

# CHEMICALS FOR VAPOR AND ATOMIC LAYER DEPOSITION

*NNCI ALD/MOCVD Symposium*  
Harvard University October 4<sup>th</sup>, 2019

# COMPANY HISTORY & BACKGROUND

- ▶ 1964 company founded, manufacturing in Danvers, MA
- ▶ 1978 moved corporate HQ to Newburyport, MA
- ▶ 1986 established European HQ in Strasbourg, France
- ▶ 2014 Strem celebrated its 50th year anniversary
- ▶ Global network of distributors
  - ▶ Europe, Asia, Middle East
- ▶ 5,000 Specialty Chemicals for Research & Production
- ▶ Custom Synthesis and cGMP Manufacturing
- ▶ World-wide customer base



***Company Strategy:*** Provide specialty chemicals of high quality, in a timely fashion

# HUMAN RESOURCES

- ▶ Small company with ~78 employees
- ▶ many employees at company over 10 years, low turnover
- ▶ 14 employees are Ph.D.'s
- ▶ Approximately 1/4 each in manufacturing, customer service, warehouse, administrative/facility
- ▶ In 2006 Strem implemented an **ESOP** (**E**mployee **S**tock **O**wnership **P**rogram), making all employees partial owners of Strem



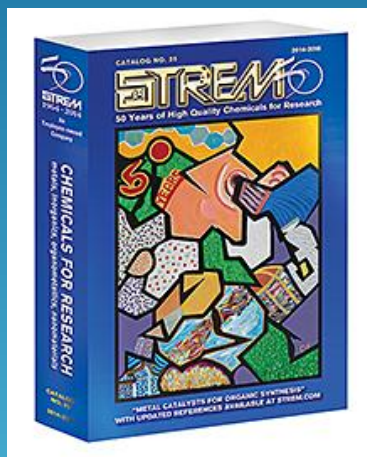
# ENVIRONMENTAL, HEALTH, SAFETY + SECURITY (EHS+S)

- ▶ Strem is a member of SOCMA (Society of Chemical Manufacturer's and Affiliates)
- ▶ Safety is of primary importance
- ▶ Strem subscribes to SOCMA's EHS+S program
- ▶ Regular training of staff, internal and external audits
- ▶ First Responders trained from lab and warehouse
- ▶ 2012-2019 Gold, Silver and Bronze Performance Improvement Awards from SOCMA for outstanding commitment to continuous improvement in EHS&S practices.
- ▶ ISO 9001:2015 certified

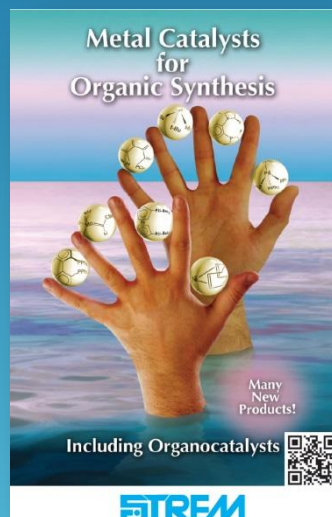


# PRODUCT & MARKETS SERVED

## Key Product Lines (product booklets available)



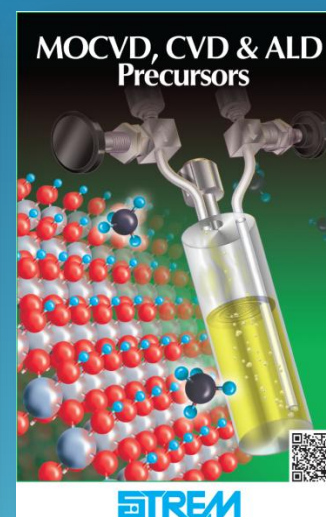
### Metal Catalysts



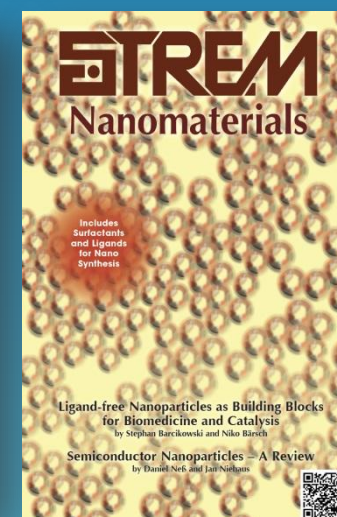
### Ligands



### MOCVD/CVD /ALD precursors



### Nanomaterials



### Markets Served

Pharmaceutical  
Chemical/Petrochemical

Micro  
Electronics

Various  
markets

Academic / Government Research Centers

# HOW STREM BUILDS IN HIGH QUALITY:

High Quality is built into the product at each step



**Metal sources 99.99 – 99.9999%**

**Organics 95 – 99%**

**Raw Materials**

**Reaction  
Vessel**

**material of composition,  
cleaning, dedicated equipment**

**Environment**

**external- clean room  
internal- dry, filtered gas**

**Distillation, sublimation,  
recrystallization**

**Product Isolation  
Purification**

**Packaging  
Handling**

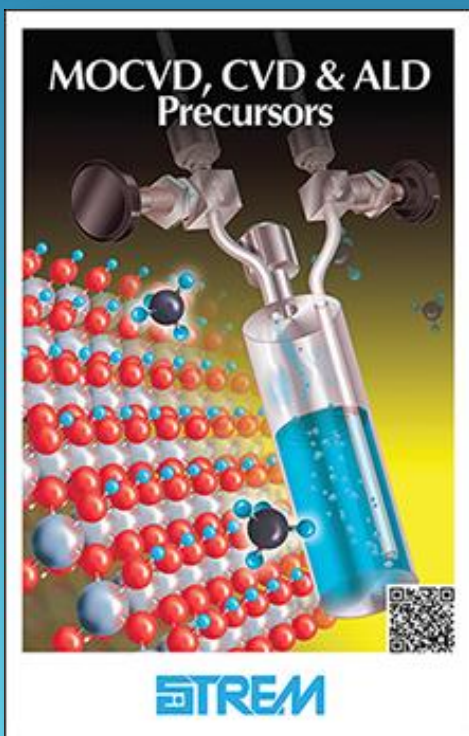
**QC  
Analytical**

**Picking  
Shipping**

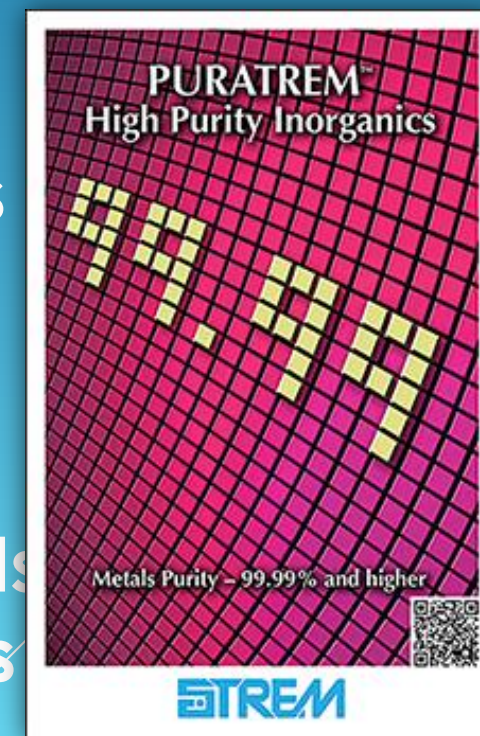


# MORE THAN 450 METAL PRECURSORS FOR CVD, ALD

Strem has a broad range of CVD/ALD precursors



- Metal alkyls
- Metal alkylamides and alkylimides
- **Metal Amidinates**
- Volatile metal carbonyls
- Metal alkoxides
- Metal betadiketonates (and ligands)
- Volatile organometallics, MetalCps
- Metal Halides



# VOLATILE PRECURSORS FOR CVD, ALD ON STREM WEBSITE

The screenshot shows the Strem Chemicals website homepage. At the top, the Strem Chemicals, Inc. logo is displayed with the tagline "an employee-owned company". Navigation links include HOME, CATALOG, NEW PRODUCTS, CUSTOM SYNTHESIS & CGMP, PRODUCT RESOURCES, and ABOUT. A search bar is present with the text "We manufacture high purity chemicals and deliver them globally." Below this, a "Search" button is visible. A featured image shows various chemical bottles. A "Contact Strem Chemicals" link is on the right. A "REQUEST THE CATALOG!" button is also present. At the bottom, there are links for "Bulk Quote Request" and "Get Quarterly Updates by Email!".

