

Virtual Project on the History of ALD (VPHA): Overview and Current Status



International workshop Atomic Layer Deposition Russia 2015, Moscow-Dolgoprudny, listed with the American Vacuum Society

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Top 10 Advanced Manufacturing and Automation Technologies 2015

1. 3D Printing
2. Multimaterial Joining Technologies
3. Composites Manufacturing
4. **Atomic Layer Deposition**
5. Nanomanufacturing
6. Digital Manufacturing
7. Micromanufacturing
8. Agile Robots
9. Advanced Lithography
10. Magnetic Levitation

*Deep Dive Analysis,
Frost & Sullivan
via BALDengineering*



Virtual Project on the History of ALD (VPHA) Background – Why? What?

- ALD developed under the names
 - Molecular Layering ML; Молекулярное Наслаивание МН
 - Atomic Layer Epitaxy ALE
- Especially the work made under the name Molecular Layering has been poorly known (and cited)
- VPHA core activity:
 - Volunteered scientists from all around the world
 - work together in an atmosphere of openness, respect and trust,
 - to better understand the early days of ALD.
 - We collect, read and comment upon ALD literature up to 1986

Openness, Respect, and Trust



Table I. Alternative Names to the ALD Method

| Name | Acronym | Comments |
|---|---------|---|
| Atomic layer deposition | ALD | General, covers all kinds of films In a close connection with the original name |
| Atomic layer epitaxy | ALE | The original name, but should be reserved for epitaxial films only |
| Atomic layer growth | ALG | Like ALD but less used |
| Atomic layer chemical vapor deposition | ALCVD | Emphasizes the relation to CVD |
| Molecular layer epitaxy | MLE | Emphasizes molecular compounds as precursors |
| Digital layer epitaxy | DLE | Emphasizes the digital thickness control |
| Molecular layering | ML | Dates back to old Russian literature |
| Successive layerwise chemisorption | | Ritala, M. & Leskelä, M. Nalwa, H. S. (Ed.) Atomic Layer Deposition Handbook of Thin Film Materials, Academic Press, 2002, 1, 103-159 |
| Sequential surface chemical reaction growth | | |
| Pulsed beam chemical vapor deposition | | |
| | | |

Puurunen, J. Appl. Phys. 2005

- “TABLE I. Some Soviet–Russian ALD investigations.”

Knez, Nielsch, Niinistö, Adv. Mat. 2007

- “Atomic layer deposition (ALD), originally called Atomic layer epitaxy (ALE), was developed in the 1970s by Suntola and Antson...”

George, Chemical Reviews 2010

- “The history of ALE and ALD dates back to the 1970s in Finland.”

Parsons, George, and co-workers JVST A 2013

- “The ALD principle... was first published under name “molecular layering” in the early 1960s”
- “A planar thin film was not produced or evaluated.”

“Early work on Atomic Layer Deposition cited” Malygin, Smirnov Solid State Technology, 2002, March, p. 14

