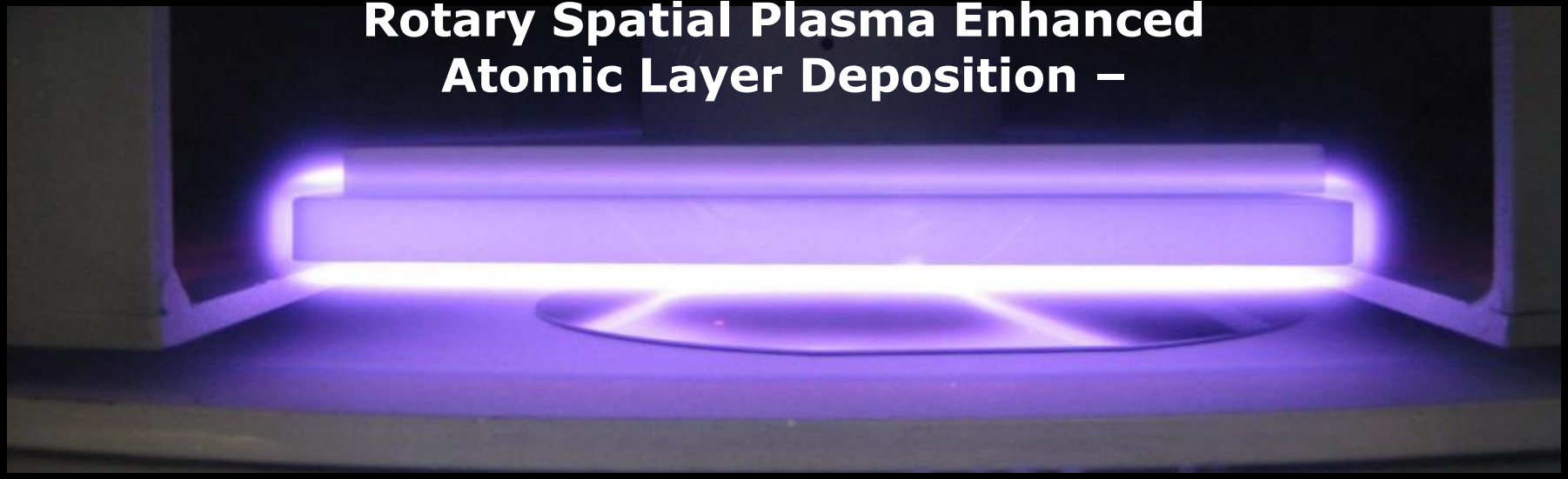
Rotary Spatial Plasma Enhanced Atomic Layer Deposition –



