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Cobalt Fab Intro & Integration from CVD to CMP (R&D Accelerator)

L. Gerlich, M. Wislicenus, J. Koch, A. Dhavamani, S. Esmaeili, R. Krause, B. Uhlig

CMC Conference 2018

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Outline

Cobalt Integration Solutions from the R&D Accelerator

- Introduction IPMS-CNT
- Motivation
- Cobalt
  - In BEoL Cu Metallization
  - Silicidation
  - TSV
  - Advanced Integration
- Conclusion

Fraunhofer Institute for Photonic Microsystems IPMS

Fraunhofer IPMS Locations within „Silicon Saxony“

BOSCH

GLOBAL FOUNDRIES

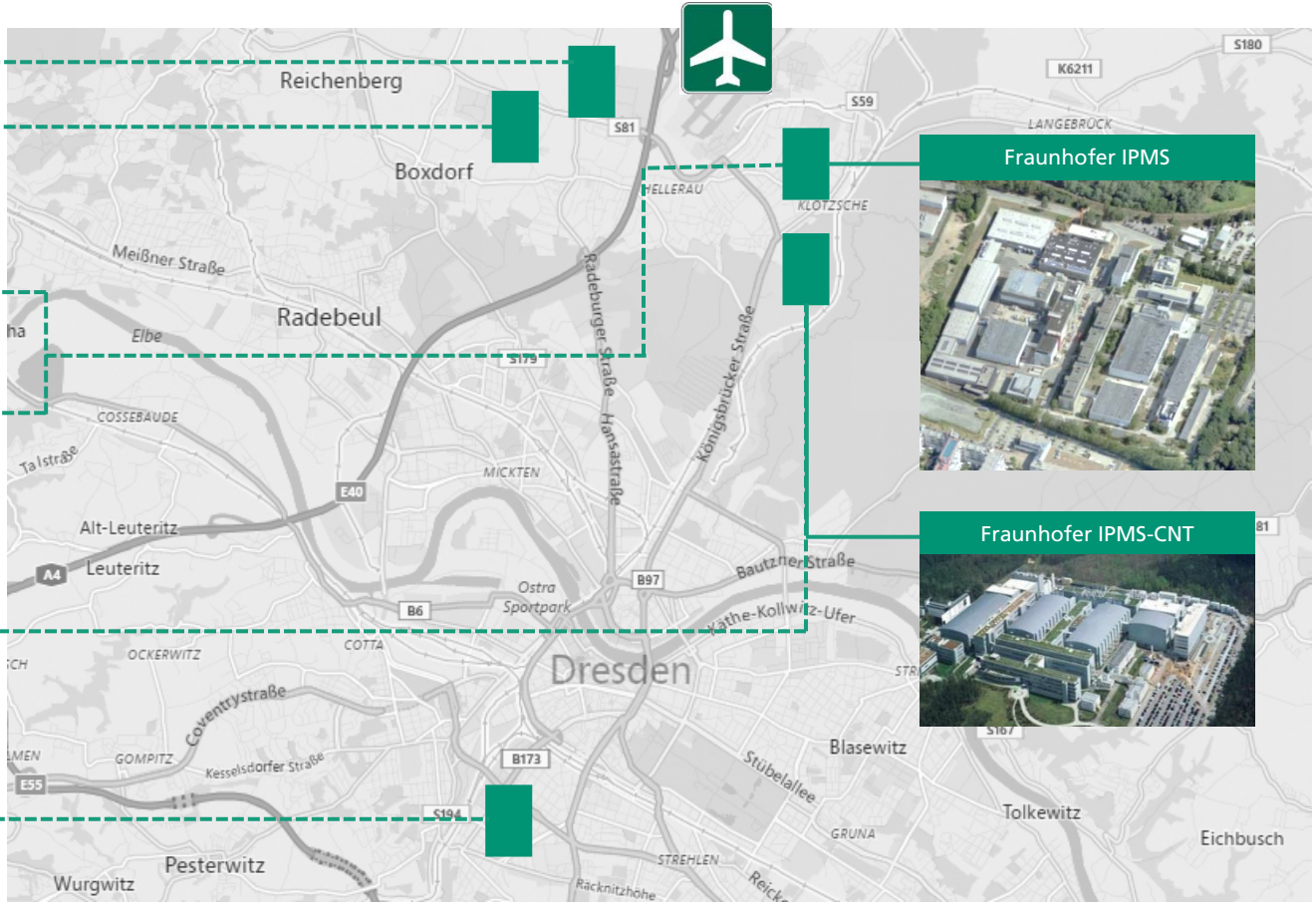
ZMDI

IDT

X-FAB MIXED-SIGNAL FOUNDRY EXPERTS

Infineon technologies

TECHNISCHE UNIVERSITÄT DRESDEN



Fraunhofer IPMS

Fraunhofer IPMS-CNT

Overview

150/200 mm MOMS/MEMS cleanroom

300 mm CNT cleanroom

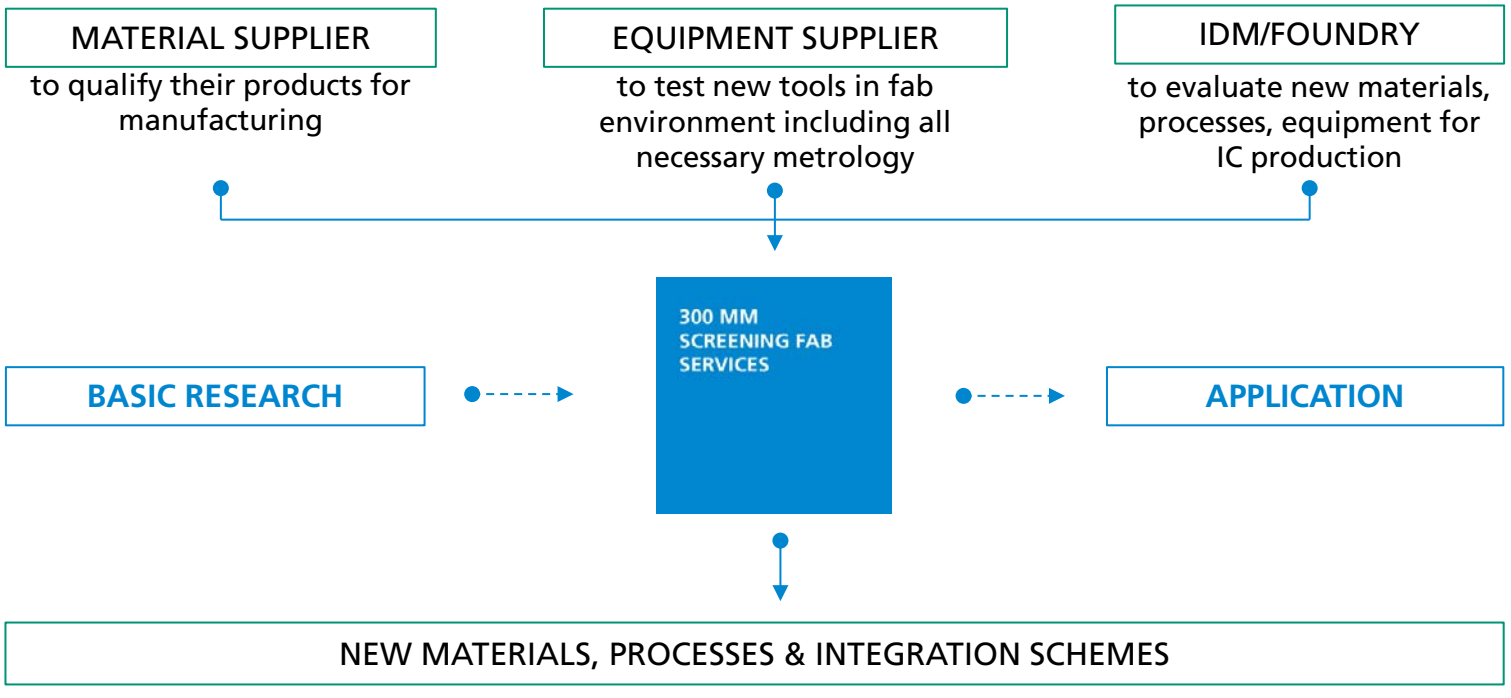
- 1500 m², class 10
- → 200 mm (8") wafer line
- 3 shift preparation for R&D and pilot fabrication
- Technological parameter supervising system
- PPS based planning and documentation
- ISO 9001 certification

- >800 m² clean room, class 1000 & 650 m² laboratory area
- >40 Tools for Wafer Processing, Patterning, Metrology & Analytics
- Qualification of processes & materials on 300 mm industrial standard equipment
- Sub-nm characterization and verification
- Full integration into customer process flow in 28 nm technology and beyond

Cu metallization line @ IPMS-CNT

ETCH	CLEAN	BLS	ECD	ANNEAL	CMP	FILMS	LITHO
AMAT	Semitool	AMAT	Semitool	TEL	AMAT	AMAT	Vistec
Centura	Raider SP	Endura	Raider ECD	Formula	Reflexion-LK	Producer	SB3050 DW
Dielectrics Metal HM open Ash	Front- /Backside Spray Megasonic Solvent	Cu PVD Ta/TaN PVD TiN PVD **Co-CVD - Volta** In-situ XPS	Cu ECD **Co** ECD	H2/N2	Cu Barrier Co Oxides STI	Oxides Nitrides Low-K ULK carbon	40 nm lines 30 nm holes p/n resists Spin-on processes

