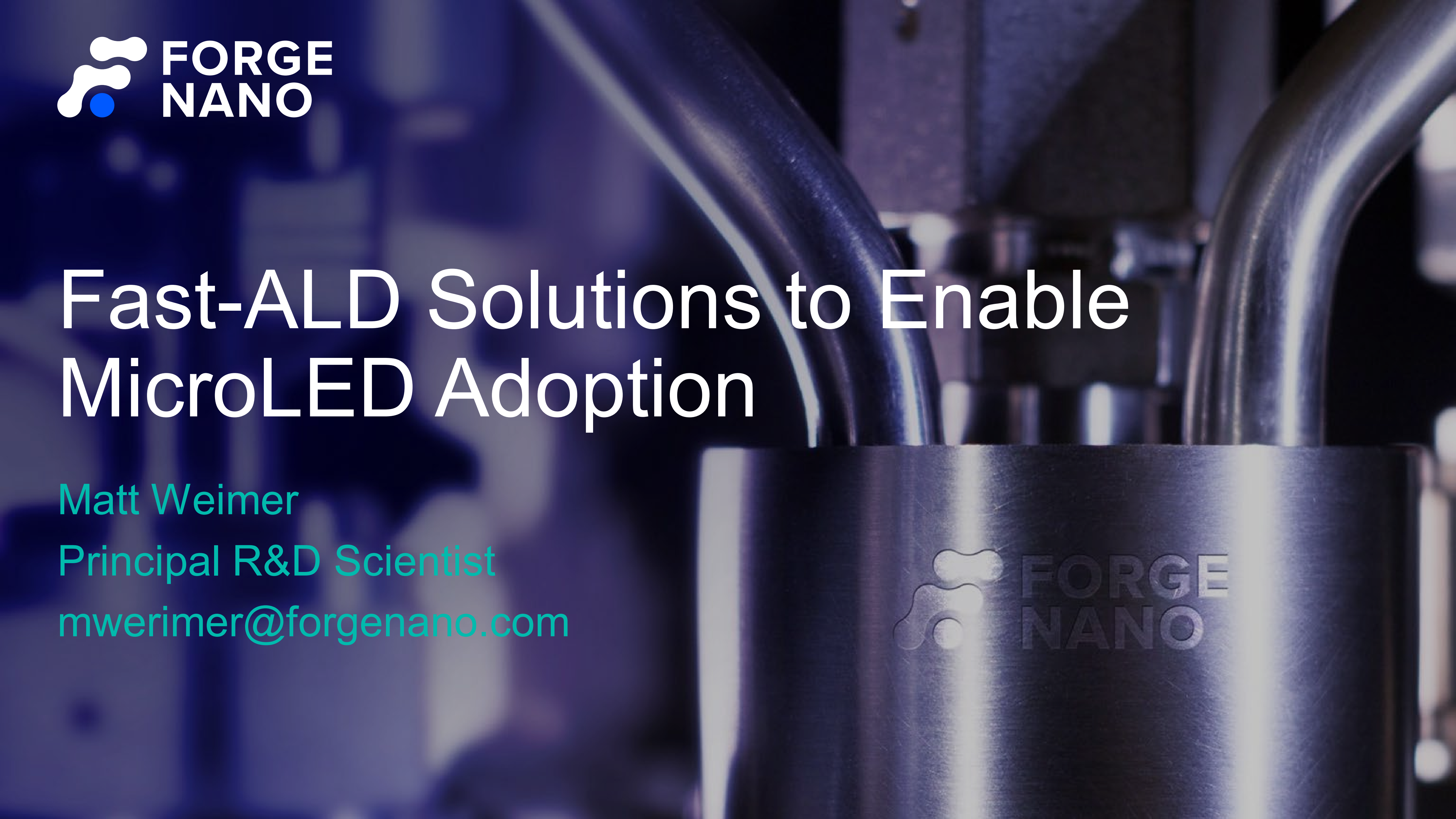


Fast-ALD Solutions to Enable MicroLED Adoption

Matt Weimer
Principal R&D Scientist
mwerimer@forgenano.com

FORGE NANO

We Make Materials Better

HQ outside Denver, Colorado, USA

Install base and satellite offices across Europe and Asia

World's largest particle ALD coating equipment

World's fastest and most efficient object/wafer ALD equipment

Sundew Technologies

Investors

LG Technology Ventures

AIR LIQUIDE ALIAD Venture Capital

VOLKSWAGEN GROUP OF AMERICA

Sumitomo Corporation of Americas

MITSUI KINZOKU

End-to-end Solutions Provider

ALD Applications to MicroLED