an enabling manufacturing technology for µm-thick ALD films

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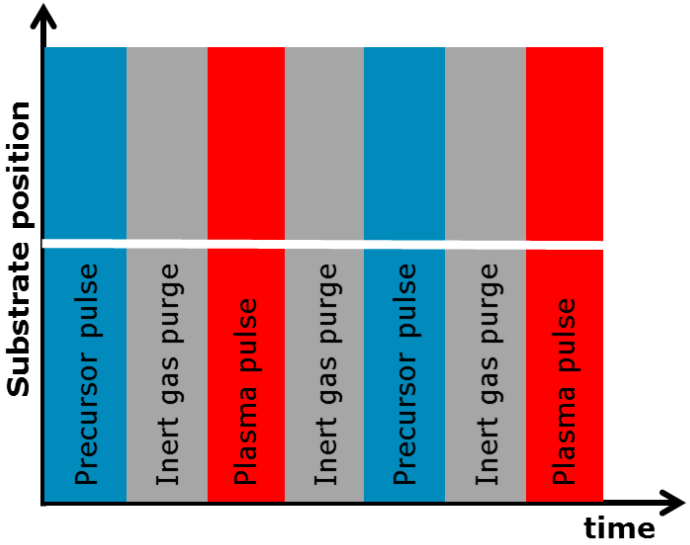
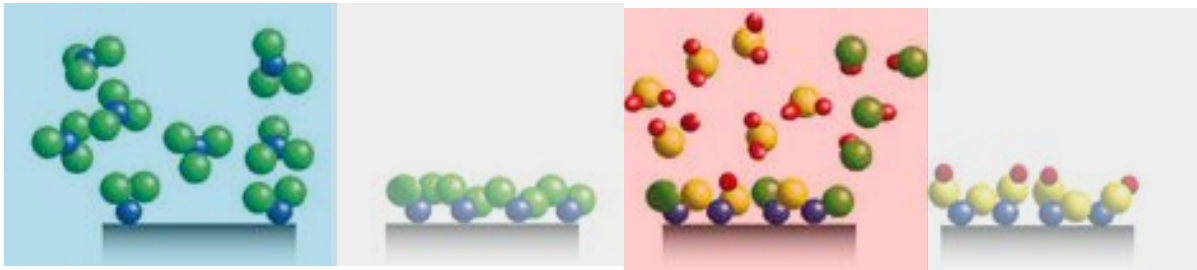
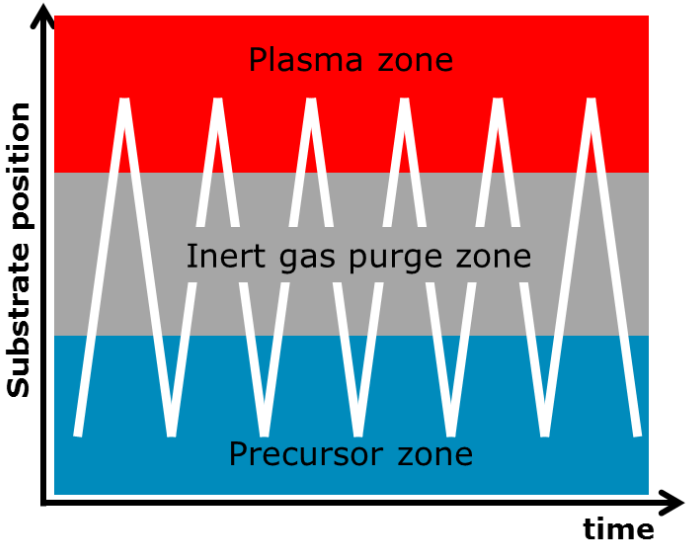
Pulsed versus Spatial ALD



Convential Pulsed ALD

- Precursors separated in time
- Substrate is stationary
- Precursor separation by inert gas purge step





Spatial ALD

- Precursors separated in space
- Substrate is moving
- Precursor separation by inert gas purge zone

