TECHNISCHE UNIVERSITÄT DRESDEN

Institute of Semiconductors and Microsystems

Atomic Layer Deposition of Tantalum Nitride-based Films

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Introduction

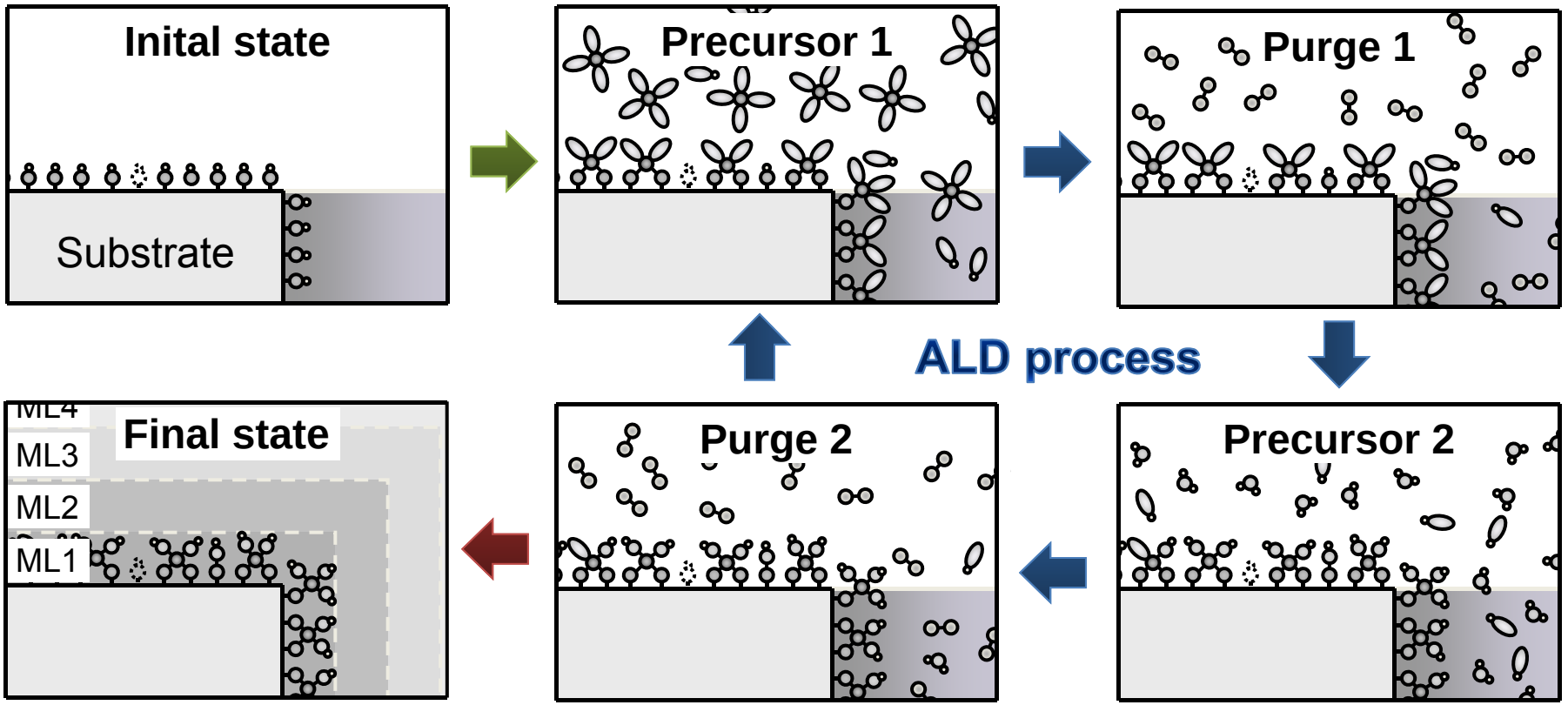
Subject of this talk

- Atomic Layer Deposition of Ta-N at TU Dresden and in literature
- Show important ALD processes in this area

