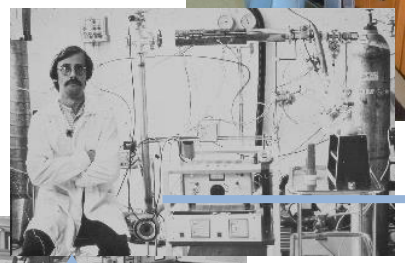
Timeline of the ALD development, commercialization steps

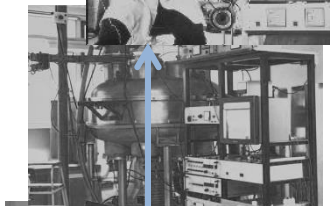
ALD reactors
– the breakthrough of ALD technology

1970 1980 1990 2010 2020









2005 Beneq Oy

2004 Picosun Oy

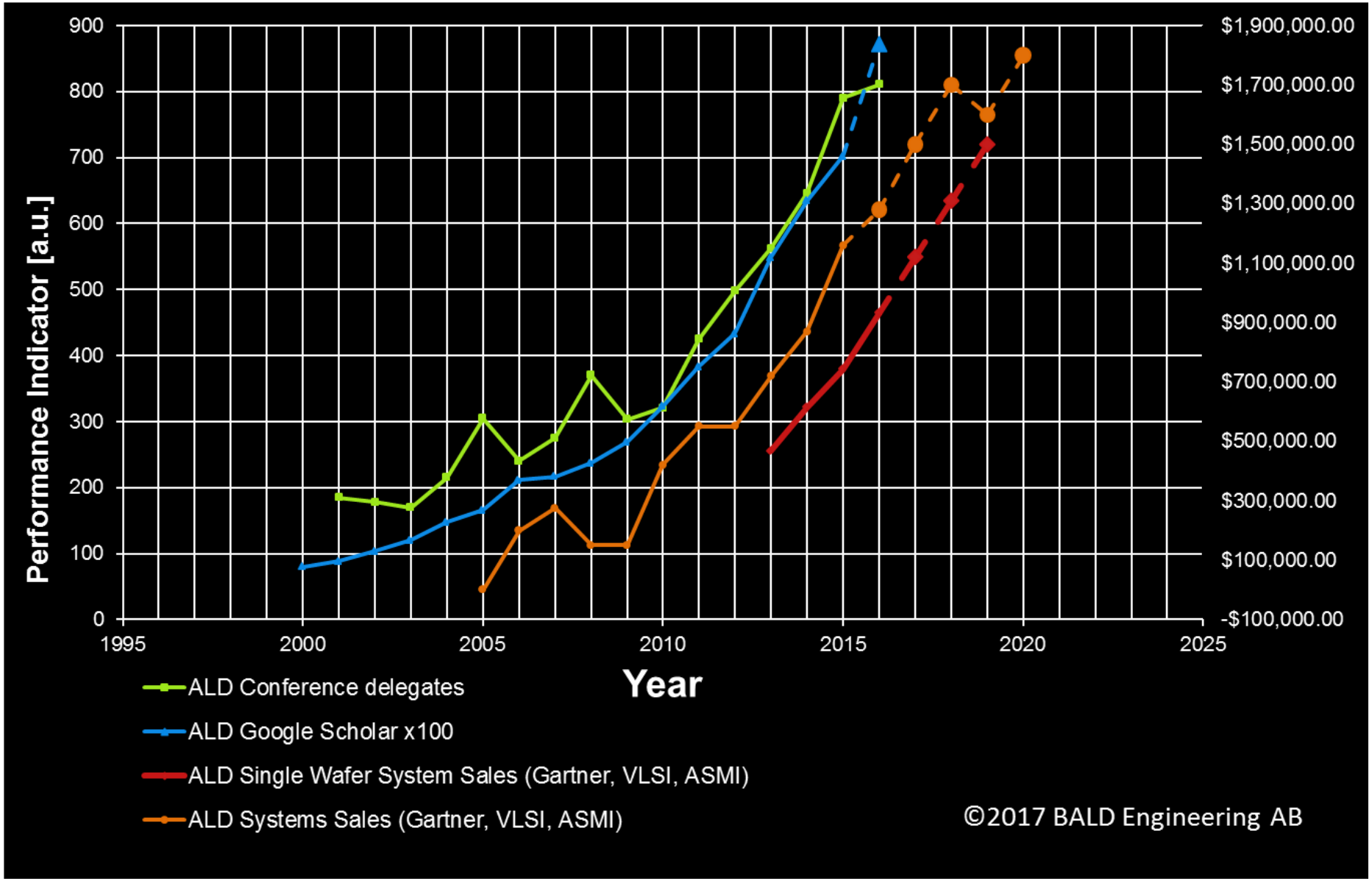
1999 ASM Microchemistry / ASM International