300 mm Screening Fab Services

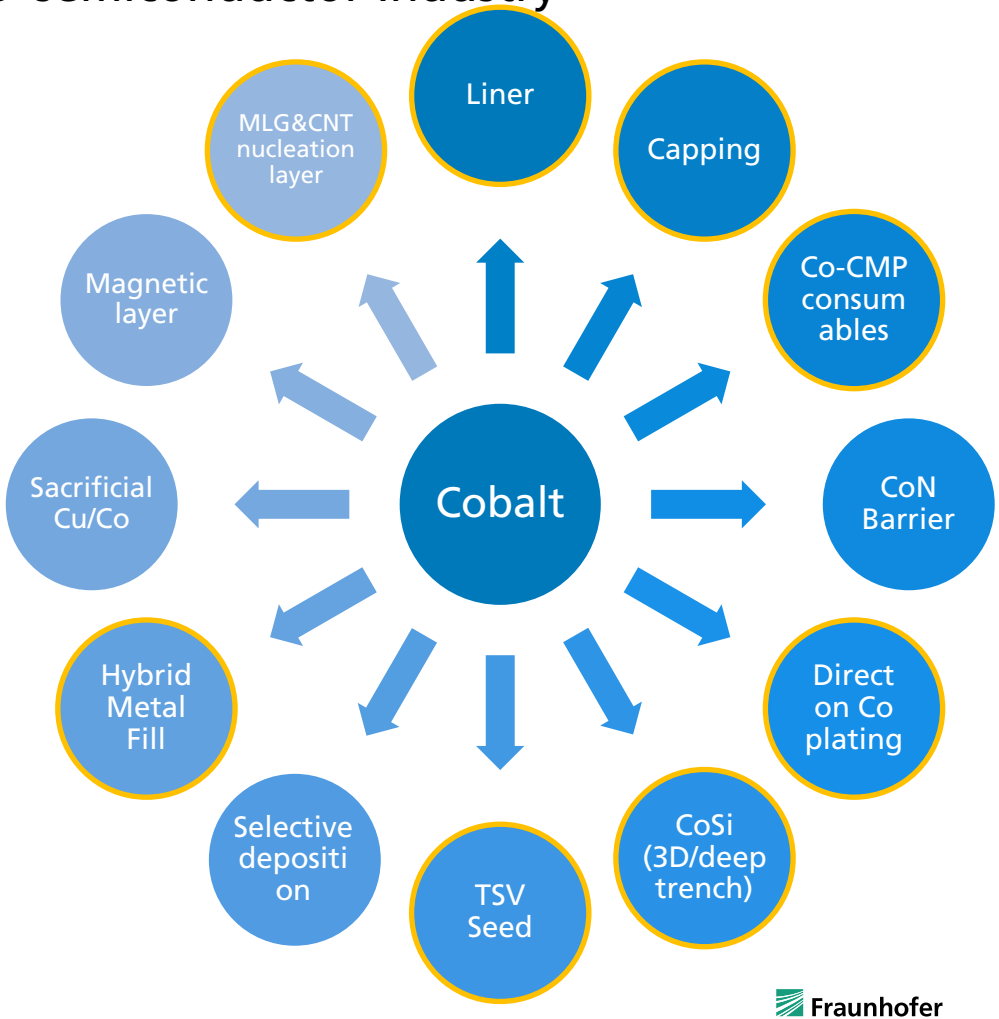


- Consumable benchmarking
- Process enhancements and further cost reductions
- Next generation technology development
- Integration, optimization, qualification

CLEANING / WET ETCH
ALD / CVD
COPPER PLATING
CMP

Co MOCVD as a flexible process for the semiconductor Industry

- Some history of Co in CMOS
  - 250 nm node: $CoSi_2$ introduction (PVD) (**1990s**)
  - **32 nm** node: CoWP introduction as capping layer (ELD)
  - **1x** nm node: Co-liner for copper metallization
- Challenge
  - Each technology needs normally a separate chamber
  - Usage one chamber (CoO)
  - Benefit from new properties

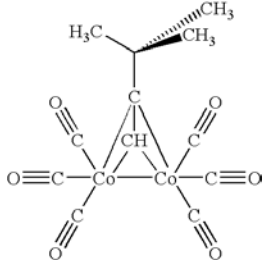
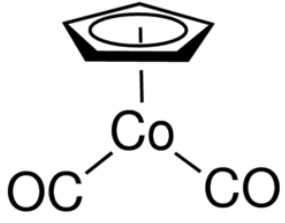


Cobalt as EHS sensitive material

27
Co
58.933

- As a **metal**
  - After nickel and chromium, cobalt is a major cause of contact dermatitis
- Organometallic compounds (CVD/ALD **precursor**s)

  - Usually full encapsulated in Bubblers
  - For maintenance/service still an issue → high procedure standards

CCTBA (dicobalt hexacarbonyl t-butylacetylene	$CpCo(CO)_2$ (Cyclopentadienyl cobalt dicarbonyl)
	

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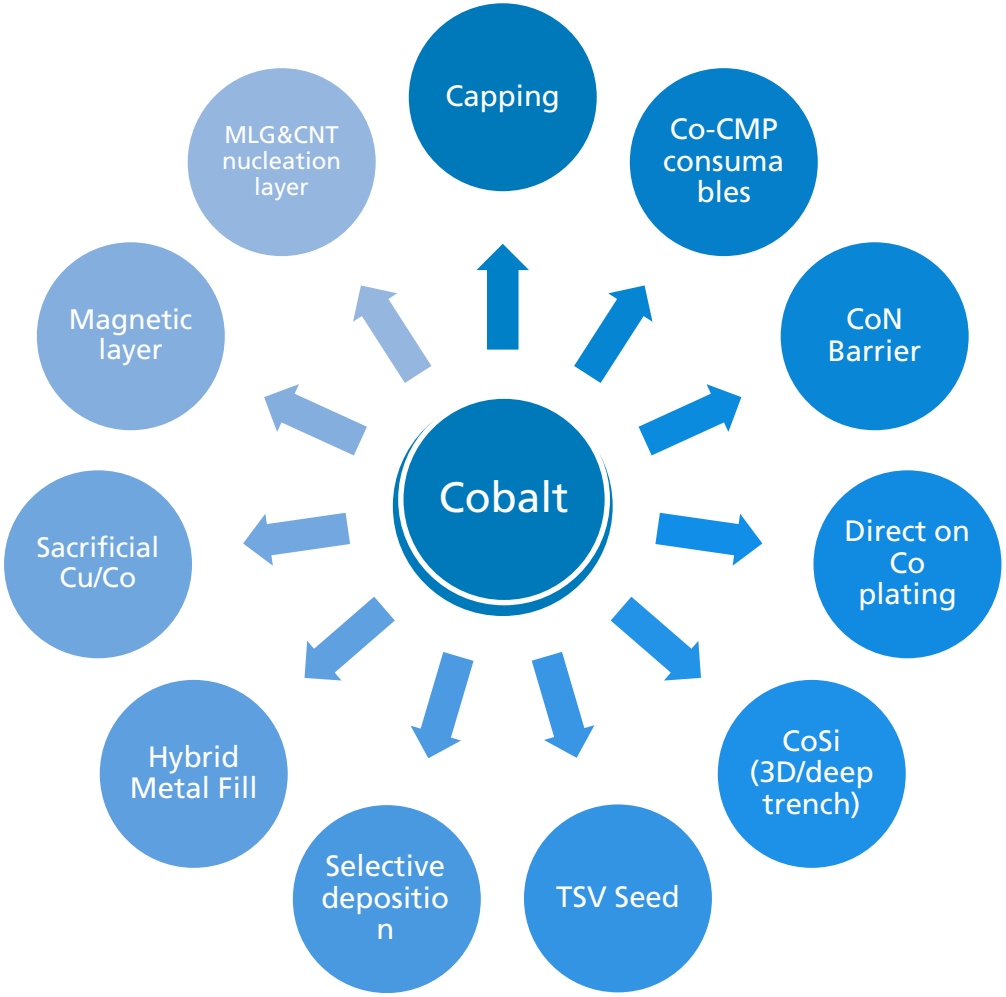
- Organometallic compounds (CVD/ALD **precursor**s)

  - Usually full encapsulated in Bubblers
  - For maintenance/service still an issue → high procedure standards
- Cobalt electrolytes $CoCl_2$, $CoSO_4$ for **Plating**

  - It is crucial to avoid crystallization to fulfill EHS requirement
  - Gender selectivity to work directly with the electrolyte is recommended

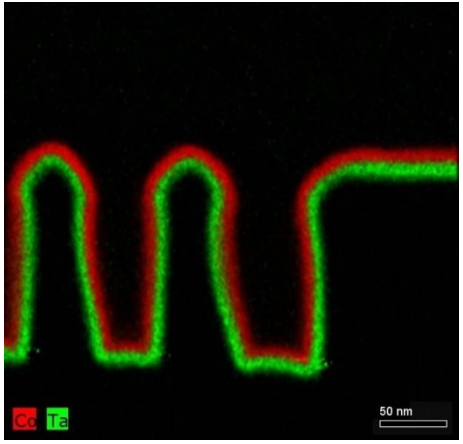
Key message: EHS is relevant, but right procedures avoid blocking points!

Cobalt wheel

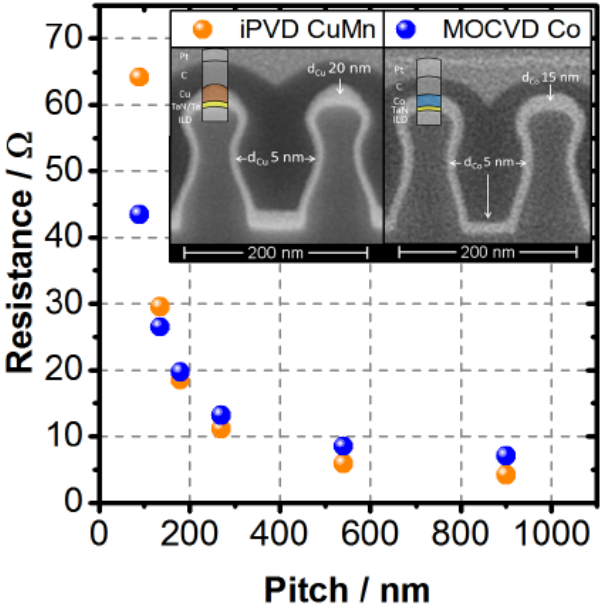


Integration of **Liner**

- Requirements
  - Low resistivity
  - Pin hole free
  - As thin as possible
- For usage as liner below Cu-seed <2 nm Co is recommended
- Strict controlled conformity with CCTBA as MOCVD-precursor

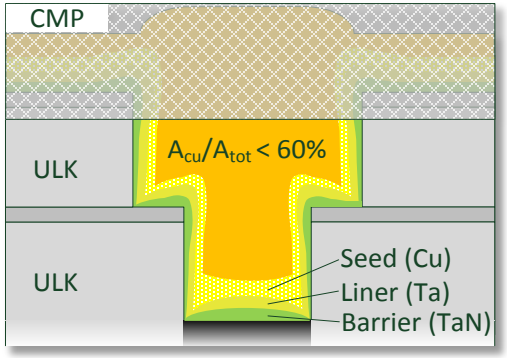


EDX/TEM : Conformal deposition in small structures (28 nm node)