Not subject of this talk

- Comprehensive knowledge about the ALD of Ta-N

Introduction – Basics of ALD



Sequential self-limiting surface reactions

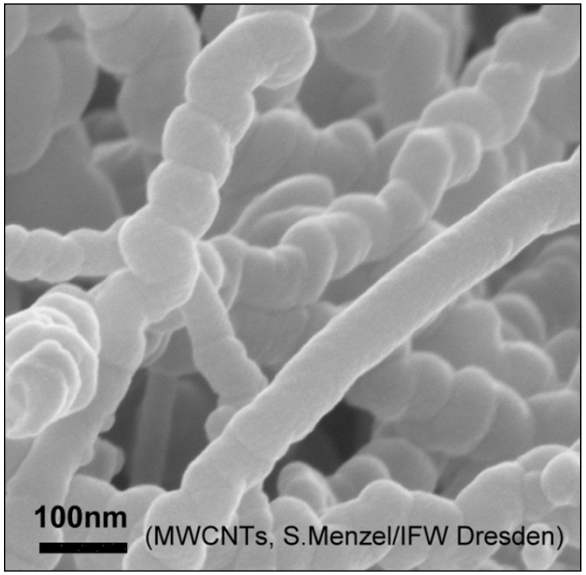
Introduction – Basics of ALD

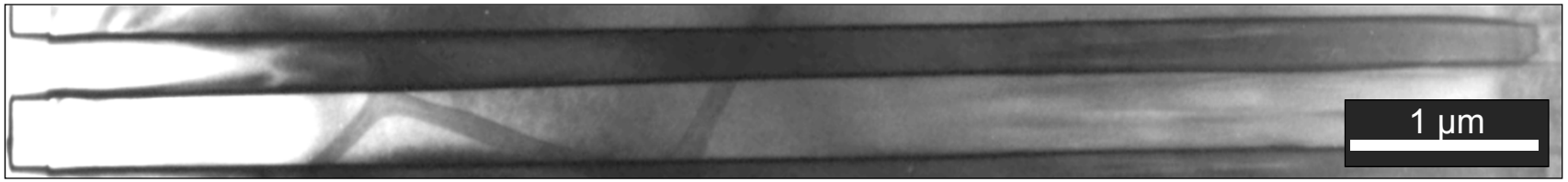
Important advantages of ALD

- Excellent step-coverage,
- Sub-nm film thickness control
- Low-deposition temperatures

Applications of ALD

- **3D structures** → TSV, CNT, DT, pourous materials, interconnects, jewelry, tools,…
- **Solar cells** → Backside passivation
- **Organic electronics** → Permeation barrier
- **…**