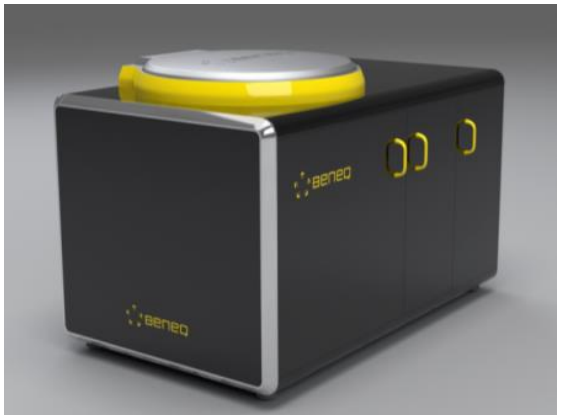
Beneq Spatial ALD

WCS 600 (2013)
- Roll-to-Roll
- 500mm wide web

SCS 1000 (2015)
- Sheet-by-sheet
- Up to 400x600mm glass

TFS 200R (2009)
- Rotary
- 100x300mm film

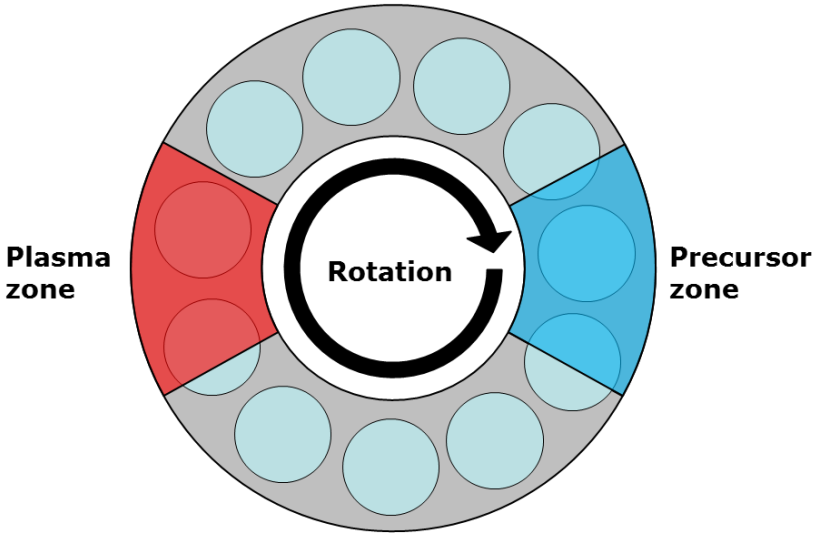
Beneq R11
- Rotary
- Up to 200mm wafers

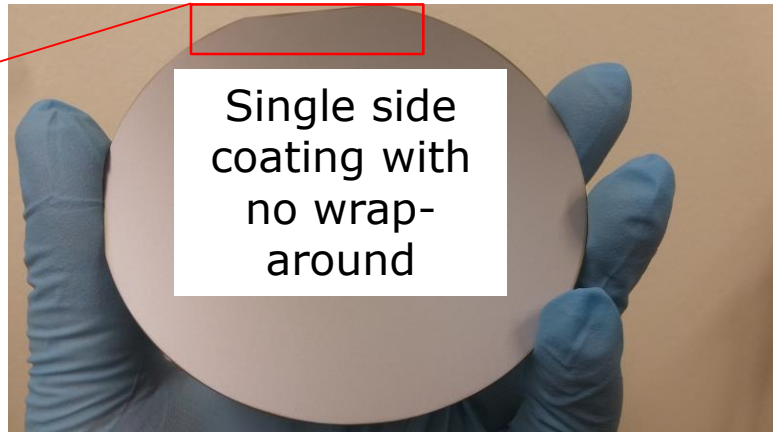


Why Rotary Spatial PEALD?

Benefits of rotary spatial PEALD

- High deposition rates (µm/h)
- Enables use of PEALD in batch mode, allowing new materials for batch production
  - Low temperature SiO_2
  - SiN
- Very low maintenance needs, only the donut-shaped area gets coated





Experimental

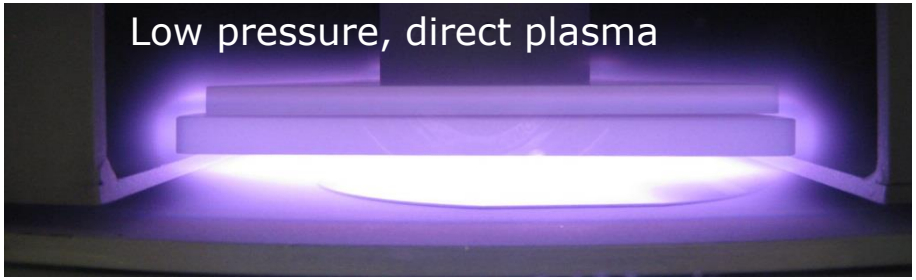
- Prototype system used for process development
- Rotational speed up to 300 rpm
- Process temperature 20-150°C
- Process pressure ~100 Pa (~1 torr)
- Technology development in collaboration with Lotus

Film composition

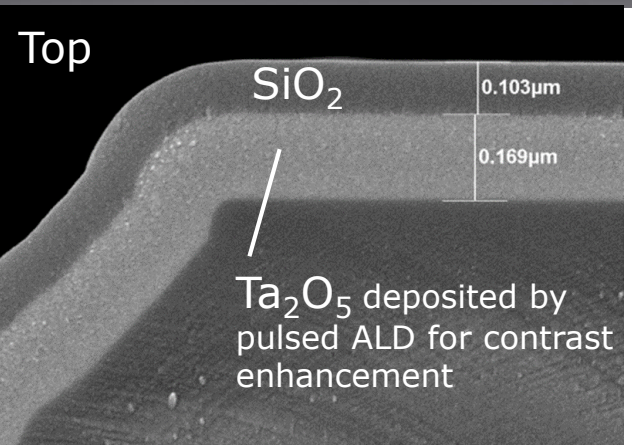
	Process Temperature	Rotation speed	Metal:Oxygen ratio (RBS)	Residual Carbon (SIMS)
SiO_2	100C	200 rpm	0.46	<0.1%
TiO_2	100C	200 rpm	0.50	2.5%
Ta_2O_5	150C	120 rpm	0.37	2.0%