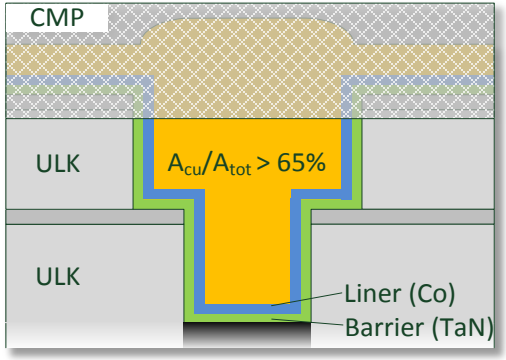


M.Wislicenus et al. MAM 2018

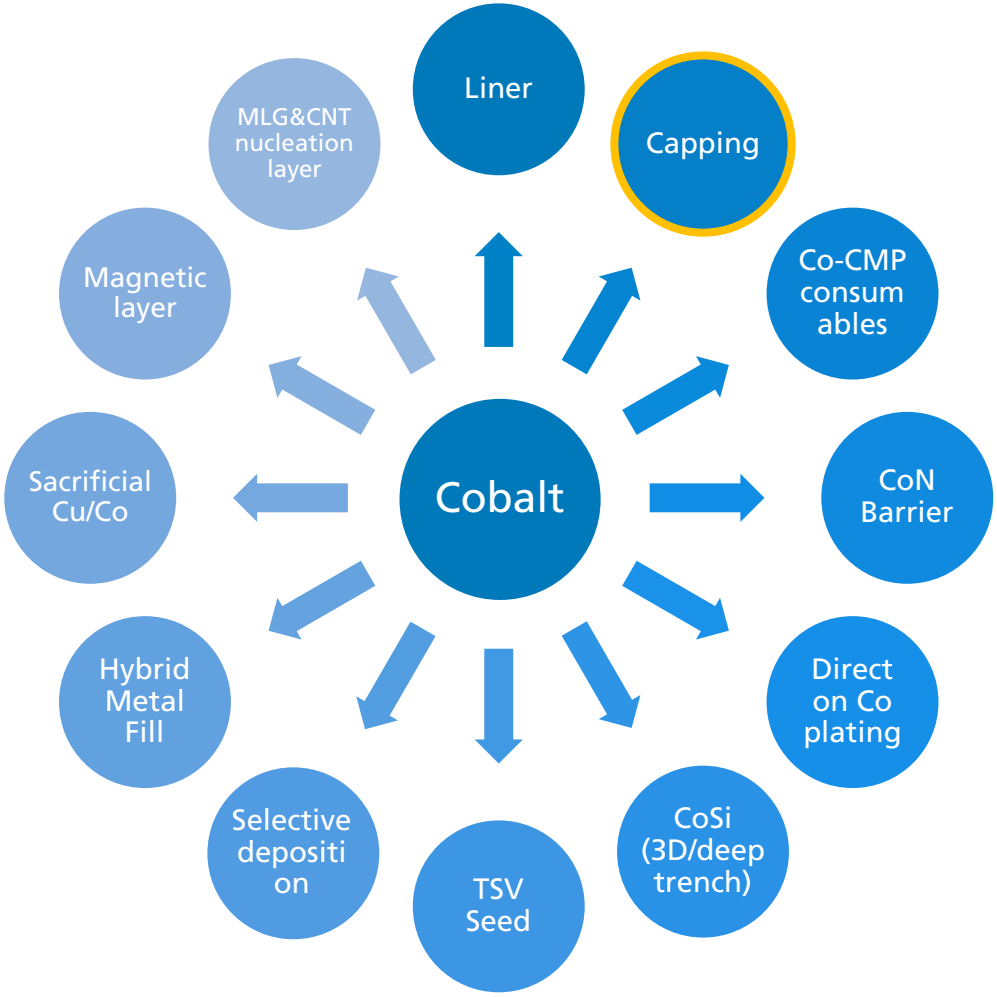
PVD



MOCVD



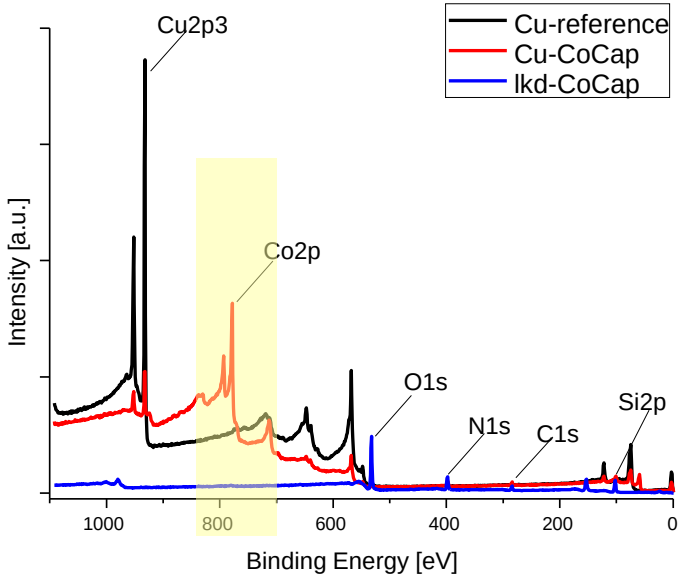
Cobalt wheel



Cobalt as **capping**

- Benefits
  - EM stability/reliability
  - Route compatibility
  - Low CoO → combination of Co
- Process

Cap	CCTBA	$CpCo(CO)_2$
Pressure	5 torr	20 torr
Temperature	100°C	≥200°C
flow	200 sccm	< 50 sccm



XPS of CpCo(CO)2 capped lkd and Cu wafers (+Cu ref)

- Area selective deposition shown
  - $CpCo(CO)_2$ as superior capping material
  - CCTBA selective for a narrow thickness range <1nm

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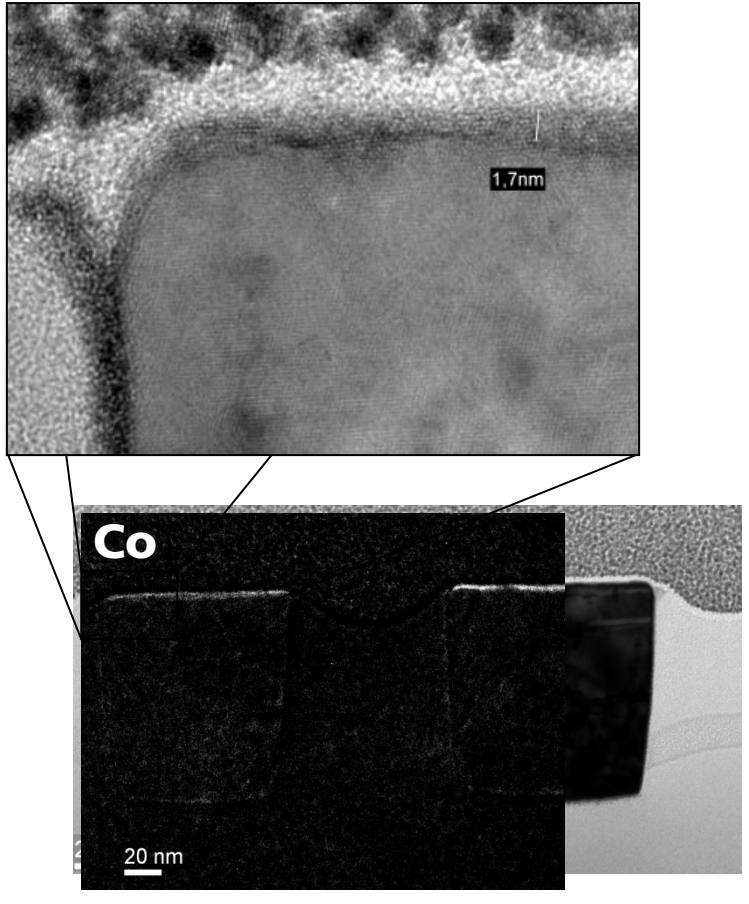
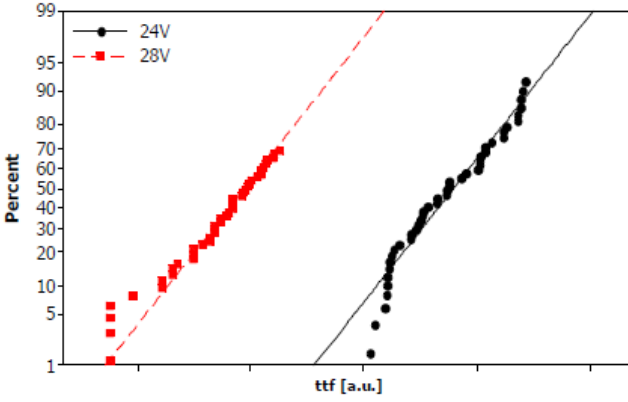


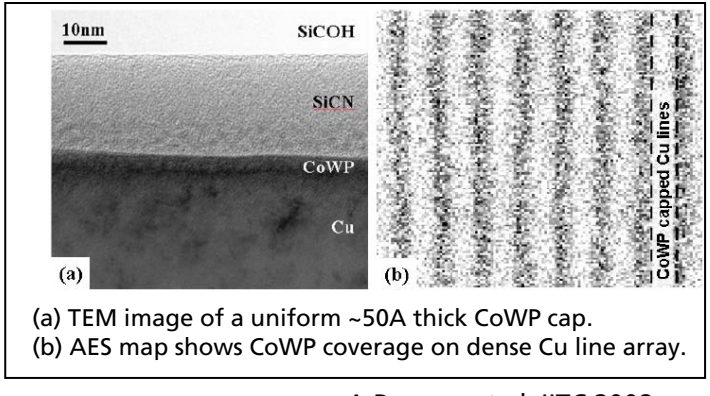
(EF)TEM of Cu-lines after selective Co-MOCVD capping with CoCp(CO)2

CoWP as **capping**

- Electroless deposition was introduced by AMD for the 32 nm node in production in 2009
- Superior reliability data were achieved
- Difficult to operate
- CoWP eless chemistry was monitored for EHS