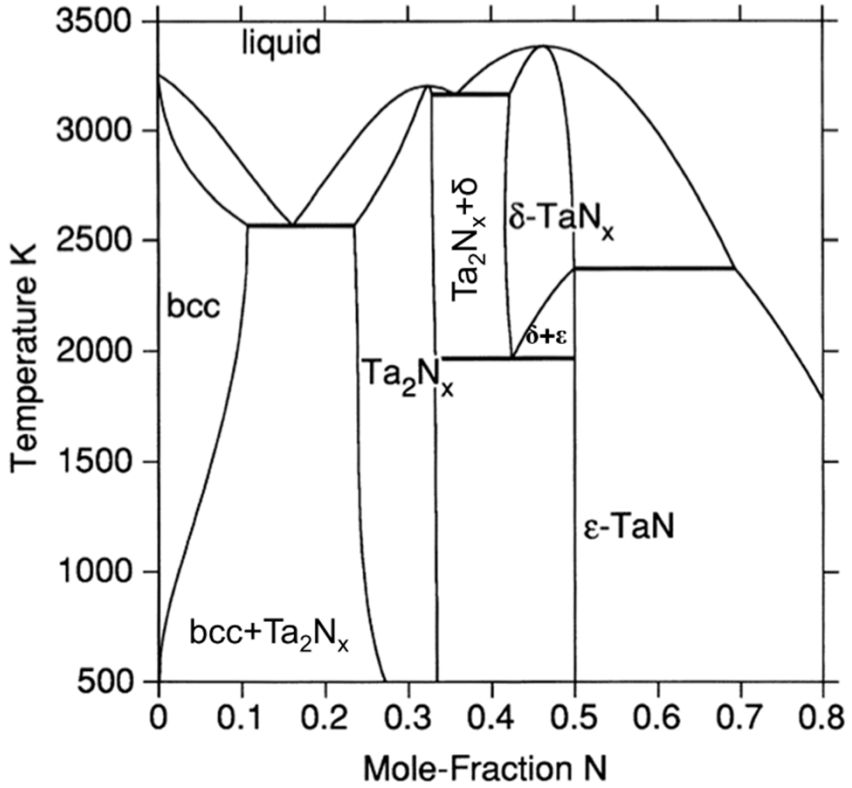




Introduction –Ta-N

Properties of Tantalum Nitride

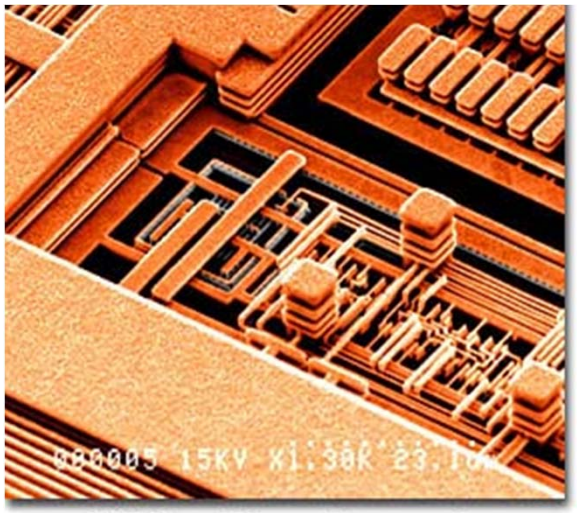
- Refractory
- High hardness
- Barrier against Cu diffusion
- Several phases
  from α-Ta(N) to Ta_3N_5
- N/Ta-ratio affects
  - Structure
  - Density
  - Resistivity
  - ...
- …



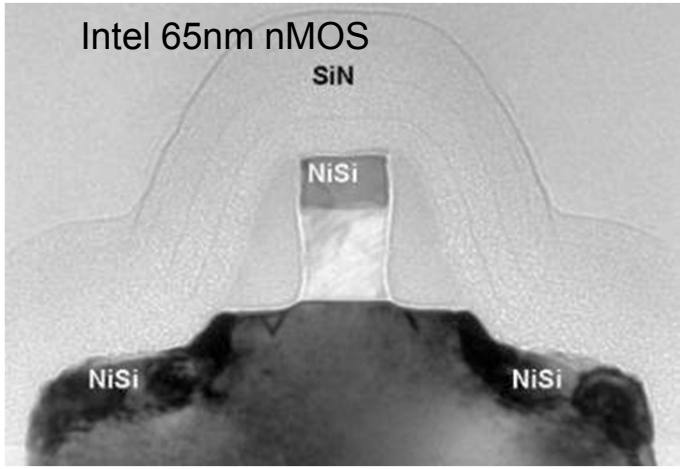
Introduction – Applications of Ta-N

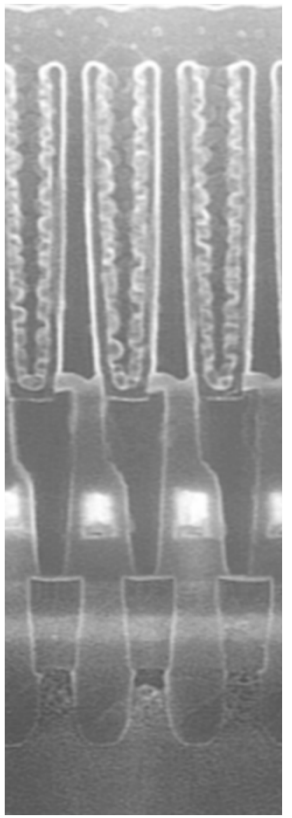
Applications of Ta-N

- Diffusion barrier
- Workfunction tuning in gate last processes
- Electrode e.g. in DRAM
- Wear resistant coating
- …



SEM view of Copper Interconnect
(IBM Microelectronics)