Microchemistry Ltd

Commercial production of EL panels

Product prototypes, reactors for EL production

Need, ideas, solution, demonstration, basic patents

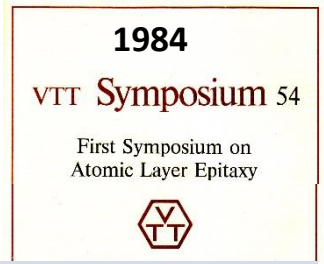


http://www.blog.baldengineering.com/2018/04/ald-research-and-development-continious.html

Timeline of the ALD scientific activity

Timeline of the ALD scientific ac

1970 1980 000 2020



1984
16th Conference on Solid State Devices and Materials
Kobe, Japan

MRS

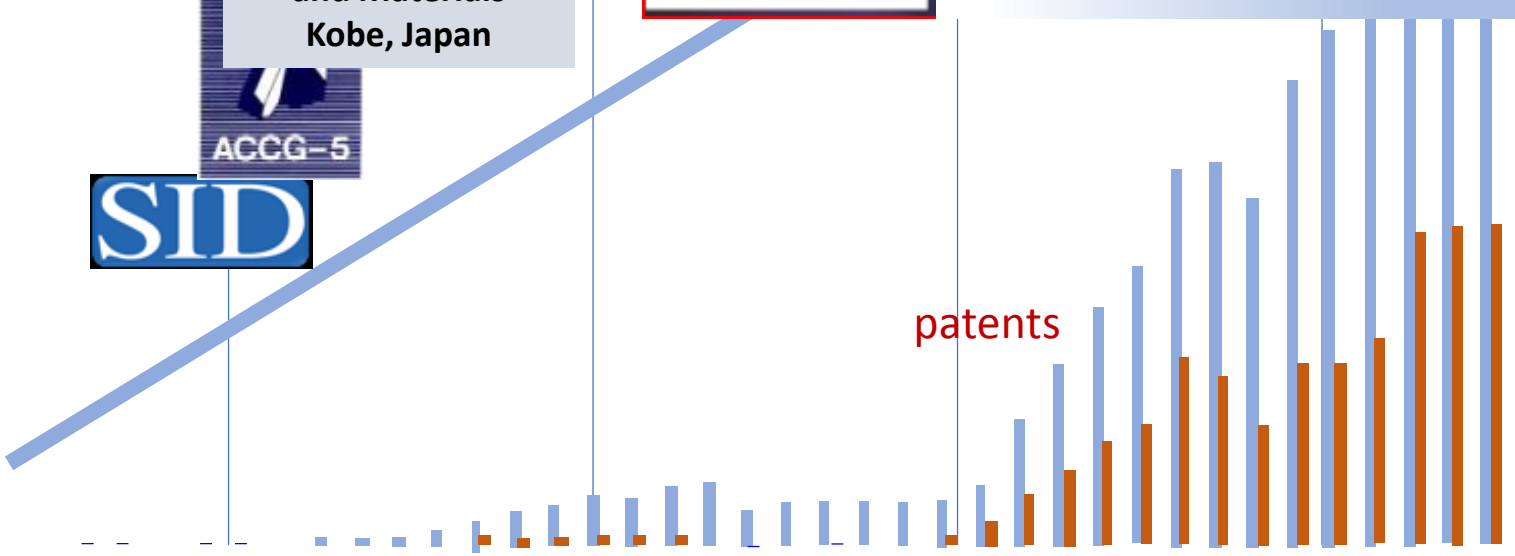
ACCG-5

SID

ALD CoE

Finnish Centre of Excellence in Atomic Layer Deposition

Explosive increase in
ALD activity - research & industrial

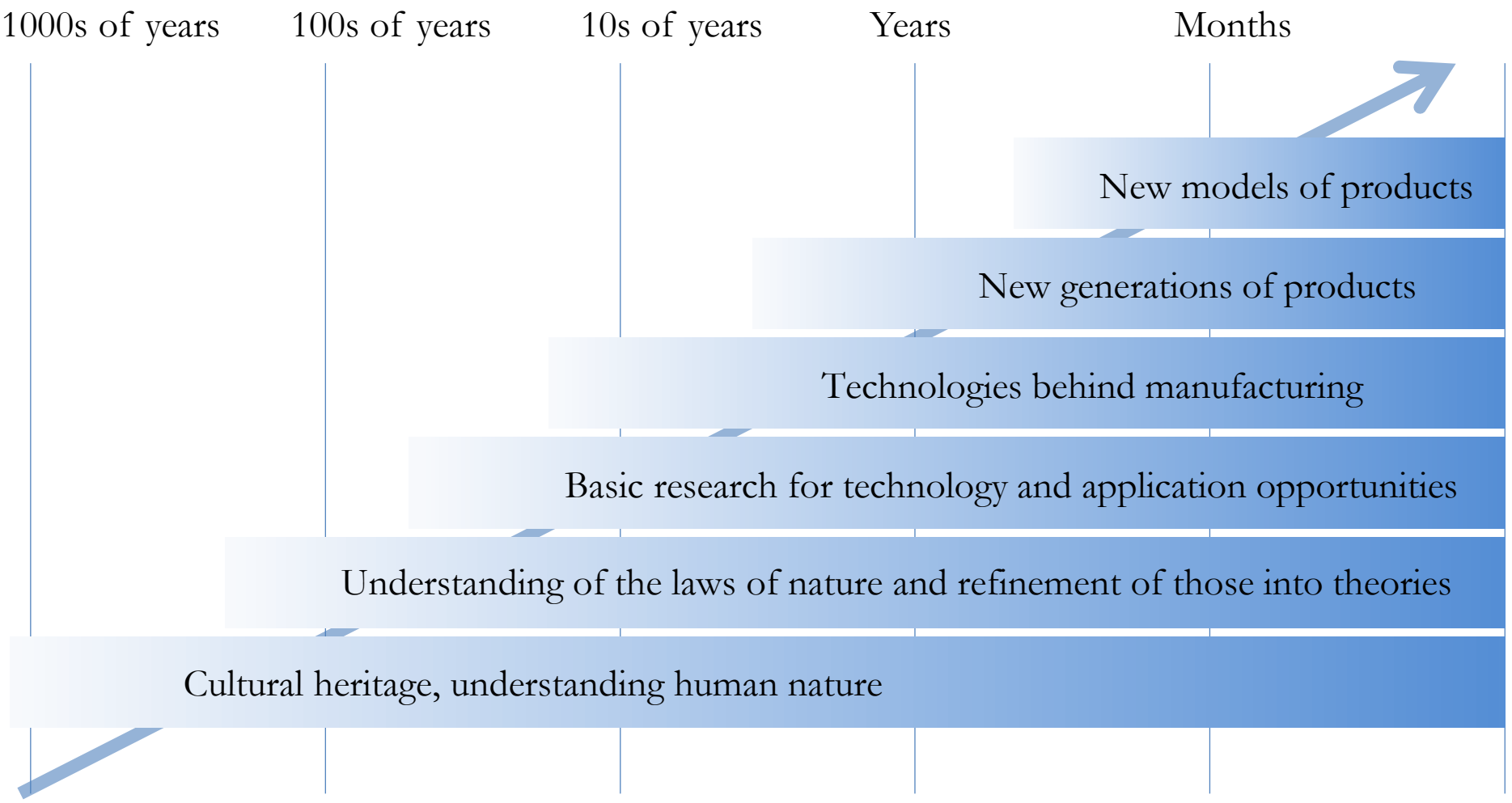


ALD patents and publications

1974-2015

Hierarchy and timespan of developments

Timespan of developments



From laboratory to commercial success

There is a Finnish saying: One drawing is worth 1000 words

- one demo is worth 1000 drawings
- one product is worth 1000 demos
- vital industry is worth millions of products

When is the work completed?

Scientist celebrates the idea,
Engineer celebrates successful demoes,
Production manager celebrates successful mass production and high yield,
Quality manager celebrates successful test results and reproducible specifications,
Marketing manager celebrates enthusiastic market response,
Sales manager celebrates orders received,
Financial manager celebrates paying customers and the money received,
General manager and owners celebrate profitable business,

Everyone can feel proud for being a part of a process benefiting the society and sustainable development.

Thank you for your attention!

Fortum Foundation's objectives

The Foundation’s purpose is to support research, education and development in natural, technical and economical sciences within the energy industry.