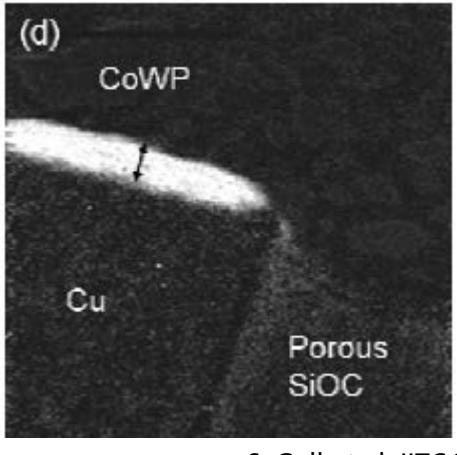


Probability plot of time to failure for CoWP
A.Preusse et al. IITC 2008



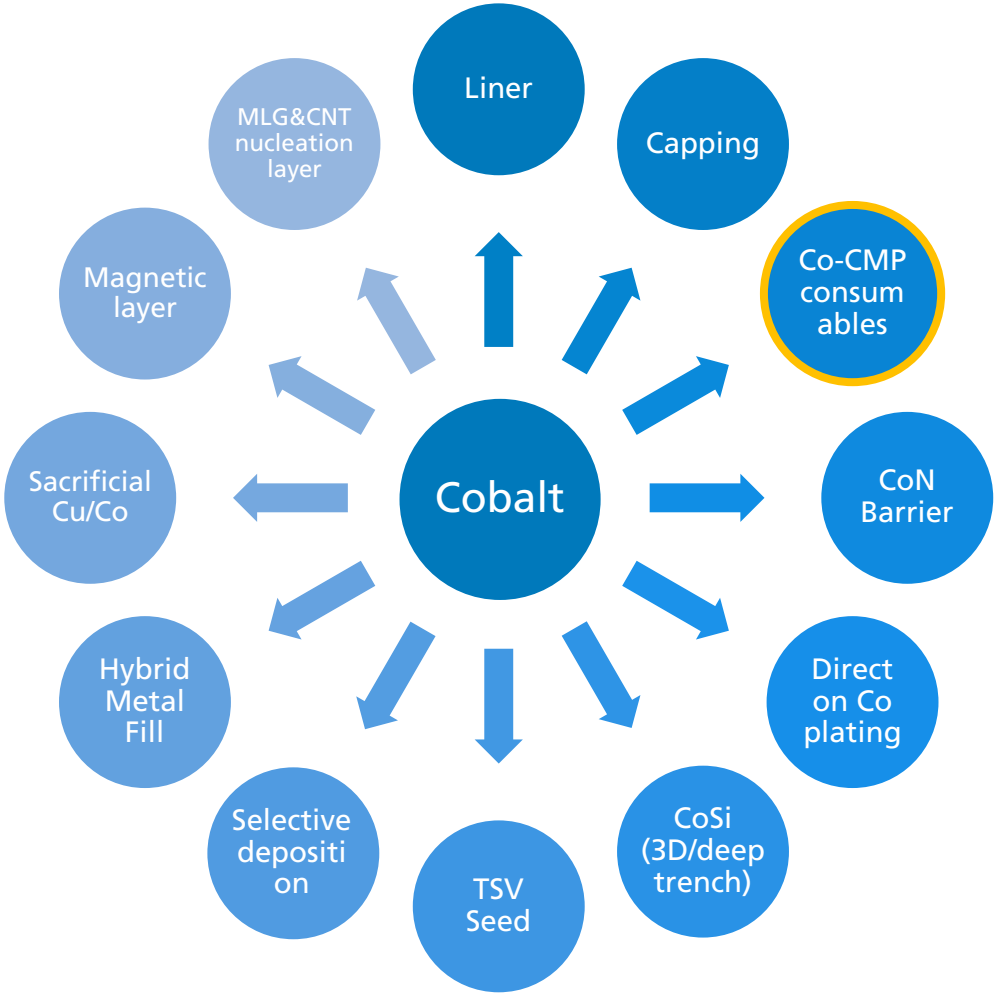
(a) TEM image of a uniform ~50A thick CoWP cap.
(b) AES map shows CoWP coverage on dense Cu line array.

A.Preusse et al. IITC 2008



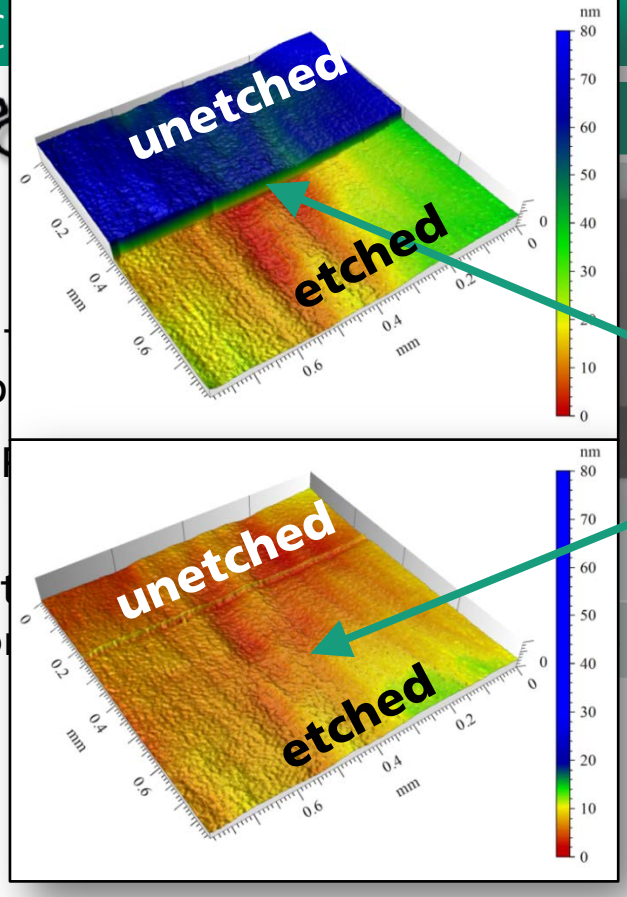
S. Gall et al. IITC 2008

Cobalt wheel



Cobalt-**CMP** consumables

- Co is very sensitive
  therefore to CMP p
- Slurry and post CMI
  be Co compatible.
- CMP of filled cobalt
  in investigation (co



A	B
	
P3 barrier slurry	
incomp.	Co comp.

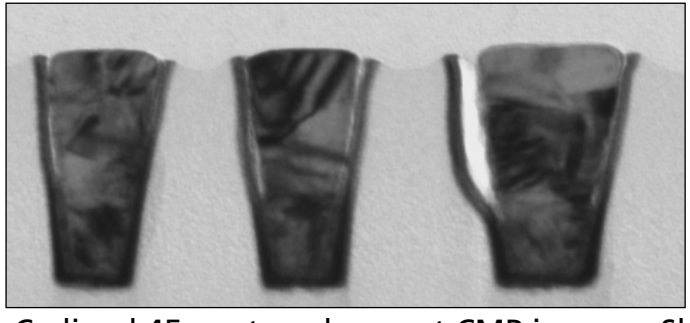
J. Koch et al. ICPT 2015

Cobalt in Copper Metallization

Cobalt-**CMP** consumables

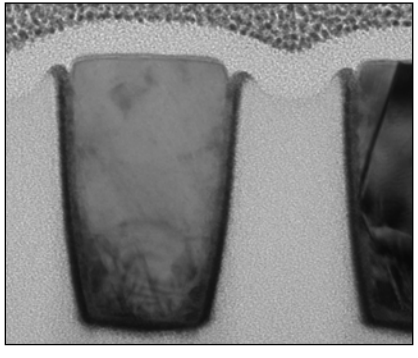
- Co is very sensitive to corrosion and therefore to CMP processes.
- Slurry and post CMP clean have to be Co compatible.
- CMP of filled cobalt lines still in investigation (consumable screening)

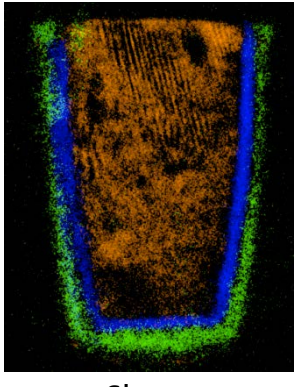
A	B
	
P3 barrier slurry	
Co **in**comp.	Co comp.