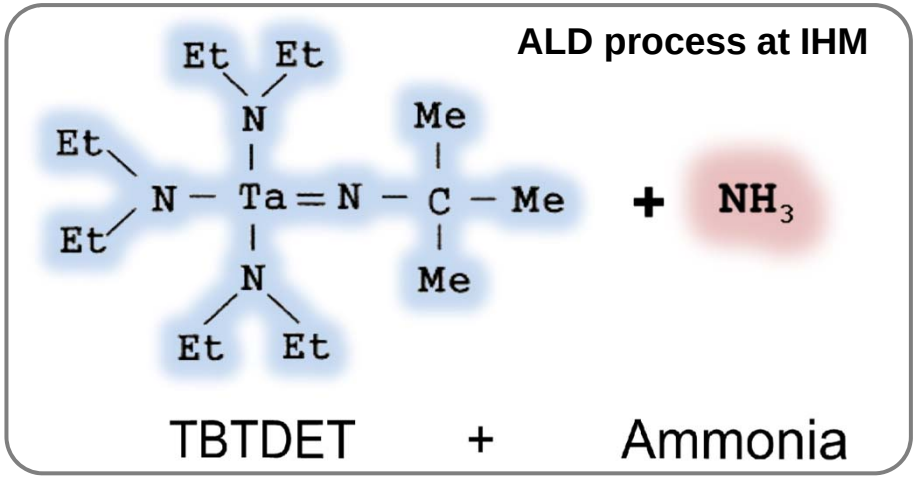




ALD of Ta-N with metalorganic precursors as-deposited

Precursors for MOALD

- TBTDET, PDMAT, TAIMATA, …
- NH_3, N_2H_4



Results in general

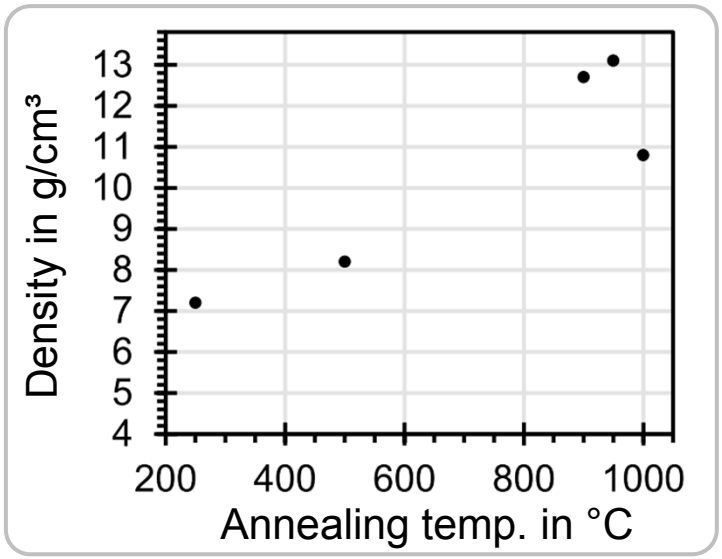
- Amorphous films
- High oxygen content
- Low density
- Poor or no conductivity
- Smooth films
- High step coverage

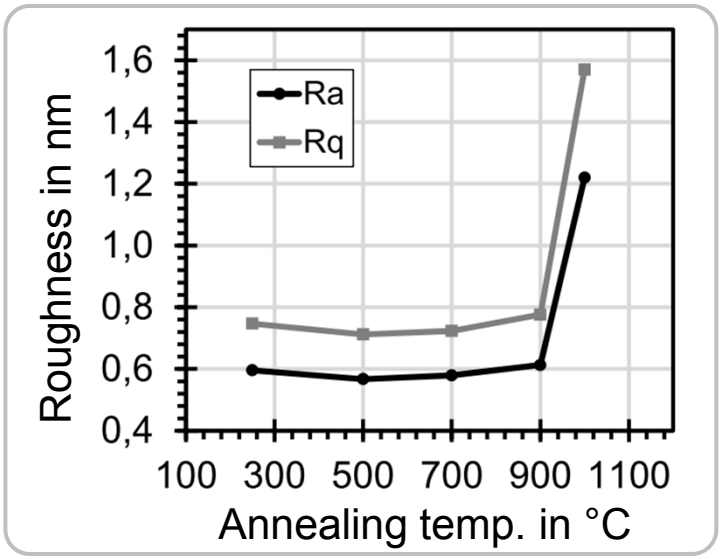
See e.g.: Schmidt et all., Microelectronic Eng. Volume 85, Issue 3, March 2008, Pages 527-533

ALD of Ta-N with metalorganic precursors
In Situ Annealing

Improve film properties by in situ Annealing

- e.g. with in situ anneal in Hydrogen atmosphere (1h)