Log In | Register

quick order form your favorites

Your cart is empty.

Contact Strem Chemicals

HOME CATALOG NEW PRODUCTS CUSTOM SYNTHESIS & CGMP PRODUCT RESOURCES ABOUT

We manufacture high purity chemicals and deliver them globally.

Product Name or Number

Search

STREM NEWS Strem Chemicals Releases New Catalog of Chemicals for Research

REQUEST THE CATALOG!

About Strem Chemicals

Established in 1964, we are a privately held company that manufactures and markets specialty chemicals of high purity. Our clients include academic, industrial and government research labs.

Learn More

Bulk Quote Request Request information on our Bulk Ordering and Pricing

Get Quarterly Updates by Email! Quick and Easy Signup for all Strem Chemicals News and Updates!

50-1150 Sn ALD Precursor

15-1661 (R)-Xyl-Garphos™

15-1157 JackiePhos

The screenshot shows a detailed view of the "Contact Strem Chemicals" page. It features a list of product categories with expandable arrows. A blue arrow points to the "Volatile Precursors for MOCVD, ALD" category. At the bottom, there is a "REQUEST THE CATALOG!" button with a "NEW!" tag.

Log In | Register

quick order form your favorites

Your cart is empty.

Contact Strem Chemicals

Metal Carbonyls

Catalysts and Chiral Catalysts

Ligands and Chiral Ligands

Volatile Precursors for MOCVD, ALD

Nanomaterials

Metal Scavengers

Ionic Liquids

PURATREM (99.99%)

Bubblers and Other Equipment

Acronyms

Kits

Product Families

Complete Product List

REQUEST THE CATALOG! NEW!



# New products for ALD/CVD (2018-2019)

03-8000

79-1700

22-1155

DIPAS, 14-1560

40-1028

64-6000

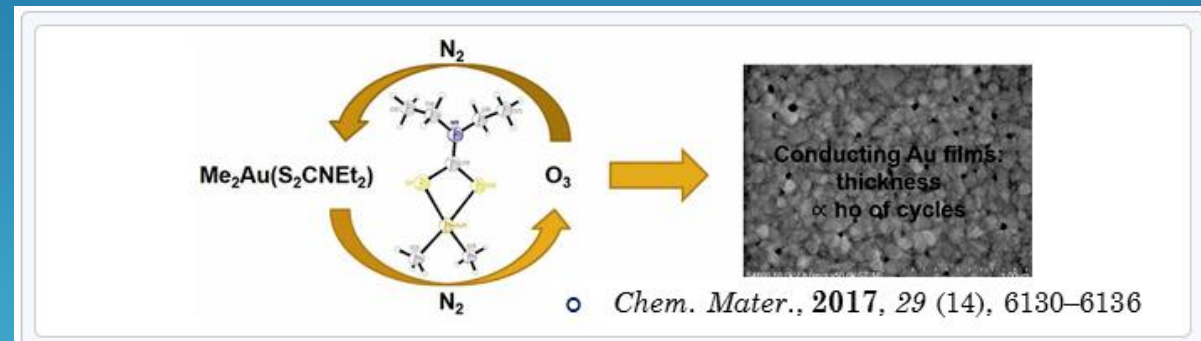
12-0865

57-1500

78-1375

# Gold ALD/CVD Precursor

- Volatile, air, light and thermally stable precursor
- 79-1700, (N,N-Diethyldithiocarbamato)dimethylgold(III), 97% (99.999%-Au) PURATREM



## Thermal Atomic Layer Deposition of Continuous and Highly Conducting Gold Thin Films

University of Helsinki

- 1. *Chem. Mater.*, 2017, 29 (14), 6130–6136
- 2. *Journal of Crystal Growth* 2015, 414, 143-150
- 3. *Physics Procedia* 2013, 46, 167-173
- 4. *Gold Bulletin (Berlin, Germany)* 2011, 44(3), 177-184

## **NEW PRODUCTS IN DEVELOPMENT; STREM # 44-5150 AND 78-0550.**

**Focused electron beam-induced deposition precursor for  
Ru and Pt;**

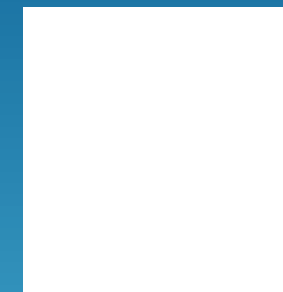
**Allylruthenium(II) tricarbonyl bromide**

**Lisa McElwee-White, University of Florida**

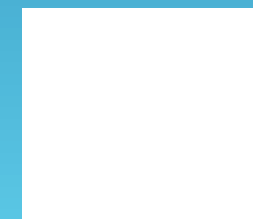
**Volatile material, sublimes at room temperature at 100 mTorr.**

**Cis-Dichlorodicarbonylplatinum(II).**

**Used for focused electron beam induced deposition of Pt**



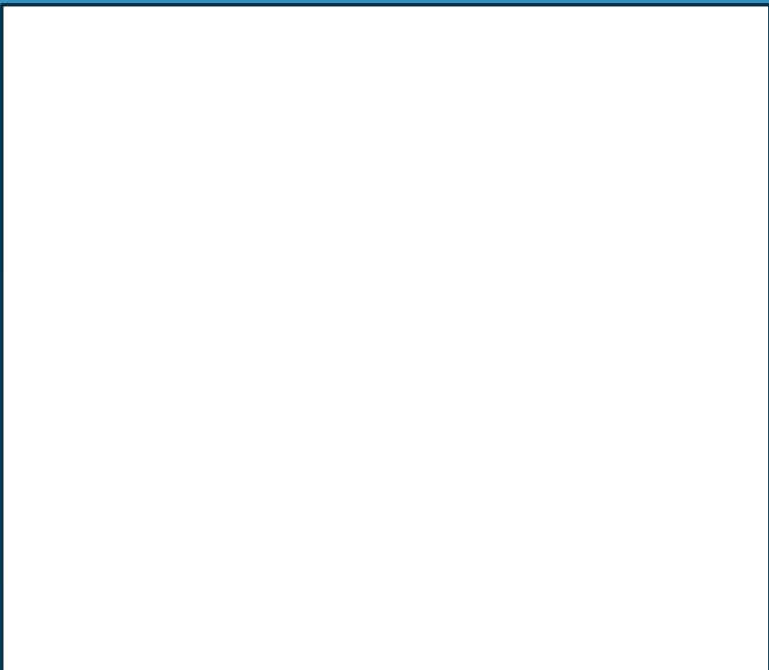
**44-5150**



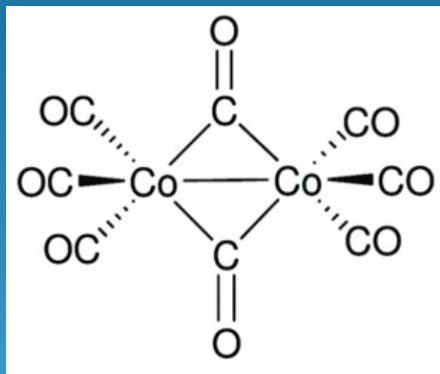
**78-0550**

# HIGH PRESSURE CAPABILITIES AT STREM CHEMICALS – METAL CARBONYLS

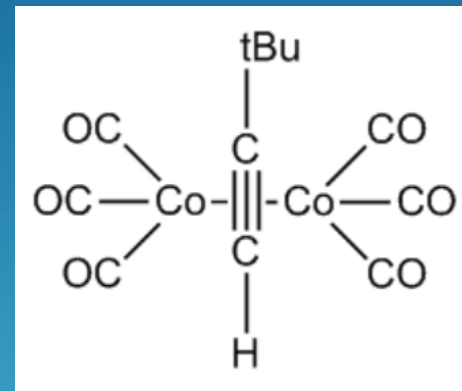
In 1964, Strem Chemicals, Inc. began manufacturing metal carbonyls and metal carbonyl derivatives utilizing two, stainless steel, high pressure reactors