Co lined 45 nm trenches post CMP incomp. Slurry

Optimized slurry

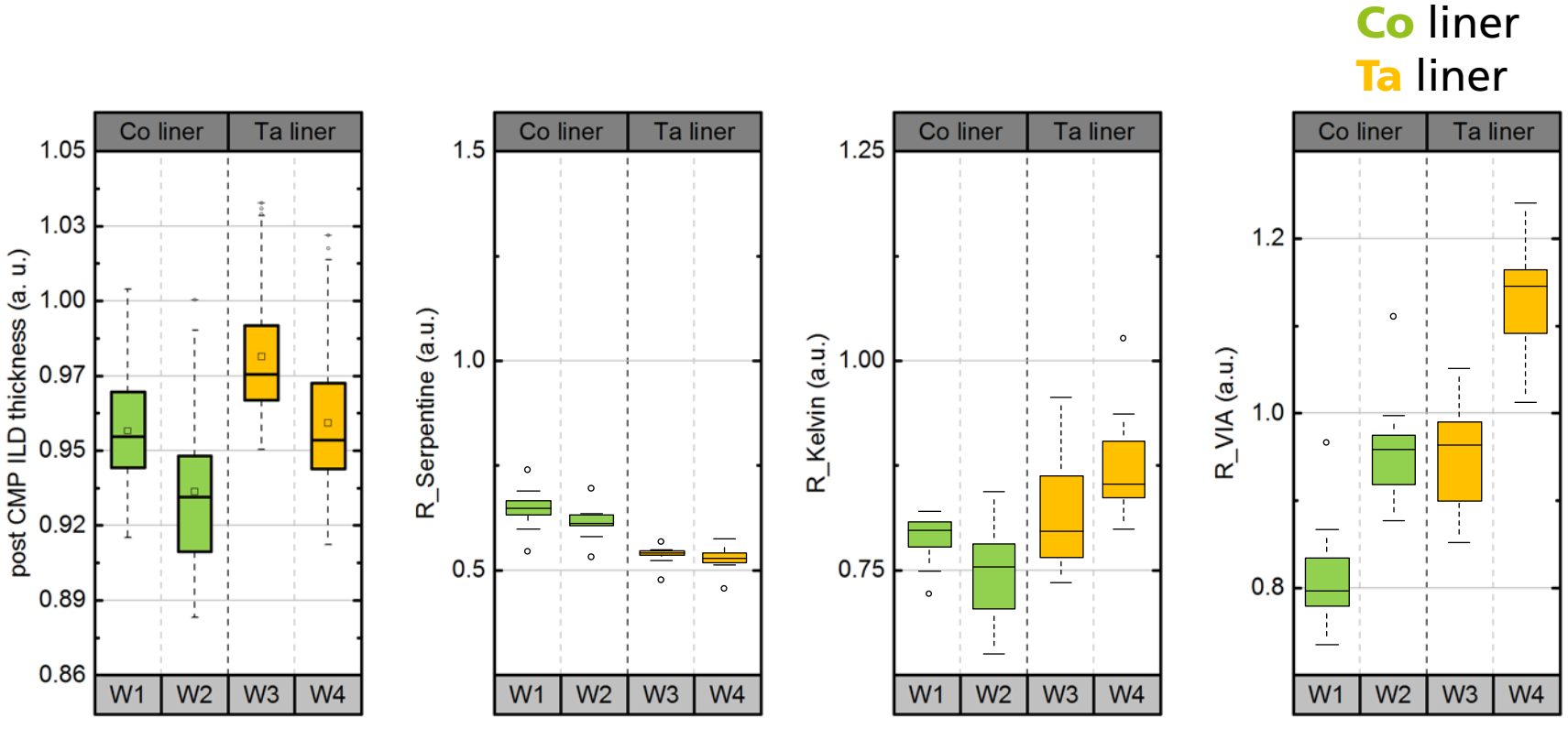




Co lined 45 nm trenches post CMP comp. Slurry

J. Koch et al. ICPT 2015

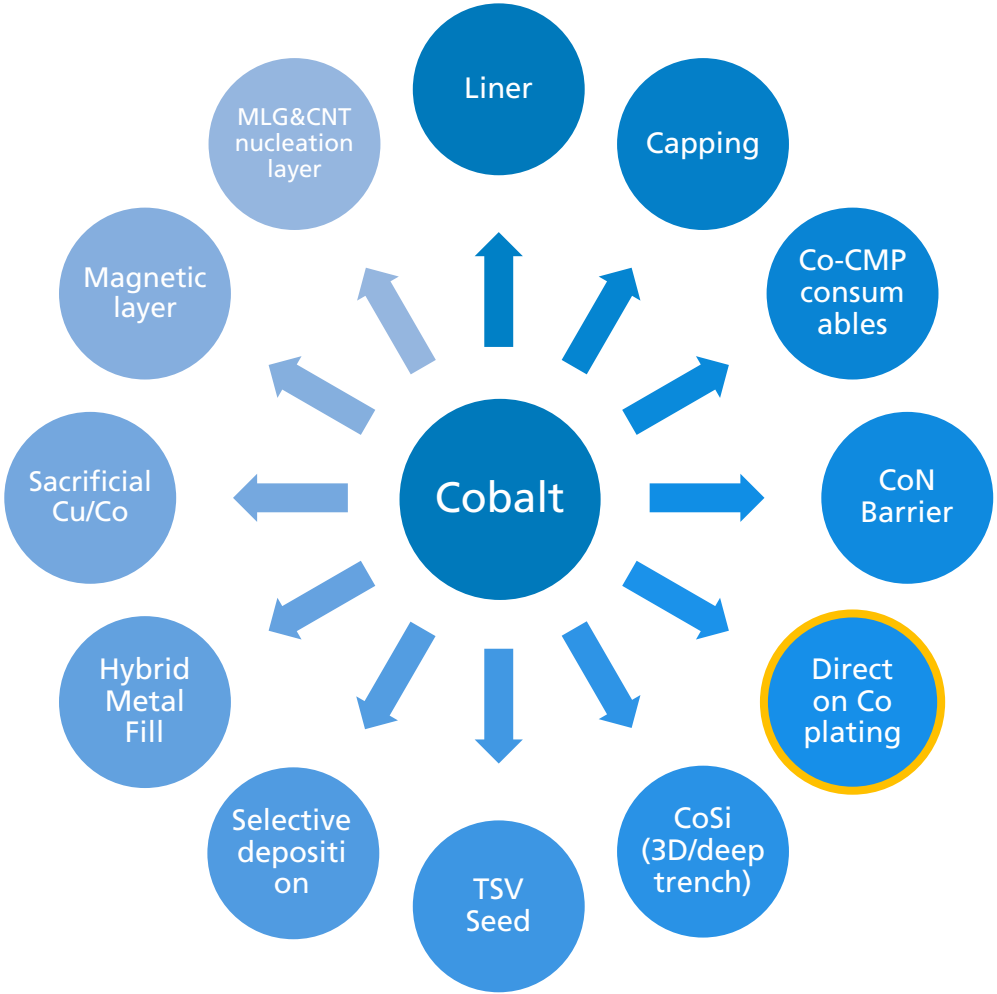
Cobalt-**CMP** - Integration of Co liner for CMP tests



- Enhanced electrical performance up to 30 % of 28-nm-node interconnects using Co as liner material.

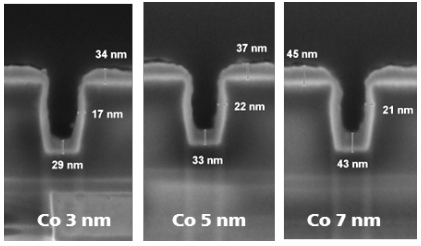
J. Koch et al. ICPT 2015

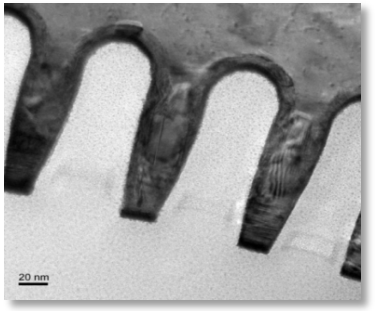
Cobalt wheel



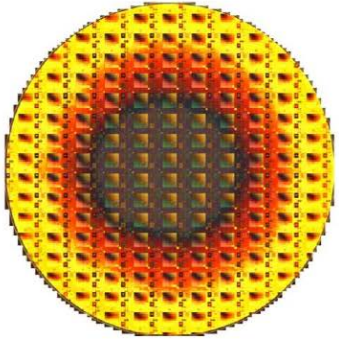
Direct on Cobalt **plating**

- Direct plating of Cu on Co
  - Certain thickness and dep. mode allows direct plating on Co seed
- Electrolyte/seed conductivity ratio affects the fill performance
  - Less feature effects at high bath and low seed conductivity
  - Strong feature effects at low bath and low seed conductivity

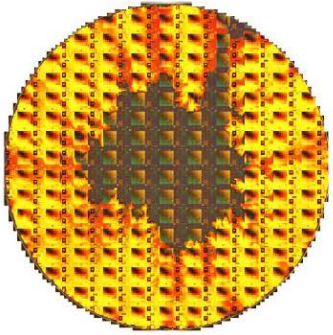




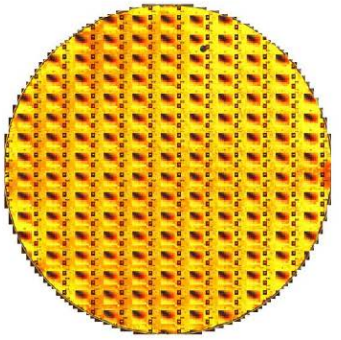
TEM of Cu plt in narrowed structures



Mid acid + conformal Co



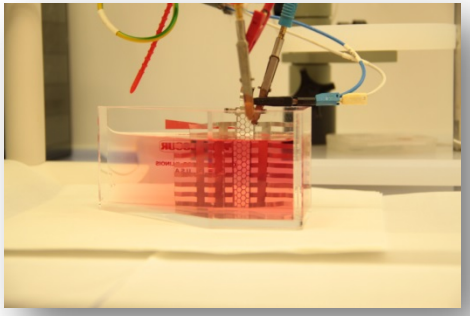
Low acid + conformal Co



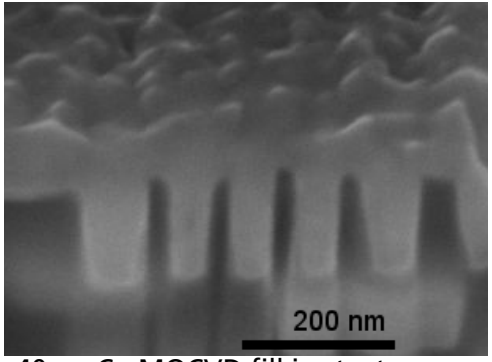
Low acid + optimized Co

Microscope stitched of 80 nm ECD-Cu depostion on MOCVD Co (M. Wislicenus et al. MAM 2018)

Cobalt fill approaches on cobalt seed

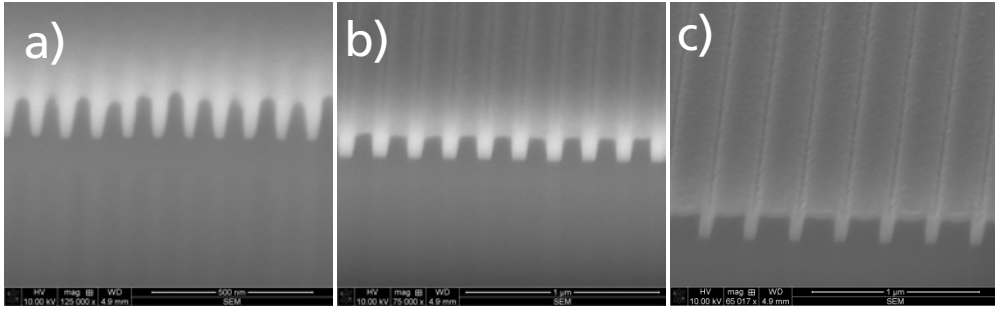


- Co **MOCVD**
  - ☹ Slow
  - ☹ Carbon contamination
  - ☺ Flexible
  - ☺ Reflow option
  - ☺ Prefill option



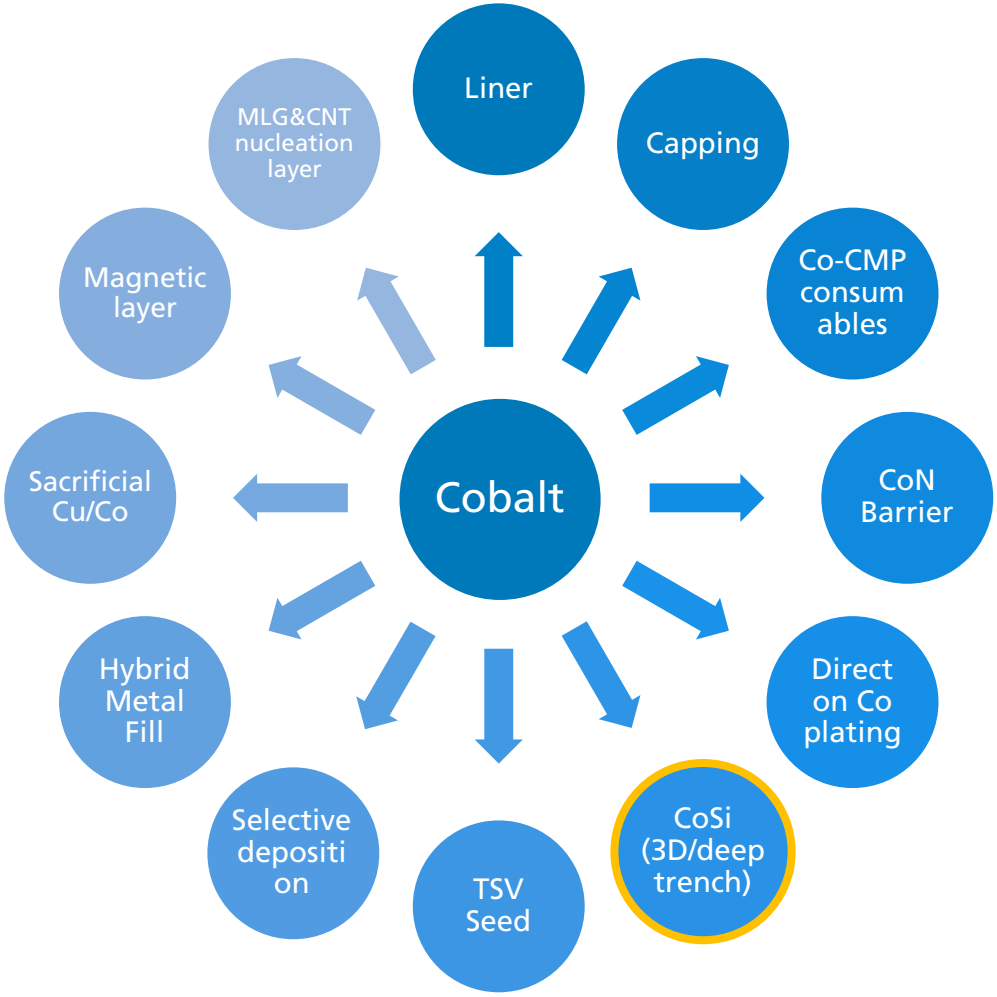
40nm Co MOCVD fill in stuctures

- Co **ECD**
  - ☺ Fast
  - ☺ Seamless fill & reflow
  - ☹ Limited to additive functionality
  - ☹ EHS concerns but possible
  - Scale up to 300 mm tool



