Atomic Layer Deposition (ALD) in Magnetism and Spintronics

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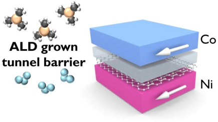

Magnetism group winter retreat
Vlachovice

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MINISTRY OF EDUCATION, YOUTH AND SPORTS
BRNO UNIVERSITY OF TECHNOLOGY
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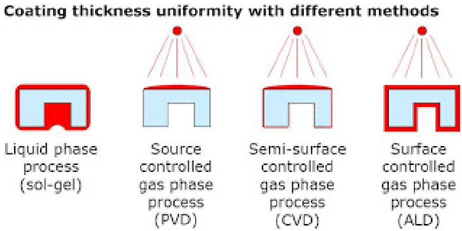
Outline of the presentation

Atomic Layer Deposition



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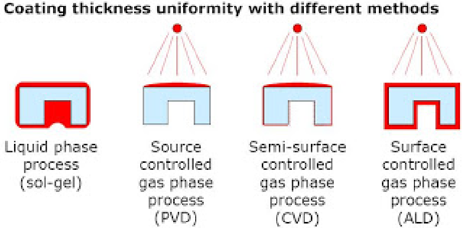
Atomic Layer Deposition



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- Special mode of Chemical Vapor Deposition (CVD)
- Sequential self-limiting surface chemical reactions
- **Conformal coating** of rough surfaces, holes, pillars, . . .
- **Precise control over film thickness** ($\approx$ 0.1 nm per cycle)

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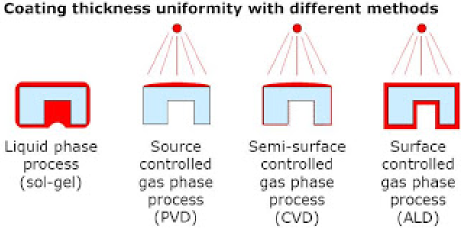

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ALD Review: George, *Chem. Rev.* **110**, 111-131 (2010)
Various info: www.plasma-ald.com

Conformal coating possible also in a solution – electroless plating

What materials can be deposited by ALD?

Close to everything:

- nitrides, oxides [AlO_x]
- metals, including Fe, Co, Ni, Pt, W, Ta, Ru, Rh, . . .
- alloys, ternary and more complex compounds

List of materials: Miikkulainen et al., *JAP* **113**, 021301 (2013)

ALD cooking: Recipe and ingredients

ALD deposition – what is needed

- **vessel**: reactor (rough vacuum, temperature control, gas inlets)
- **ingredients**: precursors and reactants
- **energy**: temperature and/or plasma
- **recipe** (process parameters: how much, how long, . . .)

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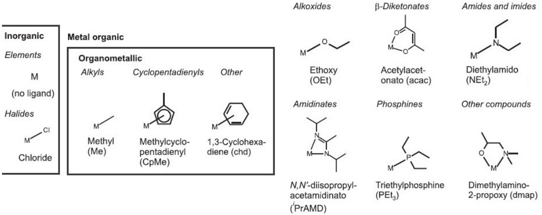

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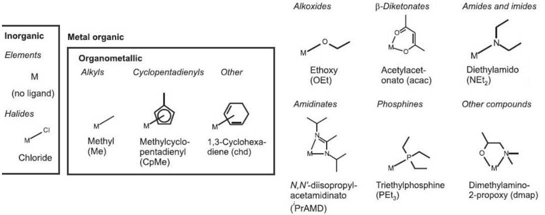

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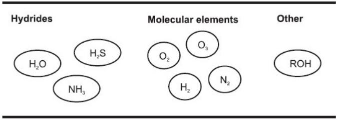
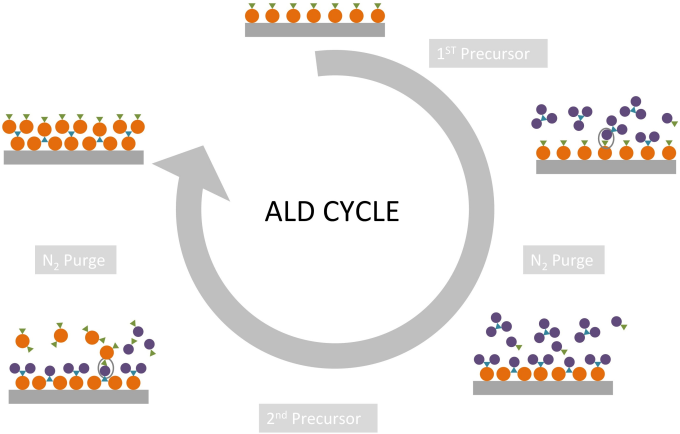


Miikkulainen et al., *JAP* **113**, 021301 (2013)