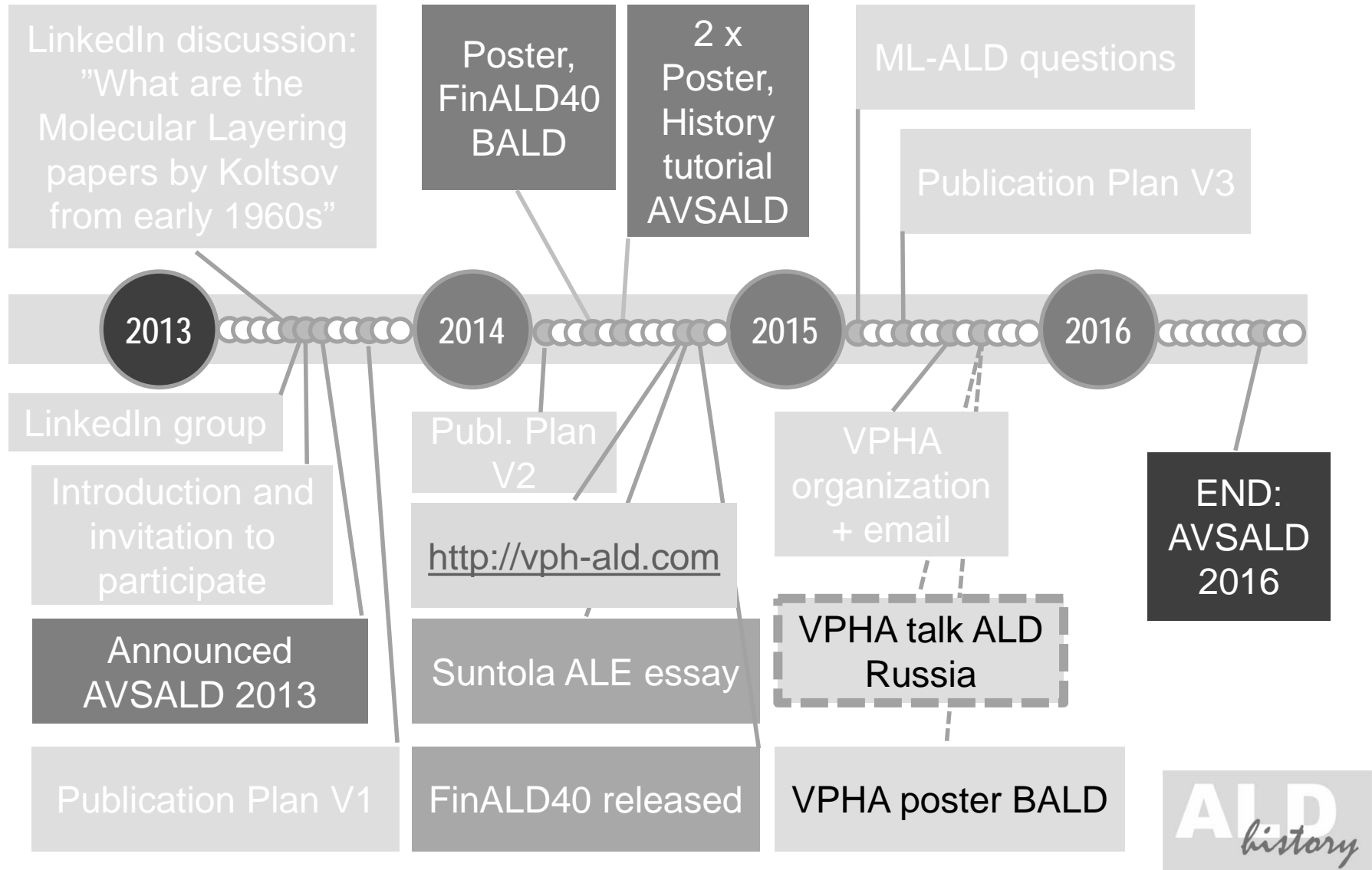




Many questions looking for answers

- What is the first public record of the invention of ALD in Russia?
- What is the Matrix hypothesis and how is it related to ALD?
- What kinds of thin film studies?
- Are there microelectronic applications?
- What kinds of reactors?
 - Powders
 - Thin films
 - ... other?
- What kind of catalysts?
- What kinds of sorbents?
- What other applications?
- How was it to do research with Aleskovskii & Koltsov?
- Is there ALD reactant development in Russia?
- ALD in industrial scale in Russia?
 - Products?
- How and when did Russian scientists get to know of other ALD groups?
- Current ALD activities in Russia?
- ...