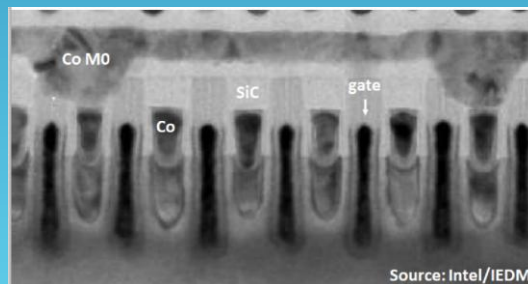
# CCTBA IS USED FOR COBALT DEPOSITION COBALT CARBONYL IS THE PRECURSOR



**Dicobalt Octacarbonyl**  
**Strem 27-0400**



**CCTBA**  
**Strem 27-0770**

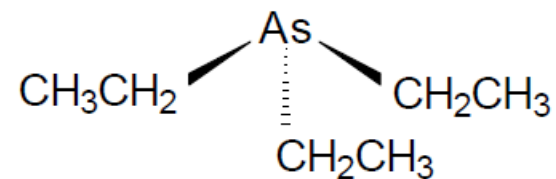


<http://semimd.com/chipworks/2017/12/18/iedm-2017-intels-10nm-platform-process/>





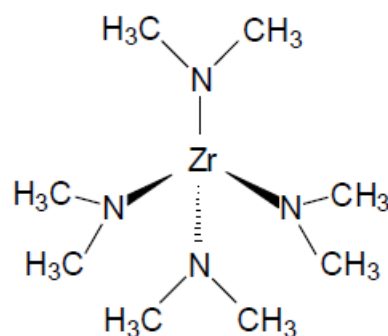
# Metal Alkyls



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

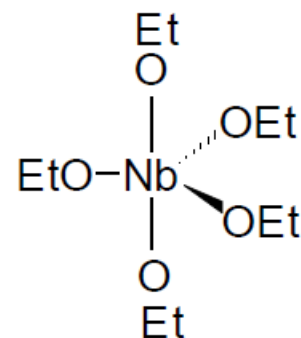
# Alkyl Amides



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

# Metal Alkoxides



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

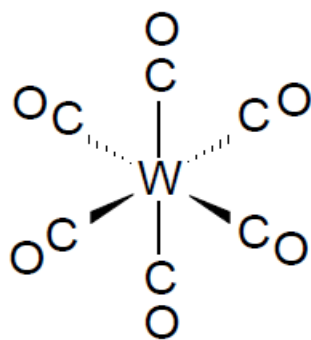
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

# Metal Halides

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

# Volatile Metal Carbonyls

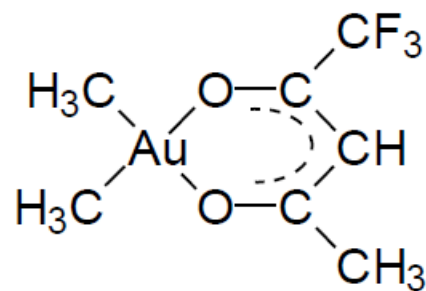


H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											



# Metal Beta-Diketonates



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn

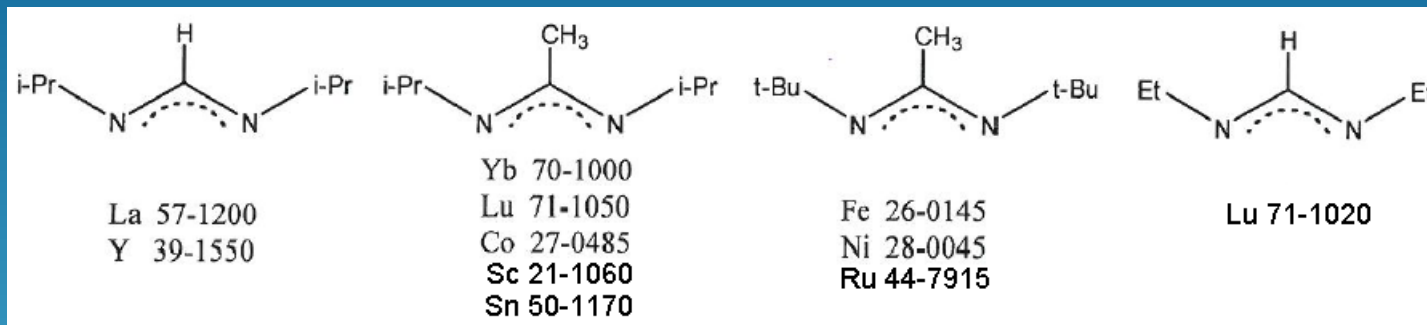
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U											

# Volatile Organometallics



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	As	Rn
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U													