(b) reactants

ALD cycle – How it works



ctechnano.com

See also https://www.plasma-ald.com/

ALD in spintronics / magnetism

- [microelectronics]: insulating, protective layers (AlO_x), conductive seed layers (Cu, Co, Ru)
- spin-Hall-active Pt thin films (order of magnitude worse than sputtered Pt, but detectable & room for improvement)
  APL **112**, 242403 (2018)
- **oxide barrier in magnetic tunnel junctions**
- **magnetic nanotubes**

Oxide barrier in magnetic tunnel junctions

Magnetic Tunnel Junction (MTJ): magnet/insulator/magnet

Tunneling MagnetoResistance (TMR=$\frac{R_{\uparrow\downarrow}(H)-R_{\uparrow\uparrow}}{R_{\uparrow\uparrow}}$) 100s % @ RT

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- AlO_x 24 % TMR @ 40 K, 1.6 nm, *APL* **102**, 202401 (2013)
  $\approx$ 1.2 Å & still good barrier height: *AIP Adv.* **9**, 025018 (2019)
- HfO_2 10 % TMR @ RT, 2 nm, *APL* **105**, 132405 (2014)
- MgO $Fe_{3-\delta}O_4$/MgO/Co – all CVD (barrier ALD): 6 % TMR @ RT
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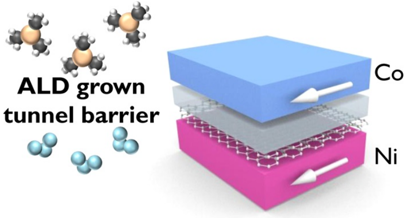
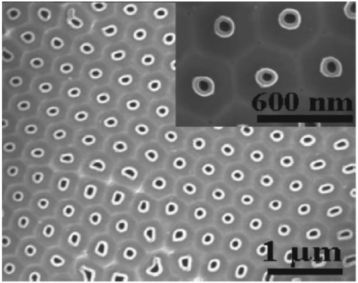
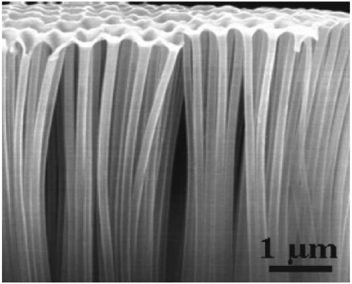


2D materials (graphene, black P)
+ $\leq$ 1 nm ALD barrier in MTJs
ACS Nano **8**(8), 7890-7895 (2014)

Magnetic nanotubes deposited using ALD

Ni, Co Nanotubes: *JAP* **111**, 09J111 (2007)
Template: pore diameter 35 nm and 160 nm, length 2-50µm
Precursor: nickelocene (NiCp2)+H_2O vapour – gives oxide
Reduction better after ALD – Ar+5 % H_2 (lower grain size)





SEM images: TiO_2/Ni/TiO_2 tubes. Left: in template (top-view), Right: liberated.

STAFF3d-spin project

Synthesis and investigation of
Synthetic **T**ubular **A**nti**F**erromagnets **F**or **3D Spin**tronics

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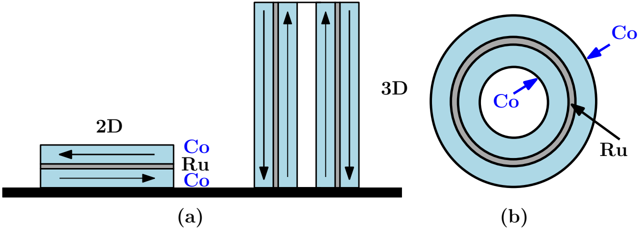
Goals:

- preparation 3D vertical arrays of tubular SAF (ALD, electroless dep.)
- test of interfaces suitability for spintronics (giant magnetoresistance)
- investigation of individual magnetic nanotubes, tubular SAFs



Synthetic antiferromagnets. (a) current planar structure (Ru $t \approx 1$ nm) versus proposed 3D vertical structure. (b) Cross-section view on the 3D tubular structure.

Summary: ALD in spintronics/magnetism

- + conformal coating, high-aspect ratio structures (even 1000:1)
- + precise control over thickness, easy for core-shell
- - slow, not suitable for thicker coatings ($\geq$ 100 nm)
- - typically highly granular
- - challenge: high purity, good magnetic properties

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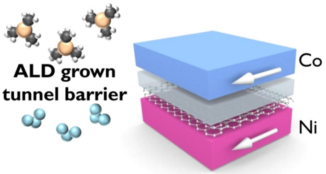

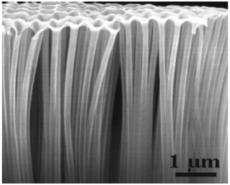

- still **mostly oxides** (cover layers, barriers in MTJs)
- first tests with **Pt for spintronics** (spin Hall effect)
- deposition of **magnetic nanotubes**, but mostly oxides or reduces from oxides (lower quality)
- only few magnetic measurements on ALD magnets (VSM)

Acknowledgements

Thank you for your attention!

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