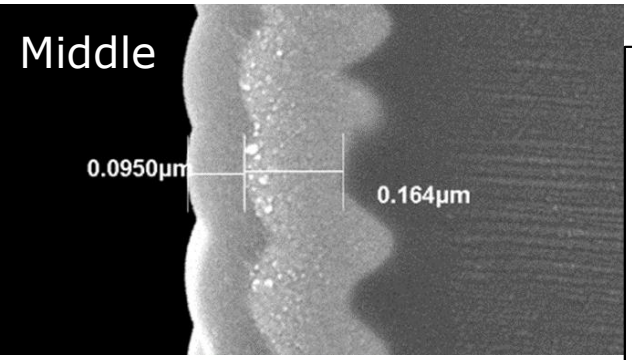
Plasma control

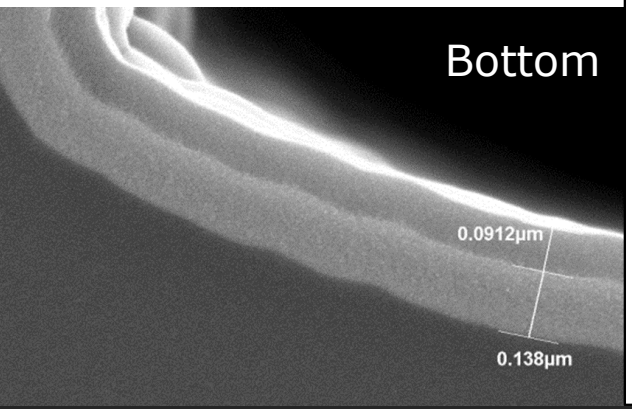
- DC-plasma
  - Voltage: 300-600 V
  - Current: ~0.5 A
  - Pressure: 100-200 Pa
- DC plasma and Substrate interaction can be easily controlled by process pressure
  - Lower pressure: direct - plasma extends to substrate surface
  - Higher pressure: indirect - plasma does not extend to substrate
- Enables in-situ plasma pre-clean or plasma post treatment
- Allows processing of sensitive substrates
- Enables film stress tuning