# Metal Amidinates

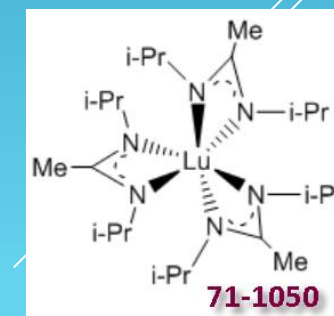
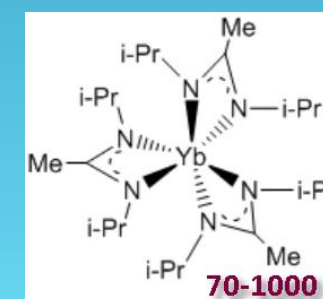
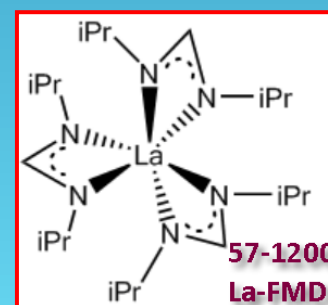
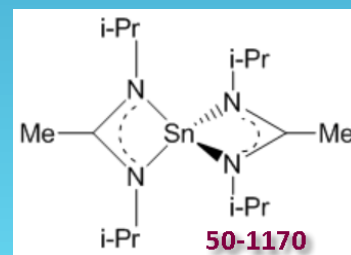
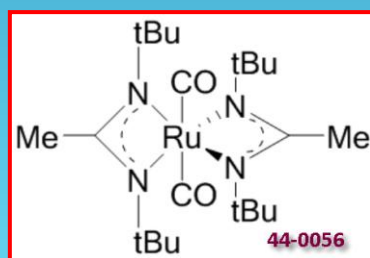
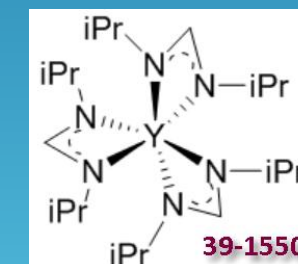
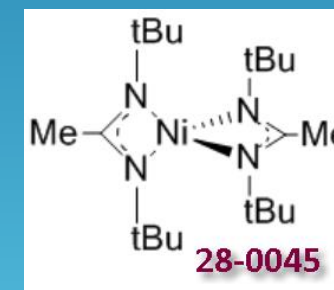
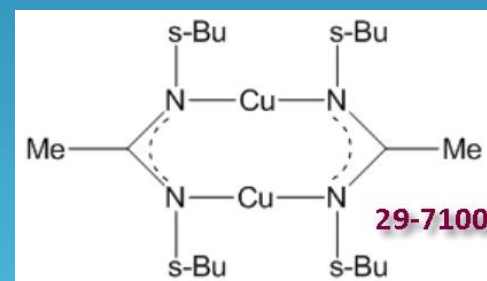
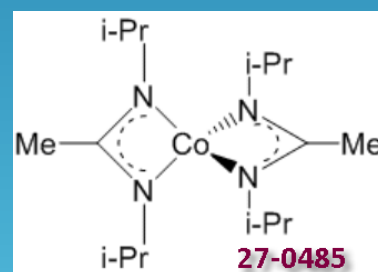
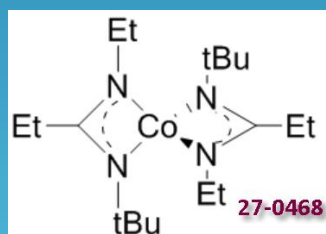
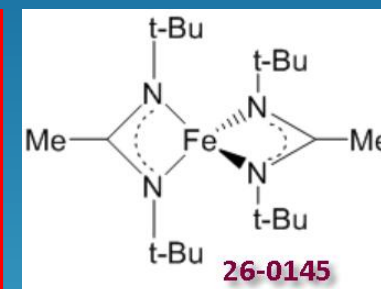
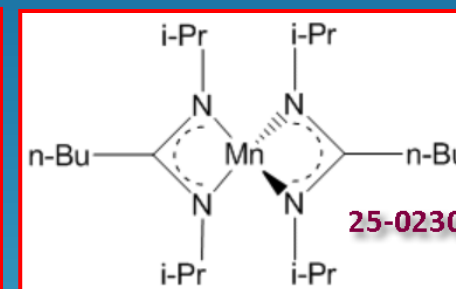
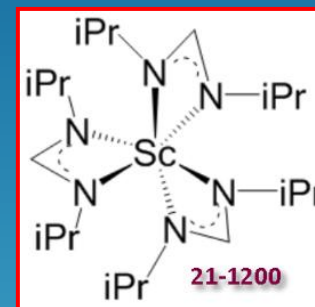
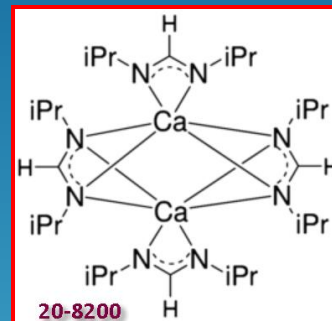
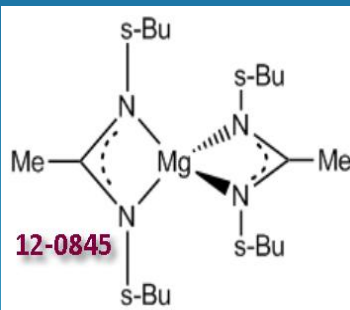


H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	Lr	No		

# PATENTED METAL AMIDINATES

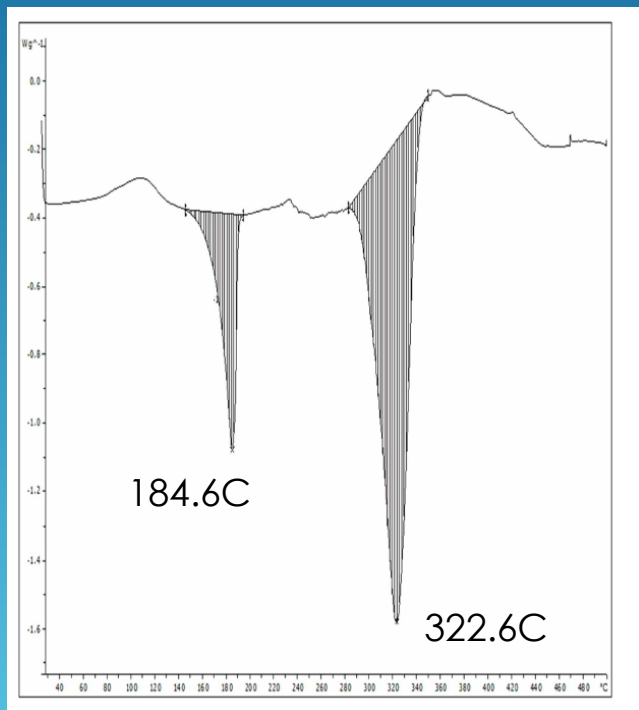
Newest  
Products

03-8000

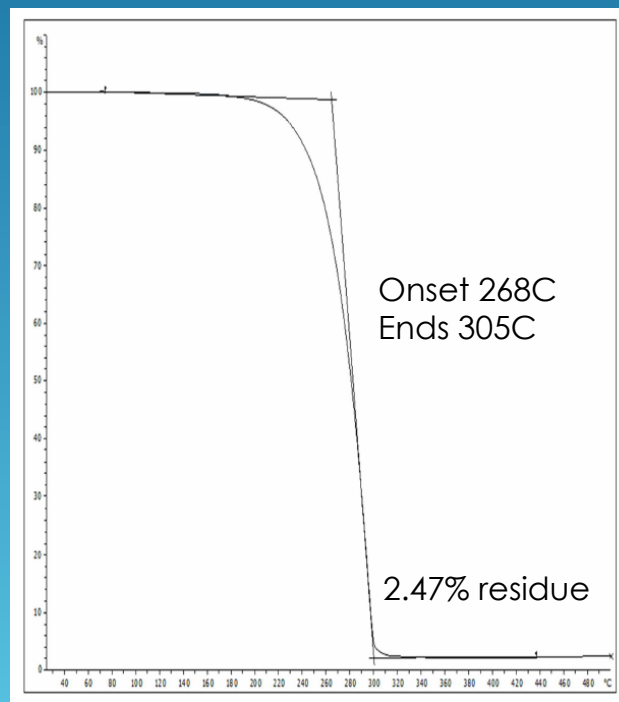


# STREM # 03-8000

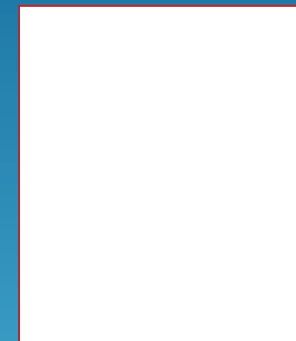
(N,N-Di-i-propylacetamidinato)lithium, min. 97% (99.99+%-Li) PURATREM



DSC



TGA





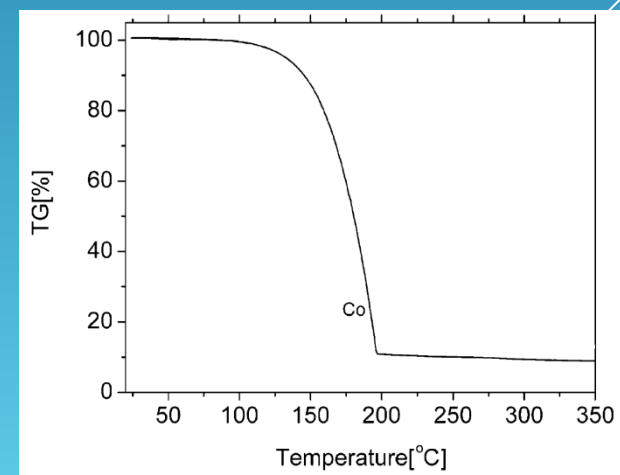
## STREM# 27-0485

Bis(N,N'-di-i-propylacetamidinato)cobalt(II), min. 98% Co(iPr-MeAMD)2

## STREM# 27-0486

Bis(N,N'-di-i-propylacetamidinato)cobalt(II), min. 98% (99.99%-Co) PURATREM (Co(iPr-MeAMD)2)

- ▶ **ALD** precursor
- ▶ Deposition of cobalt thin films on ALD WN as a glue layer for copper interconnects in micro- and nanoelectronics
- ▶ **High thermal stability** at deposition temperature (350°C)
- ▶ **Low TGA residual mass: 9%**
- ▶ Highly air and moisture sensitive



*Inorg. Chem.*, 2003, 24, 7951-7958.