Sidewall passivation with Al_2O_3 ALD

Improve quantum efficiency with thin layer, ~1nm

Reduces etch based defects which cause quenching

Improved dielectric with scaling

ALD improves leakage current over PECVD

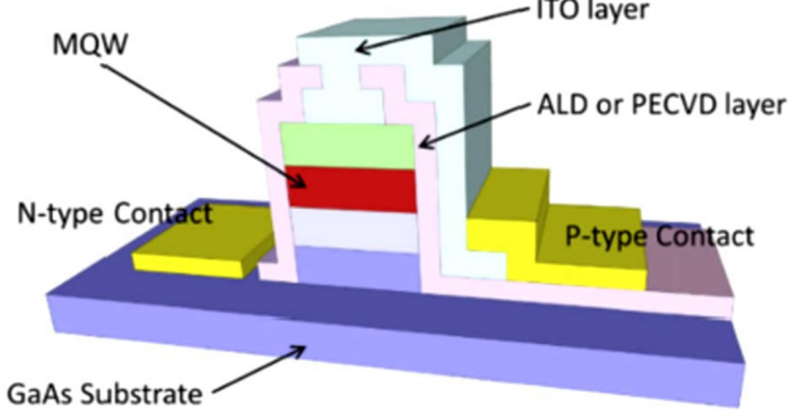
Improvement increases with smaller mesa dimensions

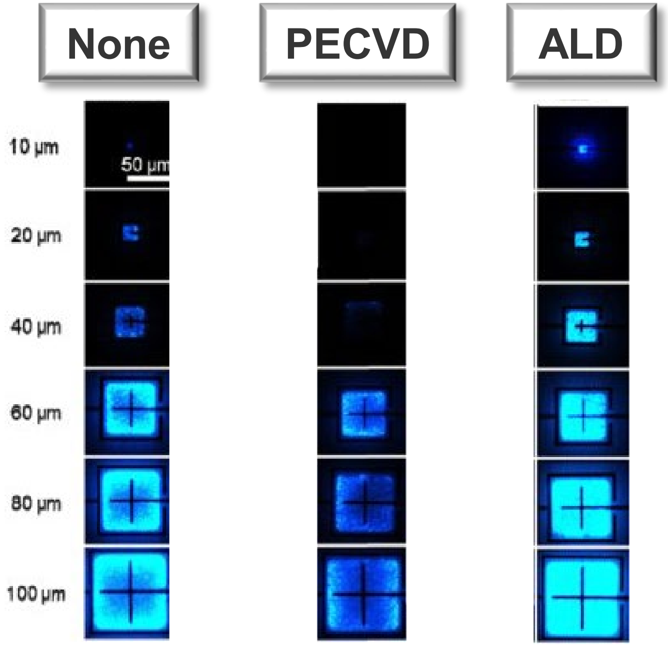
Moisture diffusion barrier

Ceramic ALD film provide superior barriers

Extends lifetime of microLED

Wong et. al., Opt. Express 28(4), 2020, 5787–5793



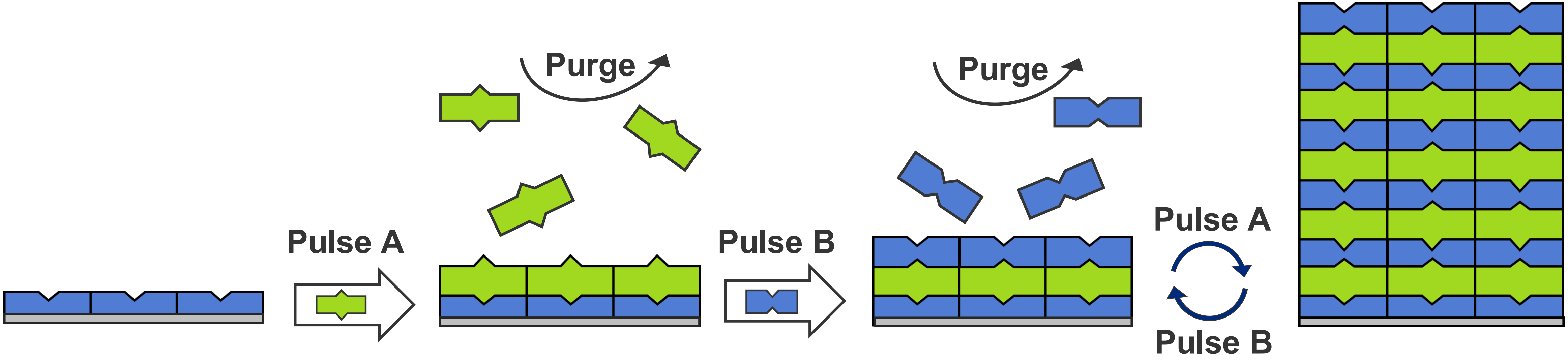


Wong et. al., Opt. Express 26(16), 2018, 21324–21331

What makes ALD special?