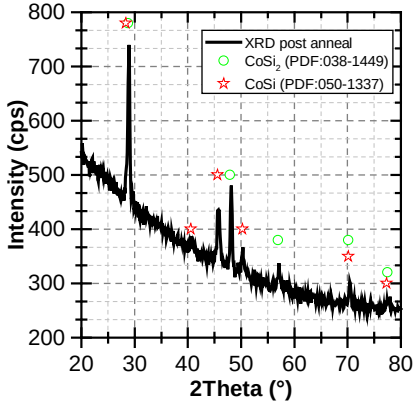
Plating of Co in a),c) 45 nm & b) 90 nm structures

Cobalt wheel

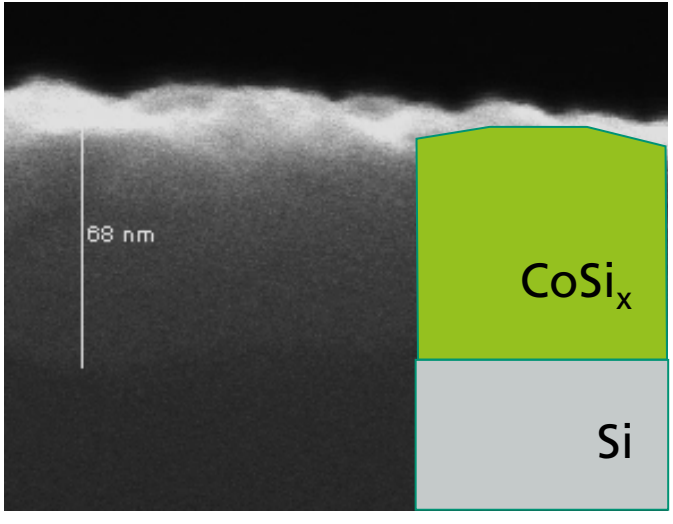


Co- **silicidation**

- Co silicide formation well known as gate silicide via PVD
- Co MOCVD meets future requirements of 3d integration
- Process
  - CCTBA direct on HF-treated Si
  - <10 torr (low pressure)
  - 150°C deposition
  - CoSi formation by RTP annealing in N_2
- Possible carbon contamination could be an issue but basic feasibility is shown



XRD of Co-MOCVD layers on Si show after anneal processes the formation of CoSix.

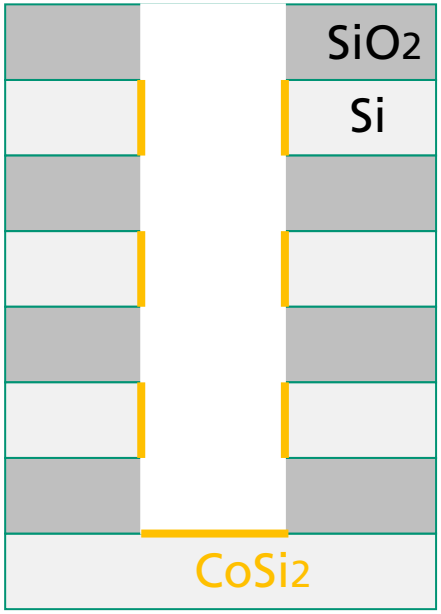


X-SEM of 20 nm Co after anneal for silicidation

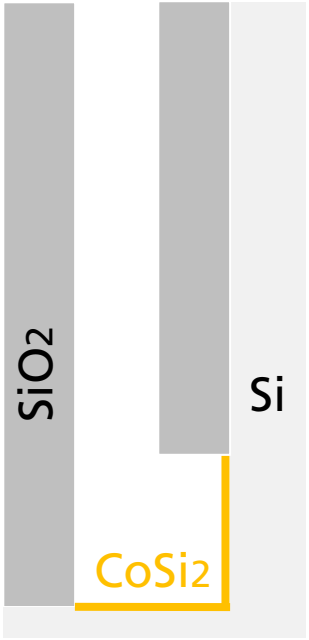
L. Gerlich et al., NanoFIS 2016

Co- **silicidation**

- Cobalt silicide formation well known as gate silicide via PVD
- Co MOCVD meets future requirements **of 3d integration**