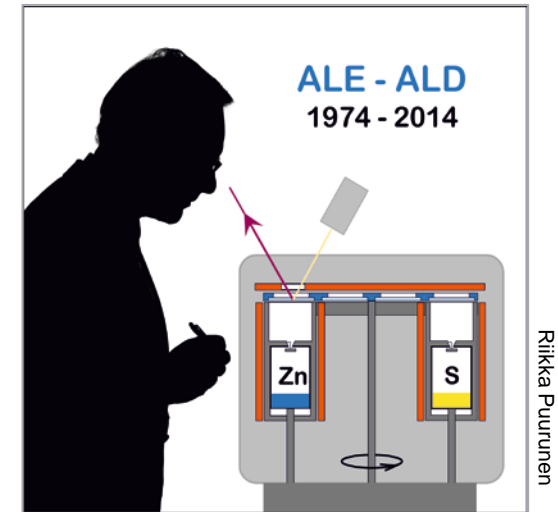
VPHA background – What? When?



VPHA publications – completed

<http://vph-ald.com/Publication%20Plan.html>

- 1) Poster at Baltic ALD 2014 ([abstract](#))
- 2) [Poster](#) at ALD 2014, Kyoto
- 3) [Presentation](#) at ALD 2014, Kyoto
- 4) ALD history [tutorial](#) at AVS-ALD 2014, Kyoto
- 5) Essay on the early history of ALE-ALD ([CVD journal](#))
- 6) Website for ALD history and VPHA (vph-ald.com)
- 7) Exhibition: 40 years of ALD in Finland - Photos, Stories ([FinALD40](#))



ALD
history

VPHA publications – on-going & future

<http://vph-ald.com/Publication%20Plan.html>

- 8) Review article/essay on the early history of ML-ALD
- 9) Presentation at AVS-ALD 2016
- 10) Optional: general ALD history review article
- 11) Updating wikipedia
- 12) Closing the VPHA (at AVS-ALD 2016)

Scientific presentations
have alphabetical author lists



VPHA in numbers

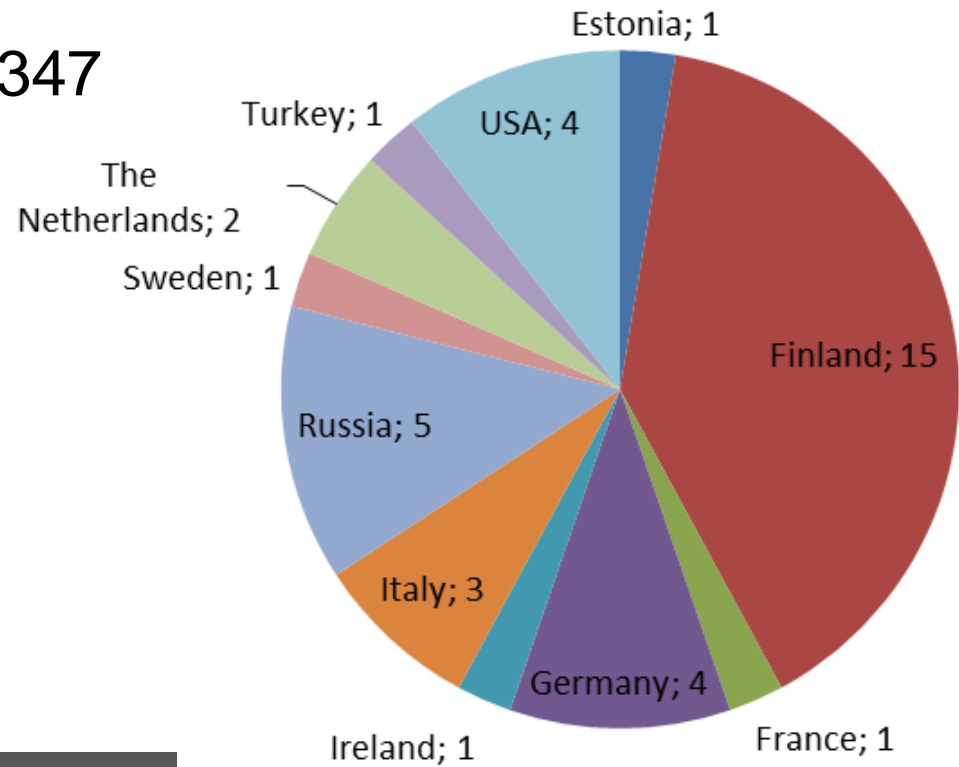
As of 20.9.2015

Core reading work:

- articles listed up to 1986: 347
- comments given: 355
- comments needed: 708

VPHA co-authors:

- 38 from
- 11 countries



Reading is 30% done

ALD-history-evolving-file

<http://vph-ald.com/VPHAopenfiles.html>

The "core" of VPHA, large file

- Contains all ALD literature up to 1986 and personal comments on their contents
- Made with Google docs, with real-time viewing, commenting and co-editing
- When finalized, this will be the major VPHA outcome and will be stored for future use

time of writing the work and looks into the future, what all can be achieved by molecular layering (ALD). I understand that [Aleskovskii](#) presents an early suggestion of surface-selective ALD ("if necessary, part of its <i.e., support's> surface is shielded by flat (monolayer) or relief coating in the form of specified pattern"). Also he notices the possibility of using templates for ALD growth ("at the end of the synthesis, the support is removed, if necessary, by chemical or mechanical methods"). The general advances of

VPHA-reading-overview-file

<http://vph-ald.com/VPHAopenfiles.html>

| Decade | Article code bib | title | Classification | Note1, organizatio | Note2, reading | # comments | date noted, by | comments still needed? | notes |
|--------|----------------------|---|------------------------|--------------------|----------------|------------|----------------|---------------------------|---|
| | | | particle / flat / ...? | | | | | | purple = no check made yet pink = missing in evolving file red = 2 or more needed yellow = one needed or not sure green = none needed, DONE |
| | Postnov VN | Synthesis of inorganic matrices using the molecular layering method and the study of their reactivity in the process of adsorption of amino acids : Dis ... Candidate . Chem. Science | | bib code missing | | 0 | 31.7. riikka | 3 | |
| | {Ylilampi1979} fi | Growth of thin oxide and aluminium oxide films through alternating surface reactions | | | | 0 | 31.7. riikka | 3 | |
| 1980s | {Suntola1980a} ru | Method and equipment for deposition of compound thin films [in Finnish], SF patent 57975, Feb 28, 1979 | | | | 1 | 3.6 Henrik | 2 | |
| | {Aho1980} en | A study of ZnTe films grown on glass substrates using an atomic layer evaporation method | | | | 2 | 3.6 Henrik | 1 | |
| | {Gordeev1980} en | | | | | | | 2 | |
| | {Drozd1980} ru | | | | | | | 2 | |
| | {Koltsov1980} en | | | | | | | 2 | |
| | {Gromov1980} ru | | | | | | | 3 | |
| | {Ivin1980} ru | | | | | | | 1 | |
| | {Kukharskaya1980} ru | | | | | | | 2 | |
| | {Malygin1980} en ru | | | | | | | 2 | |
| | {Suntola1980} en | | | | | | | 0 | |
| | Suntola & co | | | | | | | 2 | |
| | Tanninen et al | Luminescence and X-ray diffraction studies of AC-electroluminescent ZnS:Mn thin film structures | | bib code missing | | 0 | 3.6 Henrik | 3 | |
| | Gordeev , SK | Synthesis of diamond on the surface of carbon , titanium oxide and chromium, and the study of their physico- chemical properties : Diss ... Candidate . Chem. Science | | bib code missing | | 0 | 3.6 Henrik | 3 | |
| | J. Skarp, | Doping of ALE ZnS for producing different colours in electroluminescent thin films [in Finnish], Master's thesis, | | bib code missing | | 0 | 3.6 Henrik | 3 | |
| | Tolstoy VP | Synthesis and physico- chemical study of ultrathin oxide layers on metal surfaces : Dis ... Candidate . Chem. Science | | bib code missing | | 0 | 3.6 Henrik | 3 | |