# STREM# 27-0485

## RECRYSTALIZATION



## SUBLIMATION



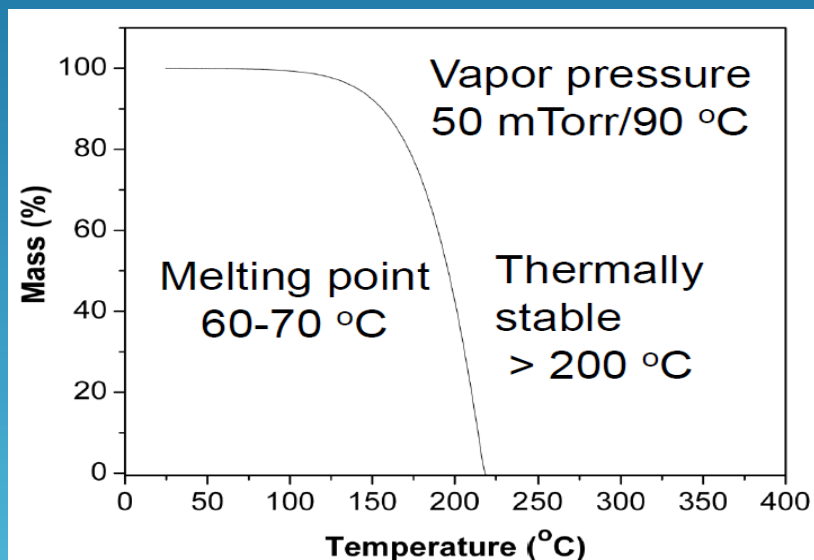
Product Detail	Technical Note	Safety Data Sheet
CAS Number:	635680-58-9	
MDL Number:	MFCD08459350	
Molecular Formula:	$C_{16}H_{34}CoN_4$	
Formula Weight:	341.40	
Chemical Formula:	$(C_8H_{17}N_2)_2Co$	
Color and Form:	green xtl.	
Note:	Product sold under, use subject to, terms and conditions of label license at <a href="http://www.strem.com/harvard2">www.strem.com/harvard2</a> .	
Stability:	air sensitive, moisture sensitive	
Physical Characteristics:	melting point 84°C, boiling point sublimes 50°C (50 mTorr)	



# 25-0230

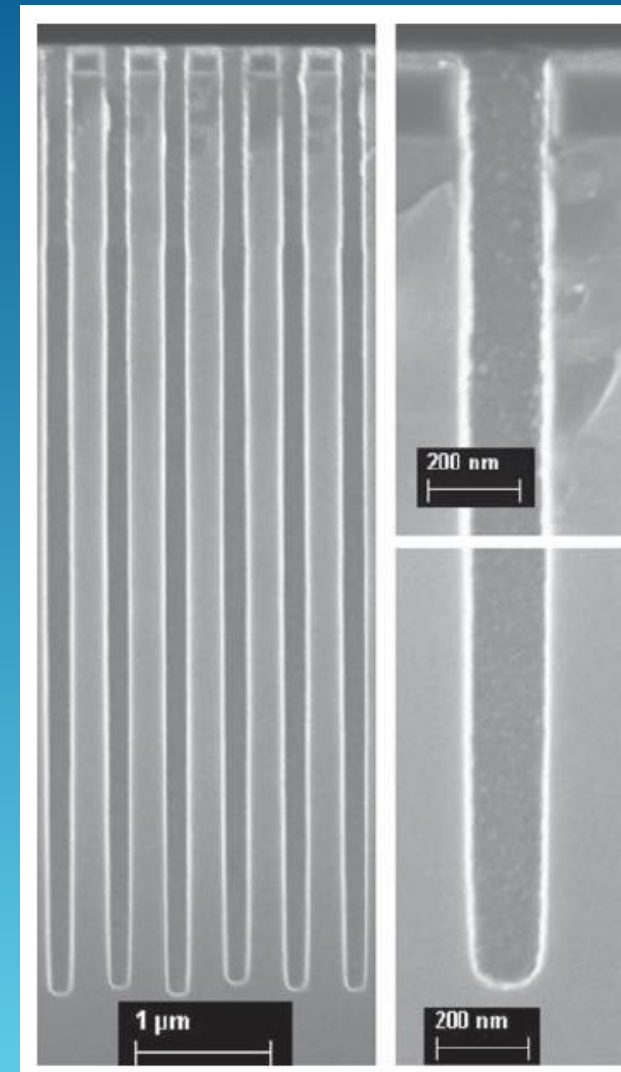
## Bis(*N,N'*-diisopropylpentylamidinato)manganese(II)

### ► High thermal stability



*Roy Gordon's Powerpoint*

### ► Superior step coverage of $Mn_4N$ films in holes with aspect ratios 52:1.

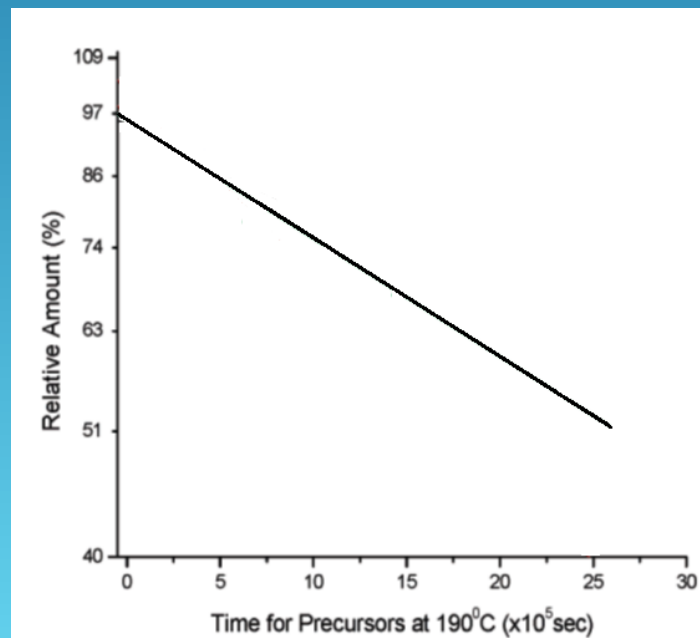
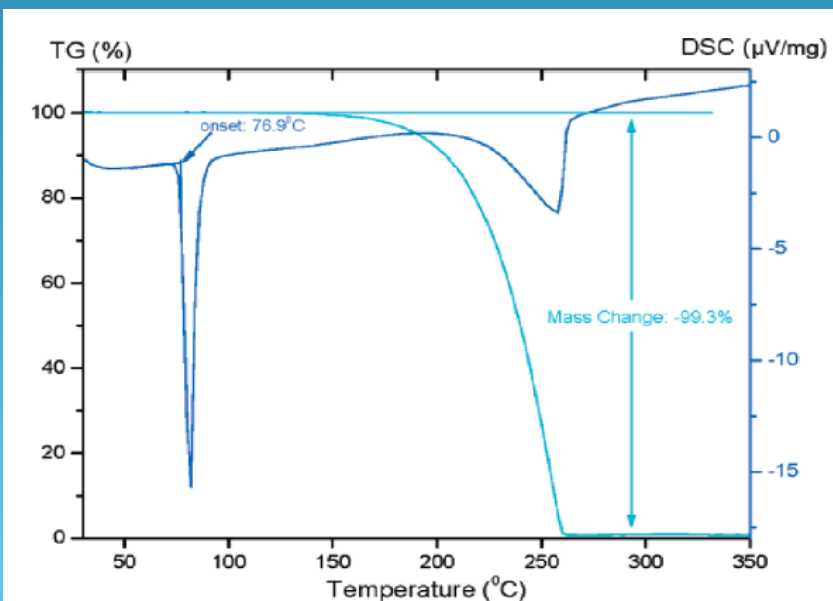