The Foundation’s focus areas within the energy industry are energy production and use and clean energy solutions for traffic with new circular and bio-economy related and digital solutions.

Scholarships 2018

	Applications 2018		Granted scholarsips	
	number	value, €	number	value, €
B1 Thesis related studies	5	36 600 €	1	8 000 €
B2 Post-graduate studies	99	4 289 232 €	31	656 800 €
B3 Other personal related	33	302 670 €	6	18 120 €
Total	137	4 628 502 €	38	682 920 €

Scolarships 2018

Matias Berg
Rinnakkain kytkettyjen verkon muodostavien vaihtosuuntaajien dynamiikka

Bela Bhuskute
Harnessing visible light photons for solar fuel generation: Scalable Artificial Leaf approach

Ding Chao
Demand response experiments – nudge into action

Eemeli Eronen
Muovijätteestä hydrotermisellä nesteytyksellä valmistettujen öljyjen koostumuksen tutkimus korkean erotuskyvyn massaspektrometrialla

Christian Giovanelli
Aggregating smart loads to participate in frequency containment reserves

José Luis Gonzáles Escobedo
Hydrodeoxygenation catalysts for advanced bifofuels

Scolarships 2018

Ashish Gulagi
Transition pathways towards a low cost fully sustainable energy system for India with integration of the industrial sector

Ondrej Haluska
Plant-based nanostructured silicon carbide for demanding applications

Iftikhar Haider
Large-area dye-sensitized solar cells with novel material composites

Jogi Ramakrishna
An integrated process for the production of green aviation fuel range cycloalkanes through hydrothermal liquefaction of lignocellulosic biomass

Martina Jokel
UV-screen active compounds from nordic microalgae

Riikka Juhola
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