Central for VPHA (self-)organization

- Article code, languages, title
- organizational notes, reading situation

VPHA-reading-workflow

<http://vph-ald.com/VPHAopenfiles.html>



1. Choose the publication to read in VPHA-reading-overview-file

- Open the VPHA-overview-file and see which articles need reading (marked with red or yellow background); feel free to choose the ones that interest you the most
- Note the paper code (in grey and in parentheses, e.g. {Koltsov1965})
- Check

Explains to the VPHA participants how the reading-over-view-file and ALD-history-evolving-file are used together

2. Get

-
-

3

- Follow the instructions in the ALD-history-evolving-file & example by others
- Your comment should be self-standing (e.g., preferably contain no referrals to comments by other people)

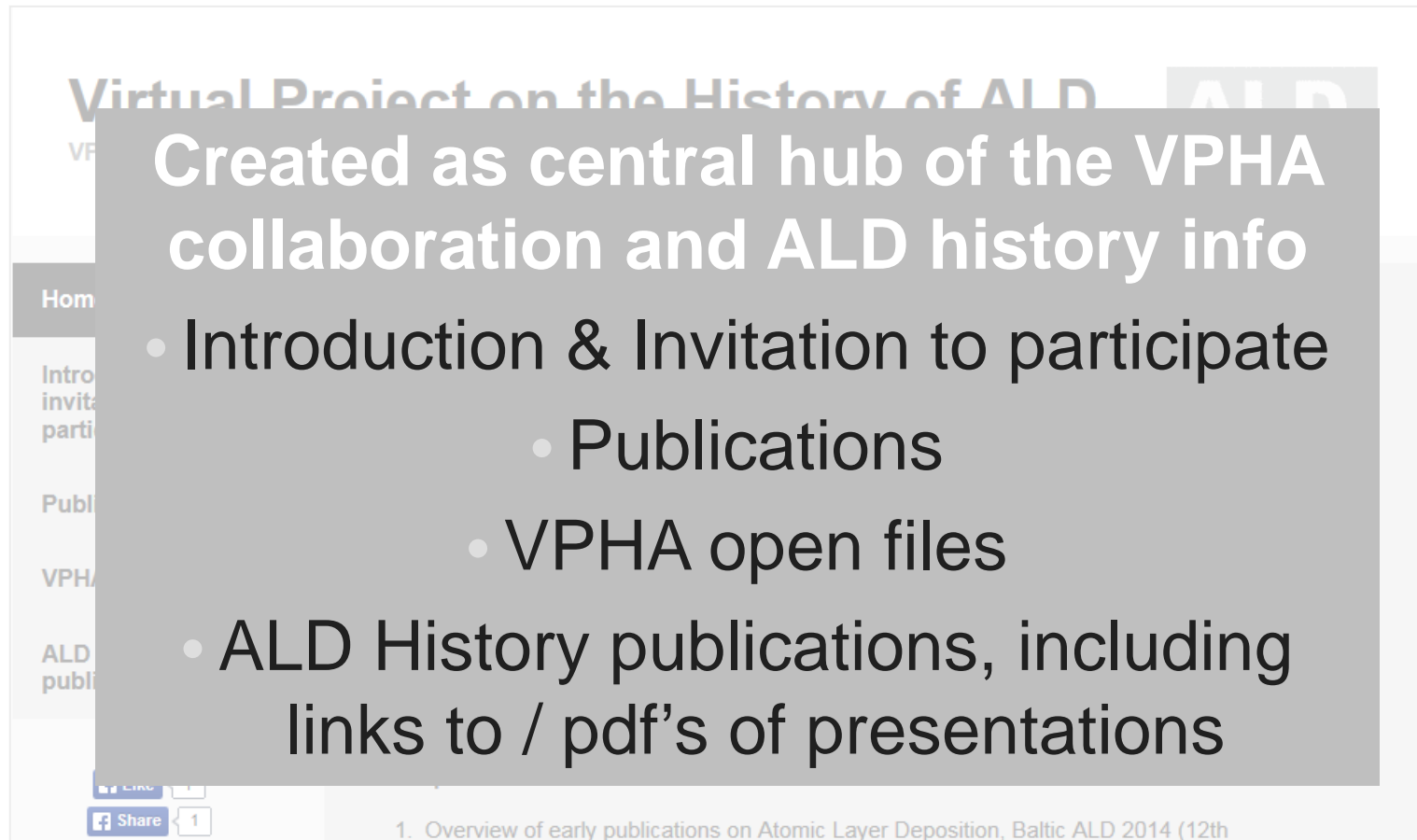
4. OPTIONAL: Update the VPHA-reading-overview-file with updated info on the reading status