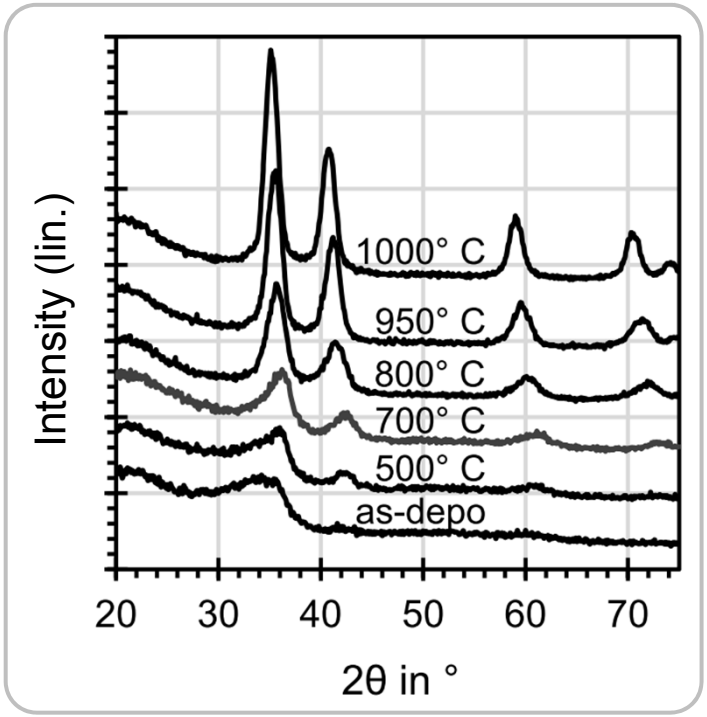


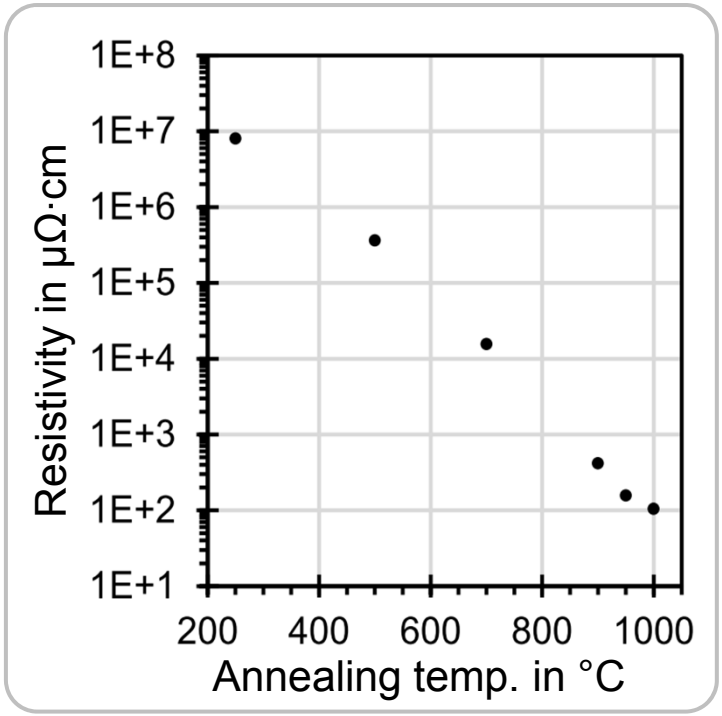


- Annealing results **in substantial film densification**
- Increasing roughness above 900 C
- No influence on step coverage

See: Hossbach et al., Talk at AVS ALD 2009 conference

ALD of Ta-N with metalorganic precursors
In Situ Annealing





- Annealing results in **film crystallization** and a **major decrease in resistivity**

- Furnace annealing method can be transformed to RTP, Laser or Flash
- Annealing atmosphere can contain reactive components
- High thermal stress