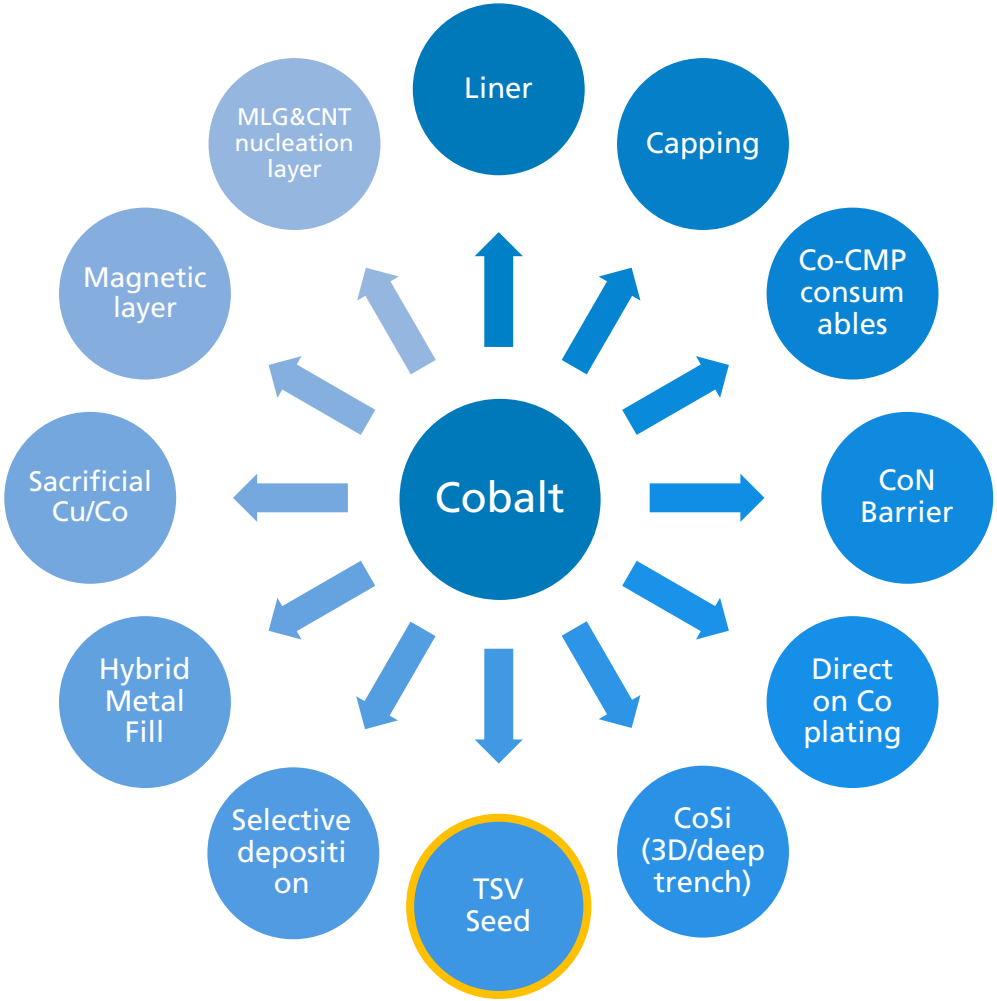


Alternating contact stack with MOCVD Co deposition and silicidation



MOCVD Co deposition in cavity and silicidation

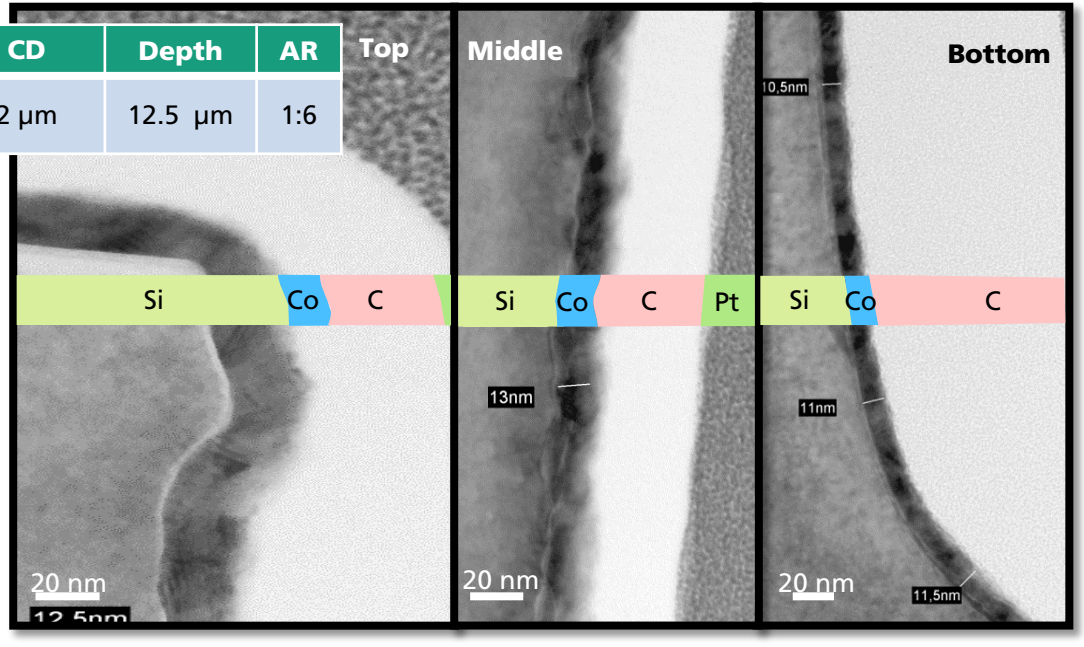
Cobalt wheel

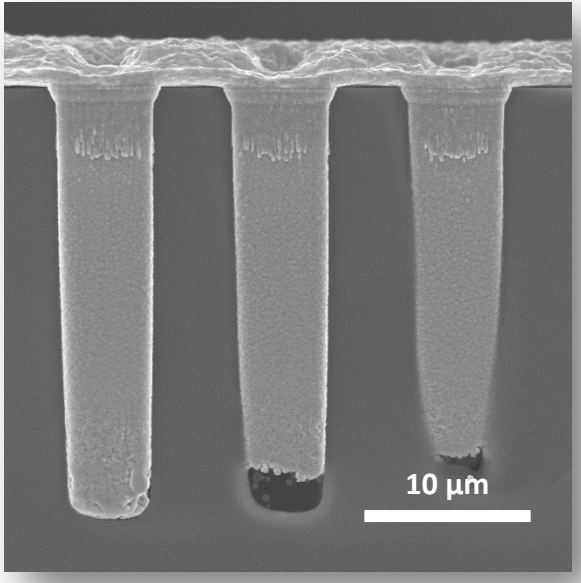


Co Thin Films as an Alternative Seed Layer for **TSV** Metallization

- Co liner for high aspect ratio TSVs
- Direct plating with Cu

CD	Depth	AR
2 µm	12.5 µm	1:6

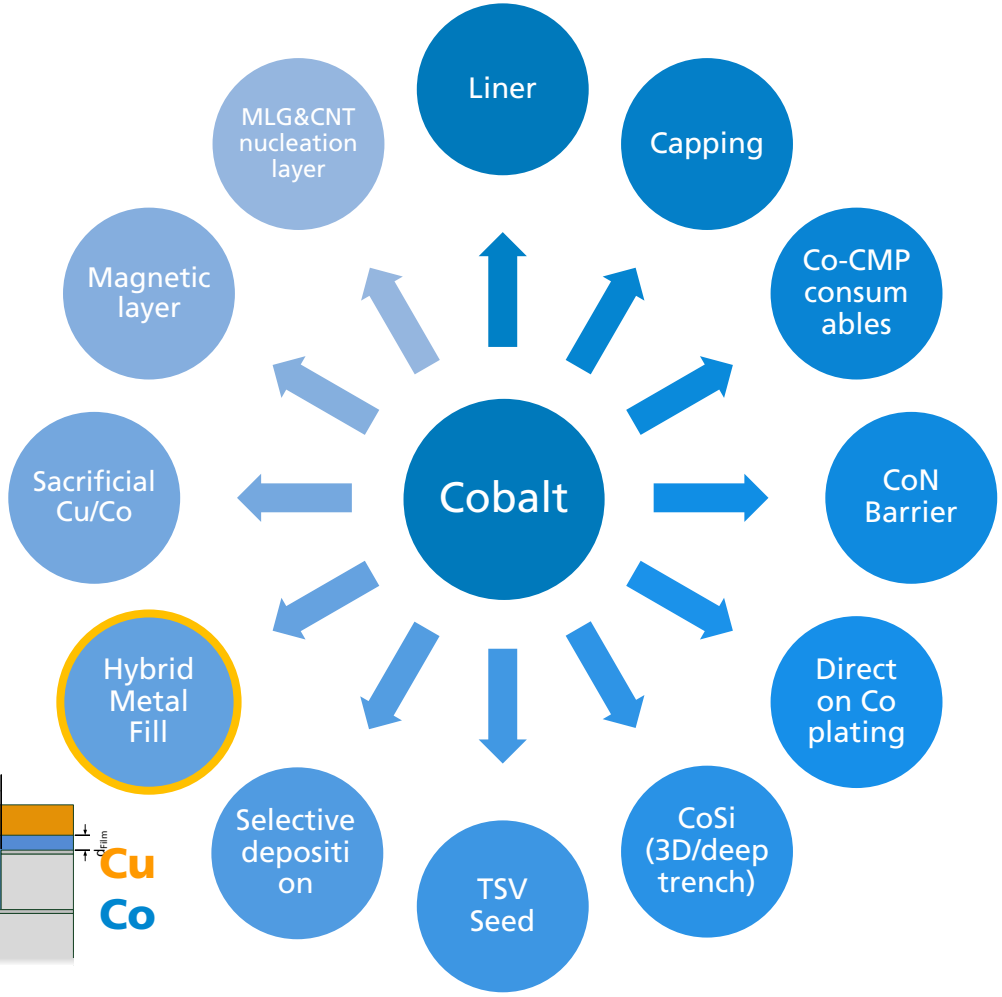




- Cu deposition without additives
- Conformal deposition possible

S. Esmaeili et al., MAM 2018

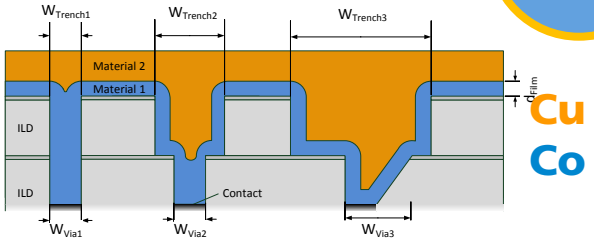
Cobalt wheel



Patent:

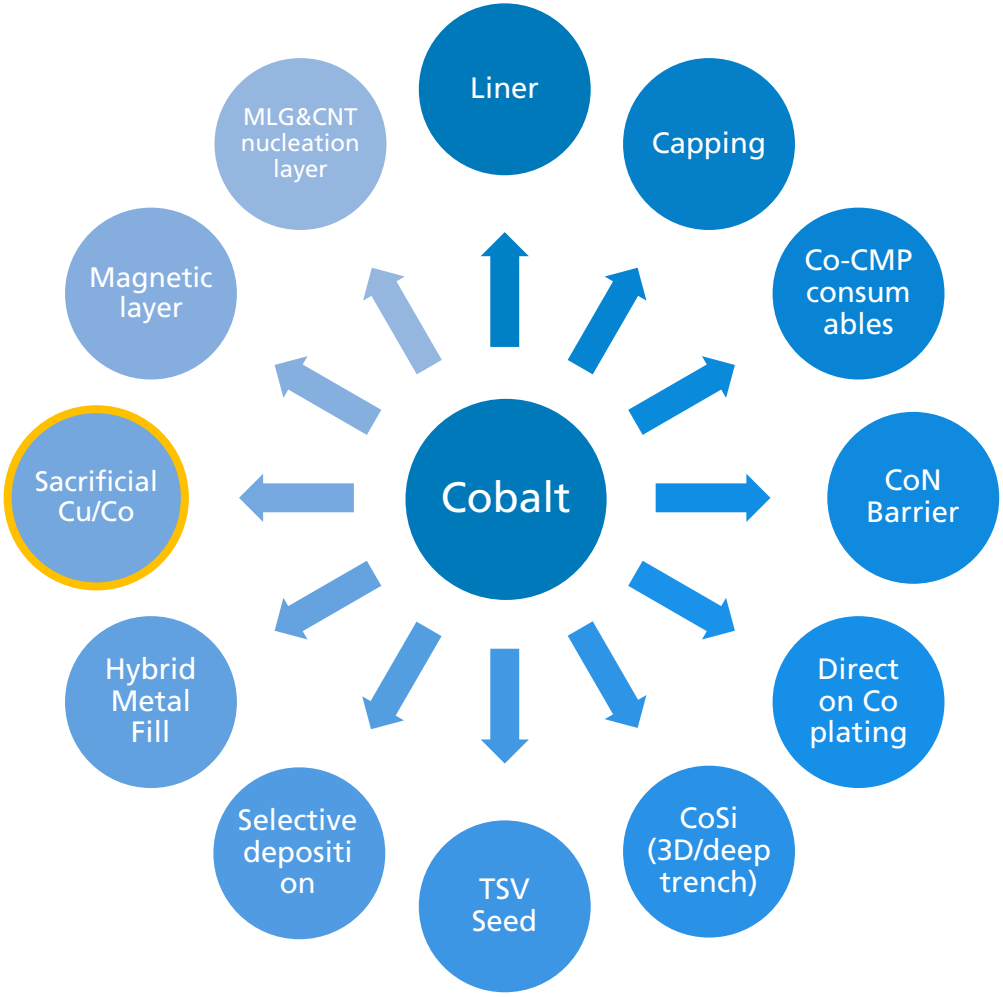
M. Wislicenus et.al

DE102016206769A



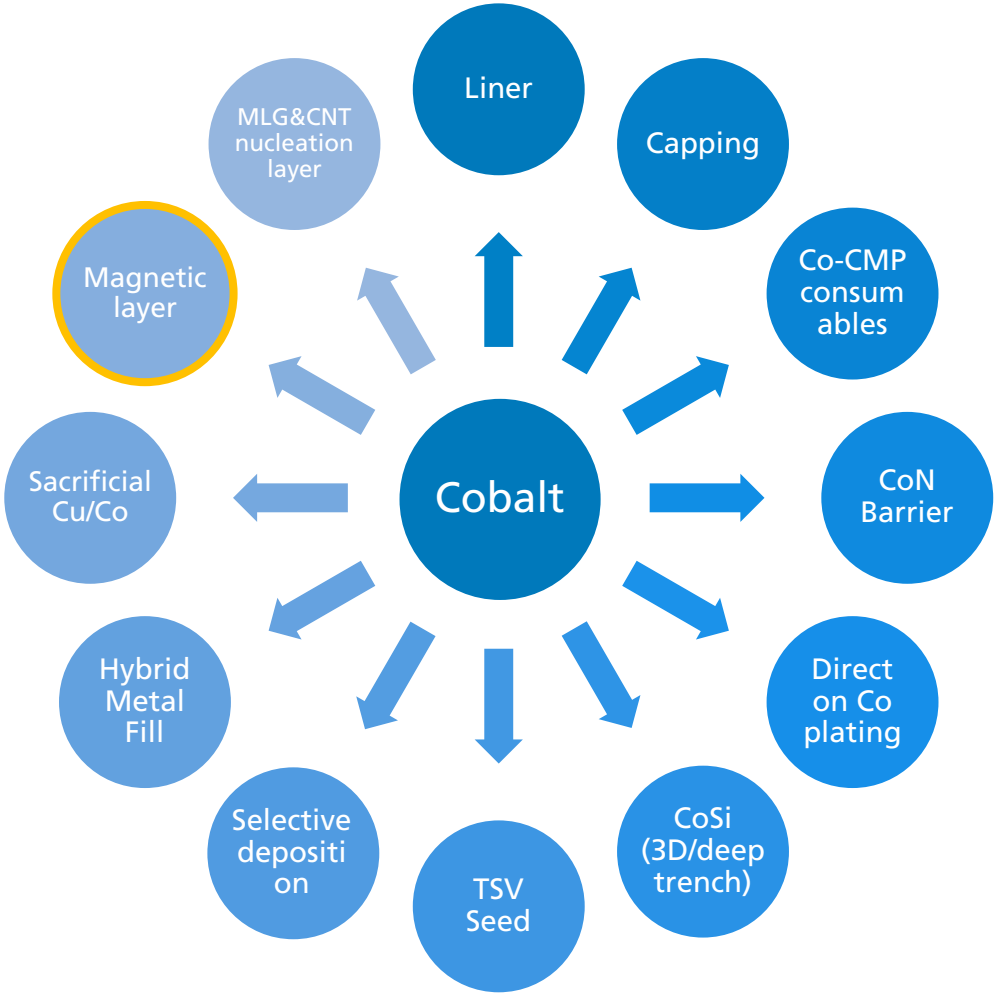
Cobalt wheel

Patent Nr. 9620453
with Globalfoundries

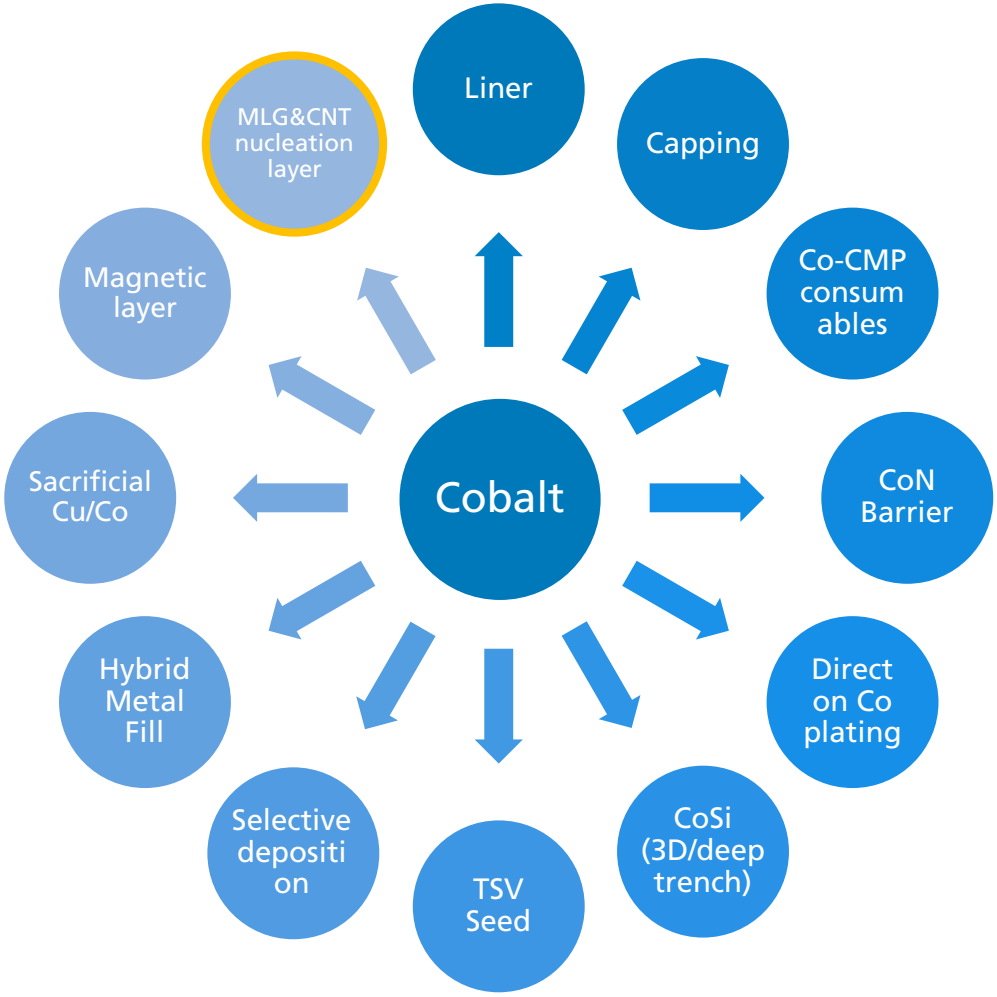


Cobalt wheel

- Multi target cluster PVD tool for NVM in purchase
- ECD formed pillars in investigation

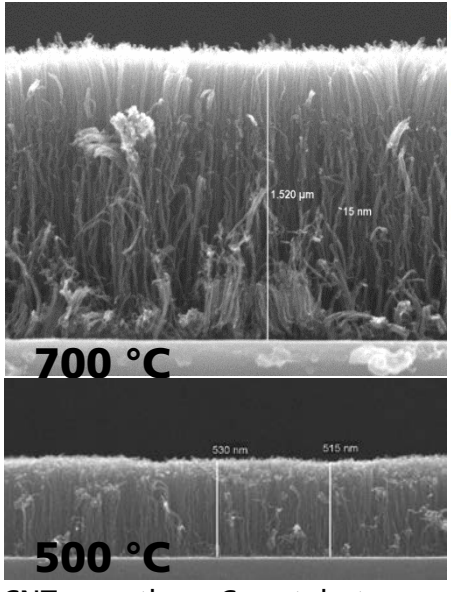


Cobalt wheel



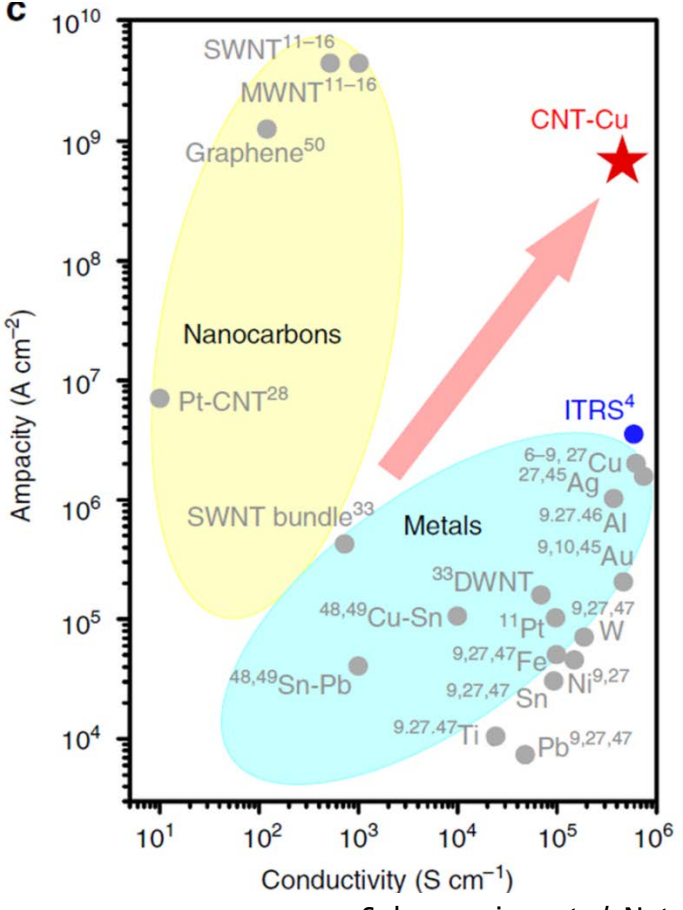
Cobalt as CMOS compatible catalyst for **CNT** growth

- CNT-Cu composites with good conductivity (performance) and high ampacity (reliability) are desired
- Challenge:
  - CMOS compatibility
  - Manufacturability
- Cooperation in EU Project with Aixtron for **300 mm** wafer processing



CNT growth on Co catalyst for different temperatures

B. Uhlig et al., Date 2018



Subramaniam *et al*, Nat. Commun. 4, 1 (2013)

Conclusion

Cobalt Deposition **MOCVD** tool

- AMAT Endura II 300 mm + Volta chamber with dual bubbler system
- Bubbler are ready to install → safe procedure
- EHS issues are solvable
- Flexible for different applications

AMAT Endura II system at Fraunhofer CNT

Cobalt Deposition **ECD** tool

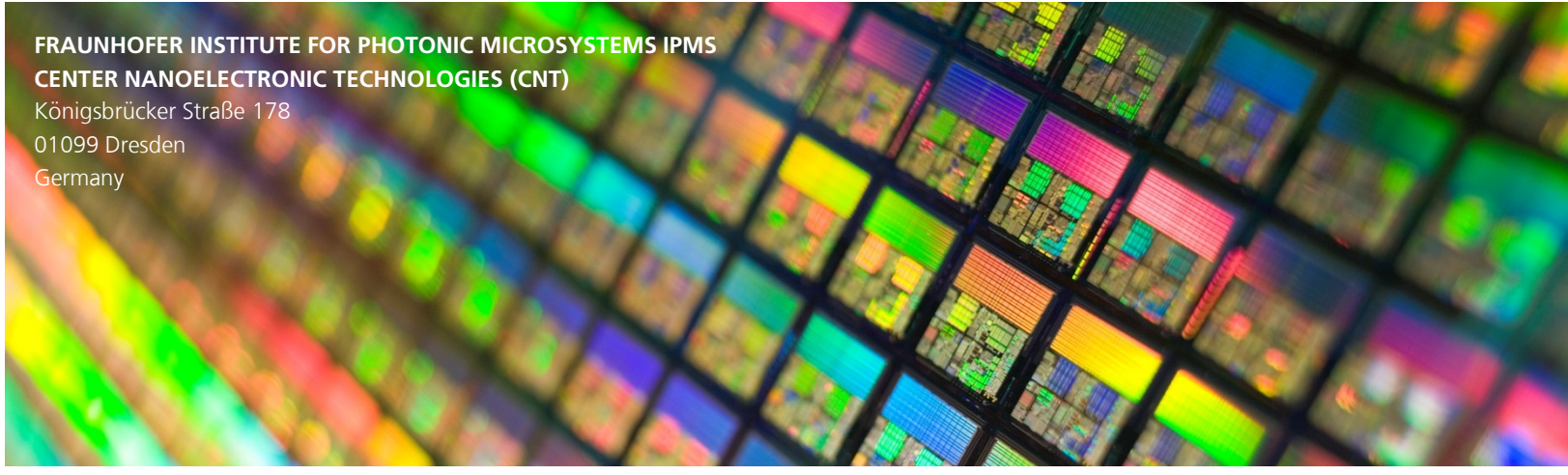
- Semitool Raider ECD 300 mm + DoB chamber
- Electrolytes with EHS sensitive issues
  - Strict procedure for usage; clean tool policy
  - Transfer & storage has to be monitored
- EHS issue can be managed

Semitool Raider system at Fraunhofer CNT

Conclusion

- **Cobalt** as promising material will be used in semiconductor fabs in future and has proven to be usable
  - in a industrial compatible process flow
  - as a competitive material
- Further advantages of a **MOCVD**-process (sidewall coverage, cavity reach) may be utilized for example
  - for 3d integration
- Cobalt **ECD** as very promising technique for contact level and local interconnects filling and magnetic applications are under invetigation

Thank you for your attention!



www.ipms.fraunhofer.de | www.cnt.fraunhofer.de | www.screening-fab.com

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