*J. Electrochem. Soc.*, 2011, 158, D248-D253.

# STREM# 29-7100

Bis(N,N'-di-sec-butylacetamidinato)dicopper(I), 99%

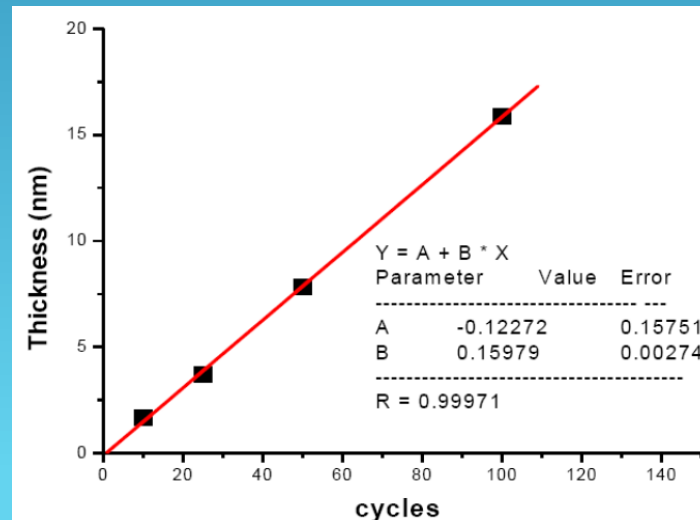
- ▶ **Extremely low TGA residual mass:** 0.7% (Negligible decomposition happened during melting and evaporation)
- ▶ **High thermal stability:**  
Very stable even at 190°C (Typical substrate temperature for ALD of copper using these precursors.)



# STREM# 57-1200

TRIS(N,N'-DI-I-PROPYLFORMAMIDINATO) LANTHANUM(III), (99.999+%-LA) PURATREM LA-FMD

- ▶ **Volatile ALD lanthanum compound. (60 mTorr at 100°C)**
- ▶ **High reactivity to H<sub>2</sub>O, O<sub>2</sub> and NH<sub>3</sub>**
- ▶ **Line starts at origin => No delay in Nucleation**



*Roy Gordon's Group*



# STREM# 57-1200

## Product Catalog

**57-1200 Lanthanum** › Tris(N,N'-di-i-propylformamidinato)lanthanum(III), (99.9

### Product Detail

### Technical Note

### Safety Data Sheet

CAS Number: 1034537-36-4

MDL Number: MFCD28411663

Molecular Formula:  $C_{21}H_{45}LaN_6$

Formula Weight: 520.53

Chemical Formula:  $C_{21}H_{45}LaN_6$

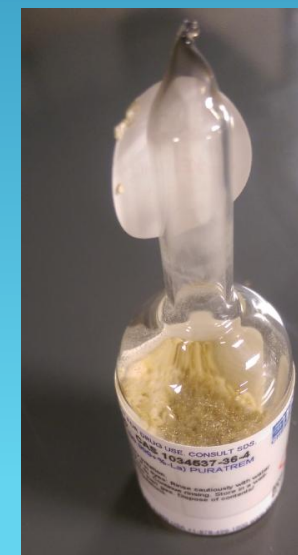
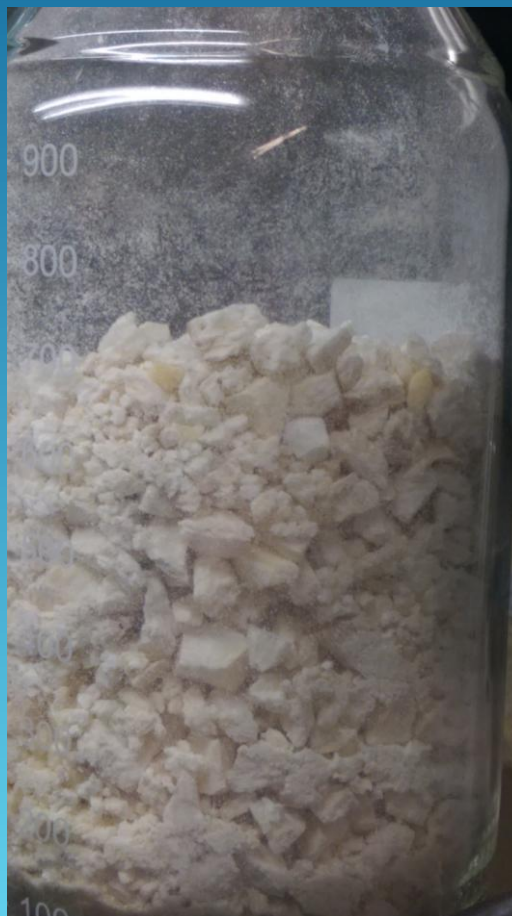
Color and Form: white to off-white powdr

Note:

Product sold under, use subject to, terms  
and conditions of label license at  
[www.strem.com/harvard2](http://www.strem.com/harvard2).

**Stability:** air sensitive, moisture sensitive

**Safety:** Hazardous - an additional Dangerous Goods freight charge may  
apply



# Bubblers for MOCVD, CVD

CVD Bubblers (150 – 1000+ml)



## ALD Cylinders

**STREM** Cylinders & Adapters

96-1070	Swagelok® Cylinder Assembly, 50ml with 1/4" VCR Male Ball Valve and Female Nut	96-1071	Swagelok® Cylinder Assembly, 50ml with 1/4" VCR Male Bellow-Sealed Valve (High Temp) and Female Nut
96-1077	Swagelok® Cylinder Assembly, 50ml with 1/4" VCR Male DP Valve (Ultra High Purity) and Female Nut, electropolished		

96-1071

96-1070

Components shown separately

Standard Ball Valve

High Temp Bellow-Sealed Valve

Female Nut

Silverplated Gasket Assembly

Cylinder body

23.5cm

---

96-1077 Swagelok® Cylinder Assembly, 50ml with 1/4" VCR Male DP Valve (Ultra High Purity) and Female Nut, electropolished components