The Basics of Atomic Layer Deposition (ALD)

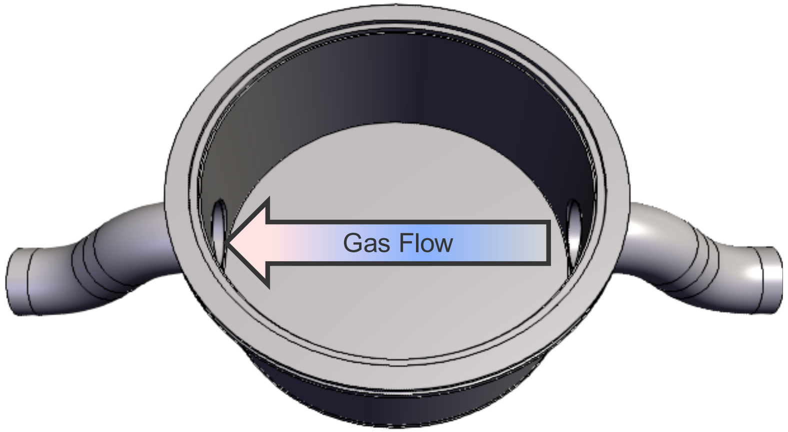
ALD is all about sequential and self-limiting surface reactions to deposition thin films atomic layer by atomic layer



Self-limiting surface chemistry deposits conformal, uniform, pin-hole free films

Barrier to ALD Adoption

Traditional ALD reactors are stuck in a tradeoff



Reactor pressure **increase**
- Precursor use improves 👍
- Purge time longer 👎

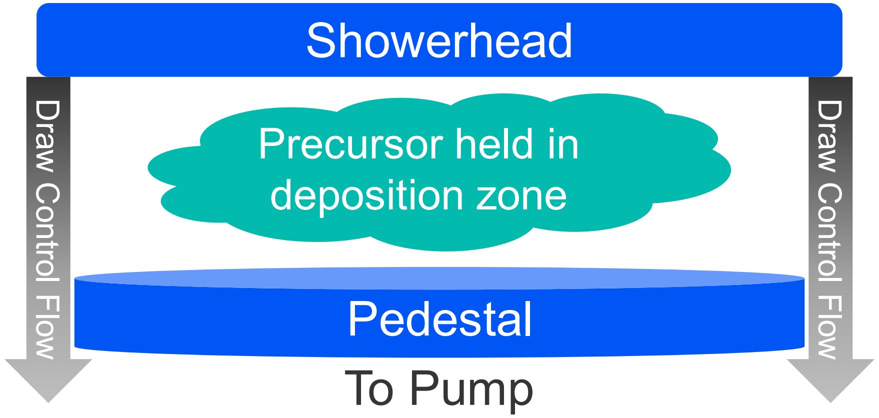
Reactor pressure **decrease**
- Precursor use degrades 👎
- Purge time shorter 👍

With traditional ALD systems, one must choose between efficient precursor use or efficient purge times

Break this tradeoff for single wafer and ALD adoption is more possible

ALD^x enables Dynamic Precursor Pressure Control

Synchronously Modulated Flow and Draw (SMFD)