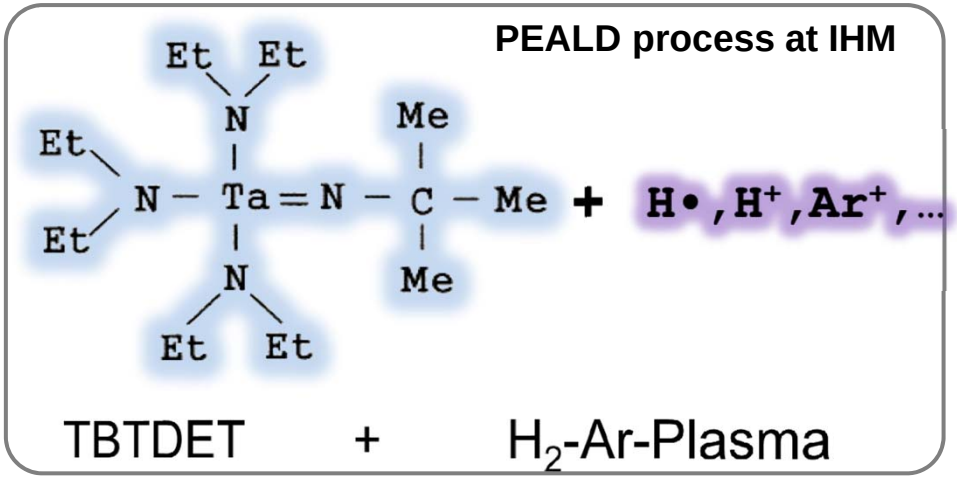
PEALD of Ta-N-C with metalorganic precursors

Improve film properties by more reactive 2nd reactant

- H•, H^+, …

and ion bombardment

- Ar^+



Plasma enhancement result in

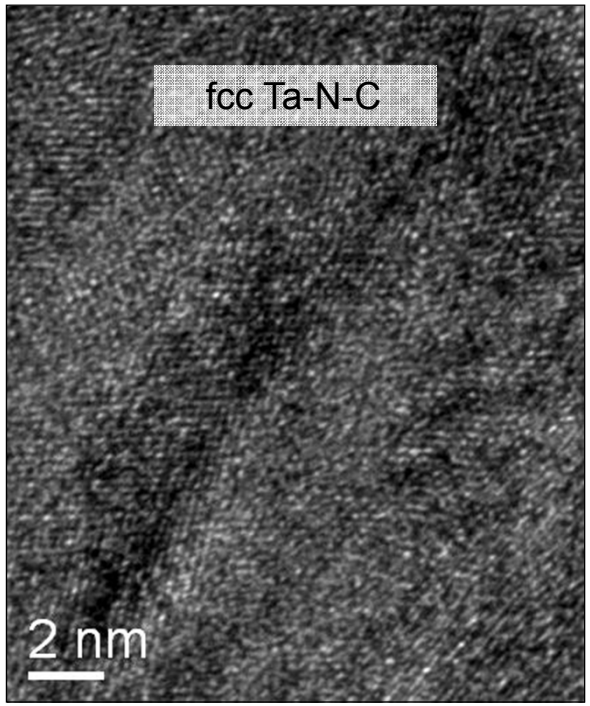
- **High film density** (13-14 g/cm³)
- **Low oxygen content** of < 5 at%
- **Increased carbon content** (~25 at%)
- **Lowered step coverage** (e.g. due to limited reactant life time and anisotropy effects)

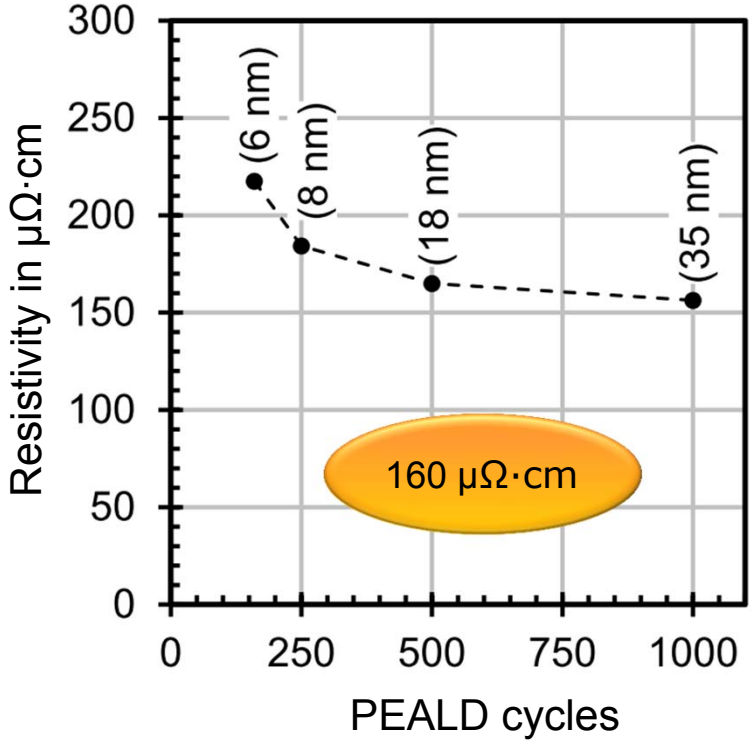
See: Hossbach et al., J.Electrochem.Soc. Vol. 156, No. 11, H852-H859, 2009