EP Male DP high pressure Diaphragm Valve

EP Female Nut

EP Unplated Gasket Assembly

EP Cylinder body

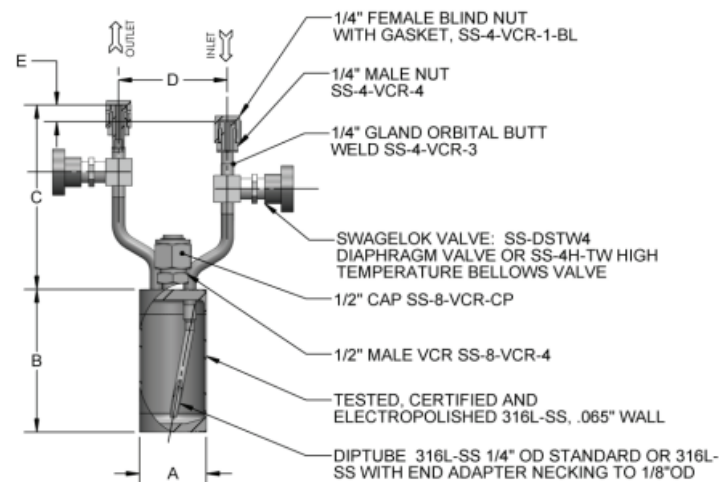
## ALD CYLINDERS (50ML)

# CVD BUBBLERS



## Stainless Steel Bubblers: Vertical Electropolished (DOT 4B, UN stamped)

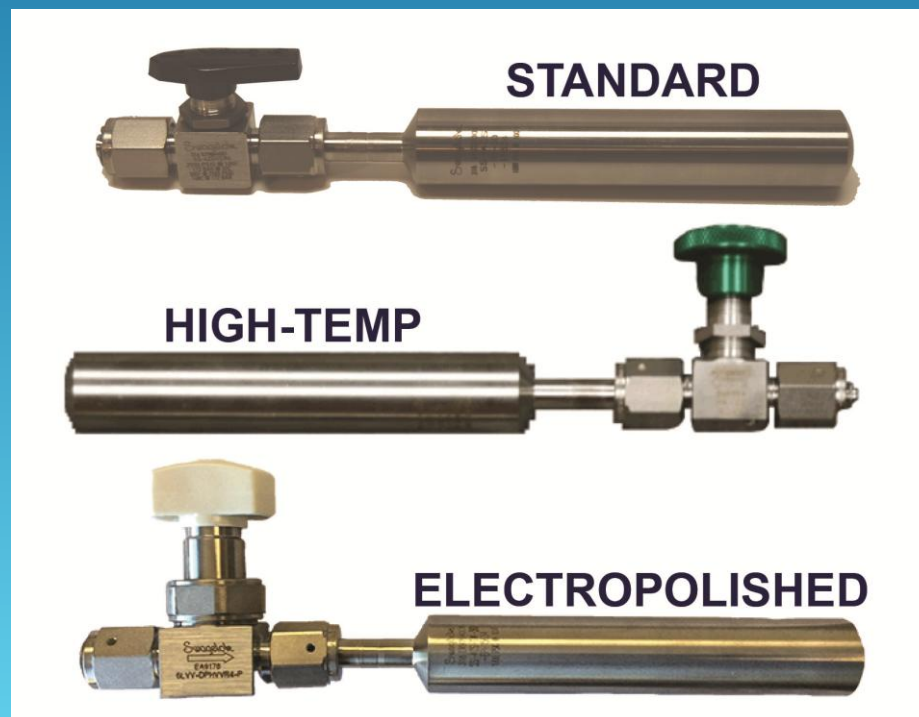
METALS • INORGANICS • ORGANOMETALLICS • CATALYSTS • LIGANDS • NANOMATERIALS • CUSTOM SYNTHESIS • cGMP FACILITIES



Stainless Steel Bubblers, vertical, electropolished with fill-port, PCTFE valve stem tip (121°C), DOT 4B, UN stamped								
Catalog #	Vol. (mL)	A mm	B mm	C mm	D mm	E mm	Temp. Valve	Special Configuration
95-4151	150	51	108	143	83	13	Standard	
95-4290	300	51	187	143	83	13	Standard	
95-4598	600	76	164	143	83	13	Standard	
95-4998	1000	76	254	143	83	13	Standard	
95-5002	1200	102	184	143	83	13	Standard	
95-5003	1500	102	223	143	83	13	Standard	
95-5001	2000	102	292	143	83	13	Standard	
95-5011	3000	152	213	140	83	13	Standard	
95-3000	150	51	108	140	83	13	Standard	replaceable-seat valves with rotated handles
95-4153	150	51	108	143	83	13	Standard	with rotated handles

# ALD CYLINDERS

**We offer a variety of precursors prepackaged in 50mL Swagelok® Cylinders.**



# SERVICES OFFERED

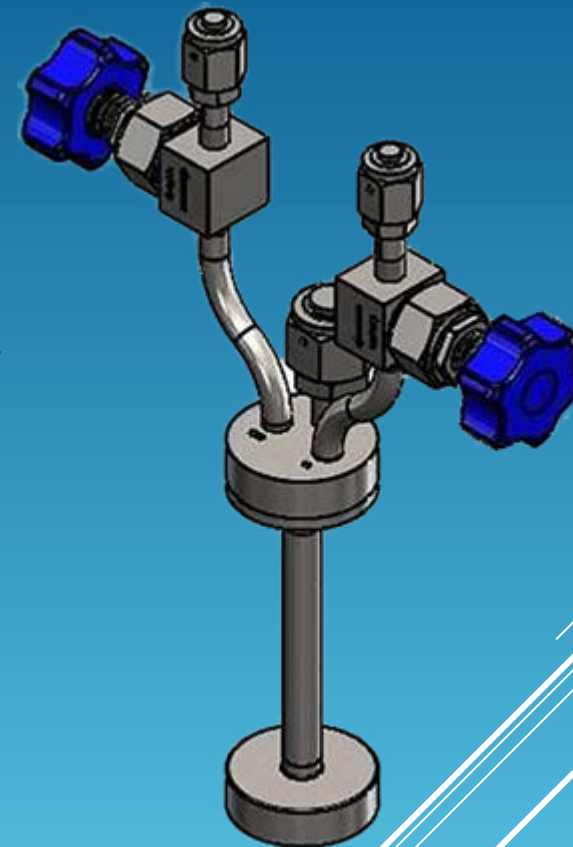
- ▶ Filling, refilling & cleaning services
- ▶ “Request to Fill/Refill Bubbler or Cylinder” form



## 97-7000

### 7ML BUBBLER FOR CVD

THIS 7ML, ELECTROPOLISHED, VERTICAL STAINLESS STEEL BUBBLER IS PERFECT FOR LOW VOLUME APPLICATIONS AND IS COMPATIBLE WITH MOST COMMON TOOL TYPES. OUR SMALL BUBBLER WILL MAXIMIZE GAS CONTACT TIME, REDUCE THE AMOUNT OF MATERIAL NEEDED TO RUN TRIALS WHILE PROVIDING THE SAME FUNCTIONS OF A REGULAR BUBBLER.





# HOW TO LOOK FOR CVD/ALD PRECURSORS & BUBBLERS/CYLINDERS ON THE STREM WEBSITE

STREM CHEMICALS, INC. ESTABLISHED 1964

ISO 9001 CERTIFIED

Search Strem.com

Log In | Register

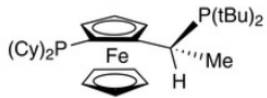
quick order form your favorites

Your cart is empty.