Showerhead

Draw Control Flow

Precursor held in deposition zone

Draw Control Flow

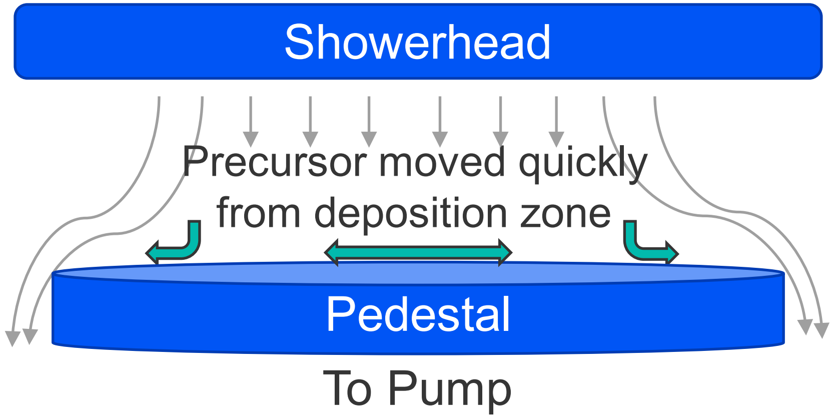
Pedestal

To Pump

Draw Control On

Equal to a long precursor residence time
80-90% chemical utilization

Enables **<u>100x less precursor use</u>**
Typical precursor exposure <50ms



Showerhead

Precursor moved quickly from deposition zone

Pedestal

To Pump

Draw Control Off

Equal to a short precursor residence time

Enables short cycle time **<u><1s per cycle</u>**
Typical fast purge time <0.5s

True ALD at > 10nm/min with efficient precursor utilization

ALD^x Enables Superior Moisture Diffusion Barrier Performance

Smaller scale necessitated by customer: ALD^x is the solution!

PECVD failed every test

ALD^x Nanolaminate of Al_2O_3 and SiO_2 = ALD-CAP®

- O_2 Permeability @ atm = <1x10^{-7} cm^3·mm/m^2·day
- Water vapor transport @ 38°C = <4x10^{-10} g·mm/m^2·day

50nm ALD Nanolaminate was solution

- Total ALD deposition time ~12 minutes

HAST Performance

Coating	Thickness (nm)	96 hours	384 hours
PECVD	>800	Fail	Fail
ALD	10	Pass	Fail
ALD	20	Pass	Pass

JEDEC JESD22-A118 = HAST - 130°C/85% relative humidity

ALD-CAP® enables up to 100x thinner moisture protection for microLEDs

Proprietary and Unique SiO_2 CRISP ALD Enhances Dielectric Performance

Smaller scale necessitated by customer: ALD^x is the solution!

- PECVD failed at every measurement
  - SiO_2 CRISP density higher than PEALD SiO_2
- ALD^x SiO_2 CRISP at 20nm
  - Dielectric constant – 4
  - Breakdown Voltage – >12 MV/cm
  - Leakage current @2 MV/cm – $<10^{-10}$ A/mm^2
- No trace of impurity/catalyst in film

FET Failure Performance

Coating	Bias	Failures after 96-hour HAST
PECVD	11V	99%
ALD	11V	2.7%
ALD	7V	0.3%

JEDEC JESD22-A110 = HAST - 130°C/85% relative humidity
Test biased at pinchoff (maximum stress condition)
Failure measured by leakage current
CS Mantec, 2013

Proprietary SiO_2 CRISP ALD has superior dielectric performance vs PECVD

ALD^x Performs Better than PEALD for SiO_2 Deposition

SiO_2 ALD at 250°C

ALD^x

✓ Shorter cycle time => **Higher throughput**

✓ Lower precursor consumption => **Lower COO**

✓ Higher density, ideal stoichiometry, no impurities, better dielectric properties => **Better film performance in devices**

PEALD

✓ Performs comparable or worse in each category

✓ Plasma can damage incoming surface

SiO_2	ALD^x	PEALD (BTBAS)	Forge Nano Difference
GPC (Å/cy)	1.2	1.1	**0.1 faster**
100 nm (hours)	0.7	2.1	**3x shorter**
Si Consumption per 100nm (Torr·s)	275	18,175	**66x less**
Thickness non-uniformity (6” full range %)	<2%	<4%	**2% more uniform**
RI (633nm)	1.44	1.45	**0.01 lower**
Density (g/cm^3)	2.32	2.19	**6% higher**
O:Si Ratio	2.0	2.1	**FN ideal**
Dielectric Constant	4.0	4.1	**0.1 lower**
Breakdown Voltage (MV/cm)	>12	>9	**33% higher**
Leakage Current @ 2MV/cm (A/mm^2)	$<10^{-10}$	$<10^{-10}$	**Same**

ALD^x technology enables higher throughput, reduced precursor consumption, and greater film performance!

Explore ALD Solutions for microLEDs

Forge Nano Apollo Solutions

Sidewall passivation – Al_2O_3/AlN/SiO_2

- Increase efficiency at smaller mesa size

Moisture barrier – Al_2O_3/SiO_2

- Improved barrier performance at a fraction of the thickness vs PECVD

DBR – SiO_2/TiO_2

- Scale mesa size
- Fine compositional control

FORGE NANO

Thank you!

Matt Weimer
Principal R&D Scientist
mwerimer@forgenano.com