PEALD of Ta-N with metalorganic precursors

PEALD with TBTDET and H_2-Ar-Plasma result in

- **nano-crystalline** films with an **excellent low resistivity**



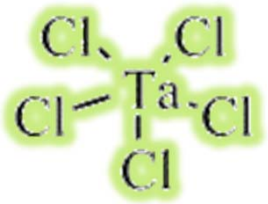


See: Hossbach et al., J.Electrochem.Soc. Vol. 156, No. 11, H852-H859, 2009

ALD of Ta-N with halide precursors

Precursors for ALD

- $TaCl_5$, TaF_5, $TaBr_5$, TaI_5, $TaCl_5$:SEt
  (no C, corrosive, solids)
- NH_3, N_2H_4



Results

- $TaCl_5$ + Ammonia → Ta_3N_5

Processes with excellent SC & reasonable low resistivity(~1000μΩ·cm)

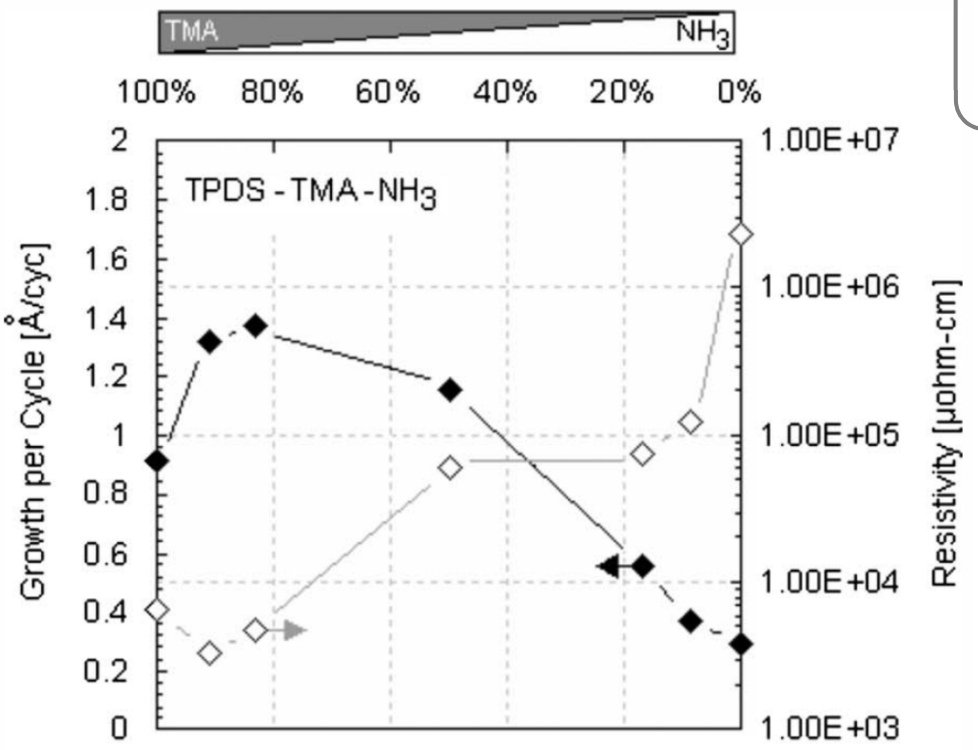
- $TaCl_5$-Zn-NH_3 (see M. Ritala et al., *Chem. Mater.*,**11**(1999)1712)
- $TaCl_5$ –TMA – NH_3 (see P. Alén et al., J.Electrochem.Soc.,148(2001)G566.
- TaF_5 –TMDS (see W.M. Li et al., AVS ALD 2007 Conference)