- Those with editing rights: update (1) the total number of comments for that particular paper, and (2) the number of comments still needed (typically, three minus the number of comments given). Change the colour of the cell background in “#comments needed” to correspond to the number (red, yellow or green). Confirm the information by filling the “date noted, by” column with your info.
- Those without editing rights: please leave a note on “#comments given”, indicating the number of comments. Please add info on who noted and when. We will periodically edit these comments into the document.

updated
31.8.2015

VPHA website

<http://vph-ald.com>



Virtual Project on the History of ALD

Created as central hub of the VPHA collaboration and ALD history info

- Introduction & Invitation to participate
 - Publications
 - VPHA open files
- ALD History publications, including links to / pdf's of presentations

1. Overview of early publications on Atomic Layer Deposition, Baltic ALD 2014 (12th

VPHA communication, social media

- LinkedIn ALD History group
 - <https://www.linkedin.com/groups/ALD-History-5072051/about>
 - A major communication centre of VPHA
- Twitter
 - [#VPHA & #ALDep](#)
 - [#BalticALD](#)
 - [#ALDRussia](#)
 - [#AVSALD](#), [#AVSALD2015](#), [#ald16](#)
- BALDengineering [Blog](#)
- ALDpulse [website](#)
- Mendeley: [ALD History](#) group



VPHA communication, email

- Periodic updates to current and prospective co-authors
- Contain the most detailed information on VPHA progress

To register for the updates, please send your email to:

- A) riikka.puurunen@vtt.fi
- B) or info@vph-ald.com, this gets forwarded (currently) to
 - Yury Koshtyal, Ioffe Institute
 - Henrik Pedersen, Linköping University
 - Riikka Puurunen, VTT Technical Research Centre of Finland
 - Jonas Sundqvist, BALDengineering



Conclusion

Warmly welcome to
join VPHA!

1. Everyone can help to understand ALD's roots
2. VPHA facilitates voluntary collaboration
3. Joint publications as outcome

Riikalle 16.10.2013

"Miesillä on halu tietää..."

"All men by nature desire to know"

Tuomo Suntola → Aristotle



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- General: Tuomo Suntola, Anatoly Malygin, Victor Drozd
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Hooking together European Research
in Atomic Layer Deposition

COST action MP1402



- Network of academic & industry researchers (150 so far) from 26 European countries + 5 other countries, 2015-2018; **new members are always welcome.**
- Institutions in neighbouring countries (Russia, Ukraine, Belarus etc.) may apply to join and then obtain funding for all network activities:
 - travel to workshops,
 - laboratory visits,
 - training schools.

Thank you, questions? СПАСИБО, ВОПРОСЫ?

атомно-слоевое осаждение 原子层沉积

Deposição por Camadas Atômicas Осаждения атомних шарів

Atomikerroskasvatus Atomik Katman Biriktirme Aatomkihtsadestus

आण्विक थर लेप Atomlagenabscheidung परमाणु परत निक्षेपण

원자층증착 **Atomic Layer Deposition** Atoomlaagdepositie

Atomlagerdeponering Depositación de Capas Atómicas

Deposizione a Strati Atomici Parmanu Parat Nishepan

Молекулярное Наслаивание εναπόθεση ατομικού στρώματος

Atomlagsdeponering שכבות אטומיות השקעת Dépôt de Couches Atomiques

Dépôt Chimique en Phase Vapeur à Flux Alternés 原子層堆積

ALD name collection in LinkedIn ALD – Atomic Layer Deposition