HOME CATALOG NEW PRODUCTS CUSTOM SYNTHESIS PRODUCT RESOURCES ABOUT Contact Strem Chemicals

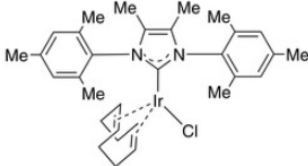
We manufacture high quality chemicals and deliver them globally

**FEATURED**




Josiphos Ligand  
Catalog # 26-0975

**FEATURED**



Iridium Catalyst  
Catalog # 77-1845

**FEATURED**



Water Prepackaged in Cylinder for ALD  
Catalog # 98-8000

Metal Carbonyls »  
Catalysts and Chiral Catalysts »  
Ligands and Chiral Ligands »  
Precursors for MOCVD/ALD »

MOCVD Bubblers »  
ALD Cylinders »  
Nanomaterials »  
Biocatalysts »

PURATREM (99.99%) »  
Acronyms »  
Kits »  
Product Families »

View Complete Product List

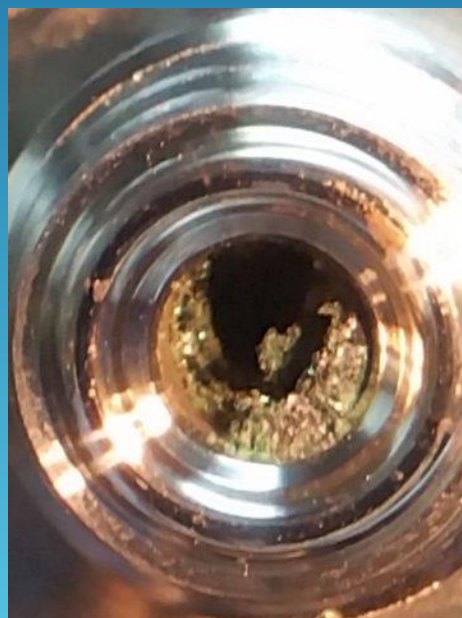
# ALD APPLICATION ISSUES: 28-1301

Bis(cyclopentadienyl)nickel, 99% (Nickelocene)

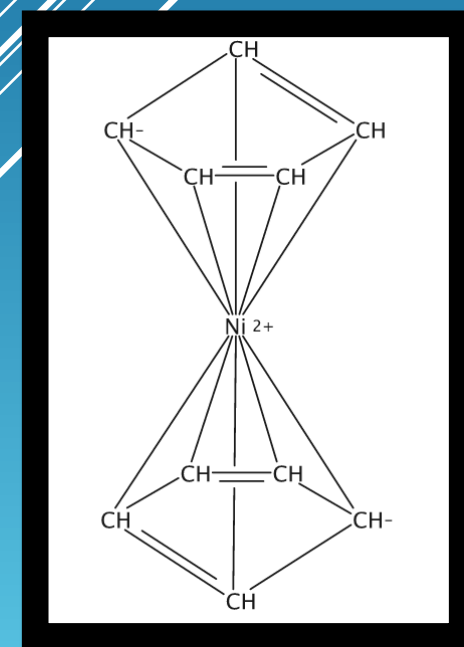
*Case study; Blockages reported in ALD Nickelocene cylinders resulting in restricted or lost flow/material delivery*



**Solids at VCR connection between cylinder and valve**



**Outlet valve blockage**





# ALD APPLICATION ISSUES

Closer inspection shows decomposition evident



Solids at top of cylinder near valve assembly (viewed via sliced end of cylinder).

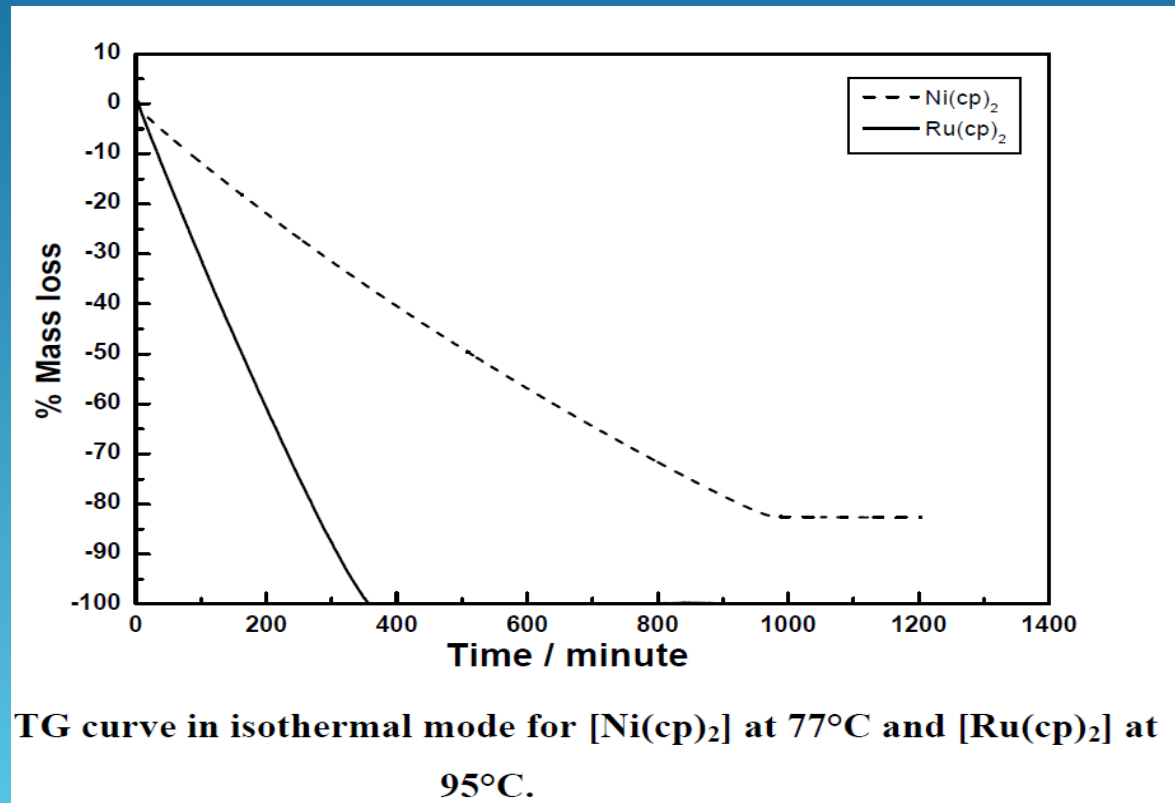


Decomposed (brown) material coating fill port of cylinder.



# NiCp<sub>2</sub> is prone to decomposition when subjected to higher temperatures over long timeframes.

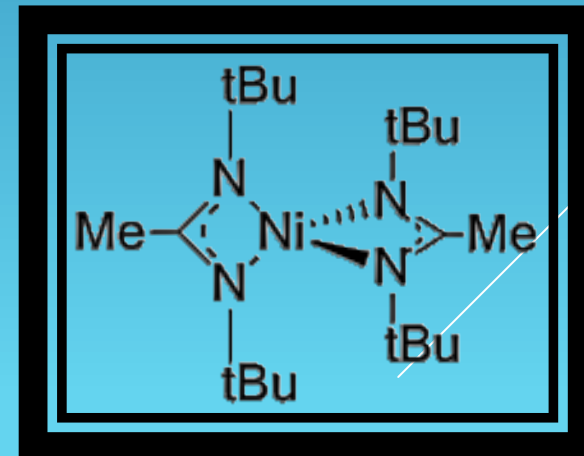
Over a short timeframe this decomposition is not detected



Over time (15 hrs at 77 C), the mass loss becomes constant leaving 18% residual mass from decomposition.

# Conclusion and Recommendations

- When selecting a precursor for ALD/CVD use, consider carrying out a more prolonged “thermal stress test” as well as the routine shorter term thermal analysis.
- When using Nickelocene, if practical run at lower temperatures (ie. < 70 C) to avoid too much decomposition.
- Similarly, during “non-run time” periods consider decreasing the heat applied
- Where possible consider using an alternative *thermally more stable* material such as Strem 28-0045.



28-0045

# THANK YOU!

**Corporate HQ**  
**Newburyport, MA, USA**  
**(48,000 sq feet)**



## Laboratory Chemicals



- Lab scale to 22 L / 50L glass reactors
- ancillary equipment (rotovap, filtration)

For larger scale Strem works with partners

## cGMP (kilo-lab)



## High Pressure



1L, 2L & 5, 25  
gallon autoclaves