TMDS…1,1,3,3-TETRAMETHYLDISILAZANE

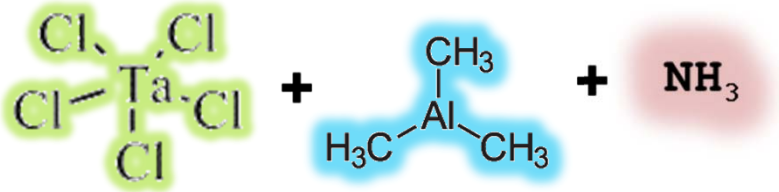
ALD with halide precursors

Nanolaminate deposition enables tuning of stoichiometry

- TaC ⇔ Ta_3N_5



ALD process at IHM



$TaCl_5$ + TMA + Ammonia

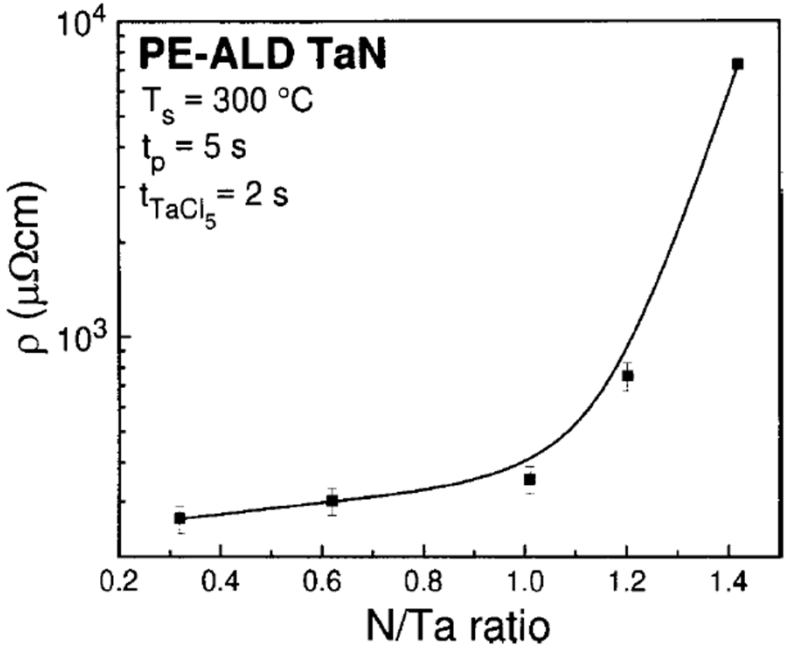
- Halogen impurities
- Carbon impurities

See: Schmidt et al., J.Electrochem.Soc. Vol. 157, No. 6, H638-H642, 2010

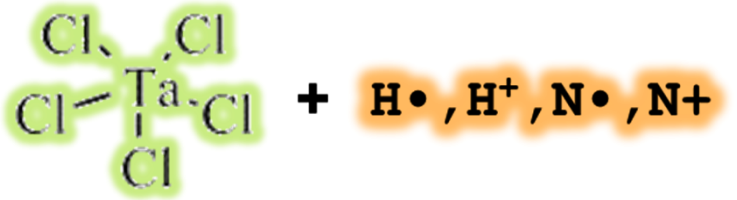
PEALD with halide precursors

Plasma enhancement allows

- Tuning of stoichiometry Ta ⇔ Ta_3N_5
  → structure, resistivity, density, …



PEALD process from Kim et al.



$TaCl_5$ + H_2-N_2 plasma

- Corrosive by-products
- Halogen impurities
- Limited step coverage

See: Kim, Kellock, Rossnagel, J. Appl. Phys. 92 (12), 7080 (2002)

Conclusions and Transition

- ALD of Ta-N has come a long way
- Results at TU Dresden
  - MOALD: In situ annealing greatly improved the Ta-N films
  - PEALD: Dense Ta-N-C with low resistivity
  - Halide ALD: Conductive films with excellent SC
  - Nanolaminates and PEALD: Tuning of film stoichiometry
  - Covers a wide range of what is possible today in ALD of Ta-N
- Each approach has its drawbacks
- Improved precursors are needed

- We are experts in barrier testing and in situ metrology
  → stay for the next presentation ☺

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Thank you for your attention!