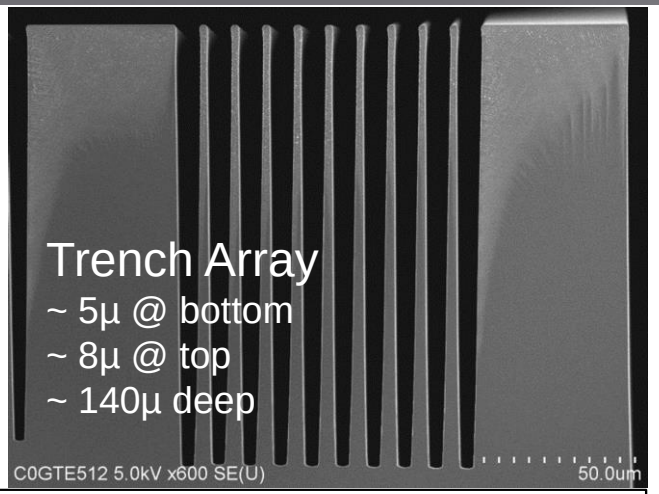
Conformality

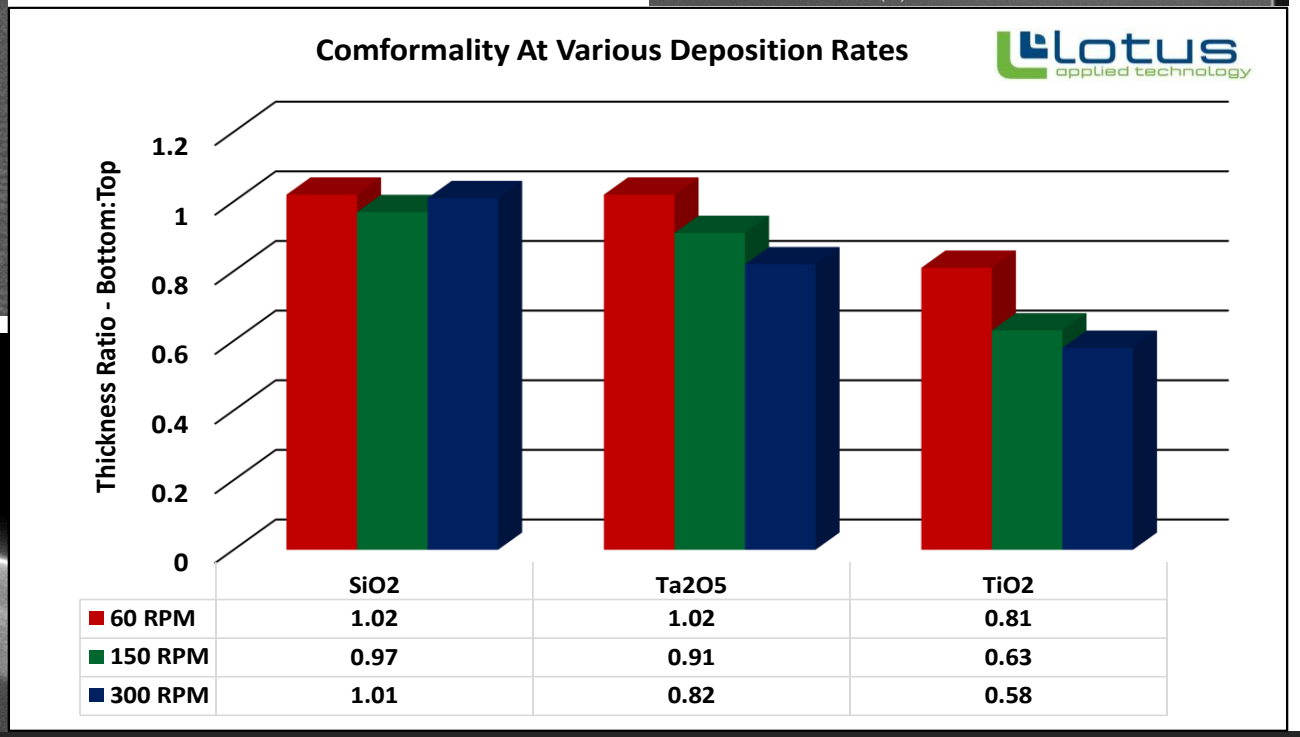






- Silicon substrates prepared using "Bosch" Deep Reactive Ion Etch to mill trenches
- Comparison of bottom-to-top film thickness using SEM





	SiO2	Ta2O5	TiO2
60 RPM	1.02	1.02	0.81
150 RPM	0.97	0.91	0.63
300 RPM	1.01	0.82	0.58

Surface roughness

- Films Deposited on ¼” thick “Super Polished” fused silica substrate (pre-characterized)

- Surface roughness measured using a Zygo 5500 Heterodyne profilometer

	Film thickness (nm)	RMS Roughness (Å)	Peak-Valley Roughnes (Å)
SiO_2	1 000	0.8	5.5
TiO_2	240	0.6	4.0
Ta_2O_5	250	0.5	2.9

Deposition rate

- Rotary Spatial PEALD (Beneq R11)

	Rotation speed (rpm)	Growth-per-cycle (Å)	Deposition rate (Å/min)	Batch size (wafers)
SiO_2	200	1.20	240	10
Al_2O_3	200	1.70	340	10
TiO_2	200	0.82	164	10
Ta_2O_5	200	0.54	108	10

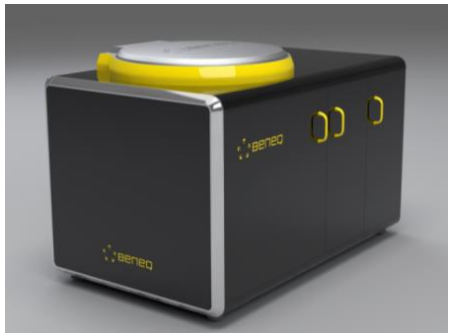
- Conventional Pulsed PEALD (Beneq TFS 200)

	Cycle time (s)	Growth-per-cycle (Å)	Deposition rate (Å/min)	Batch size (wafers)
Al_2O_3	2	1.20	36	1

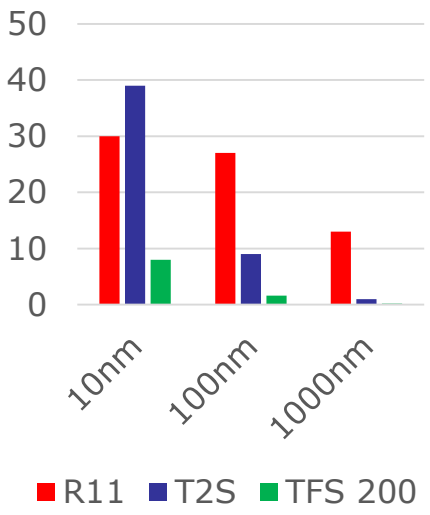
- Deposition rate ~10x higher with Rotary Spatial PEALD
- Batch size 10x larger
- Productivity ~100x higher!

Capacity

- Comparison of capacity with different wafer tool platforms - all fully automated with transfer module, one ALD module, preheating station, cooling station and cassette load port
- Rotary Spatial PEALD is superior for thick films

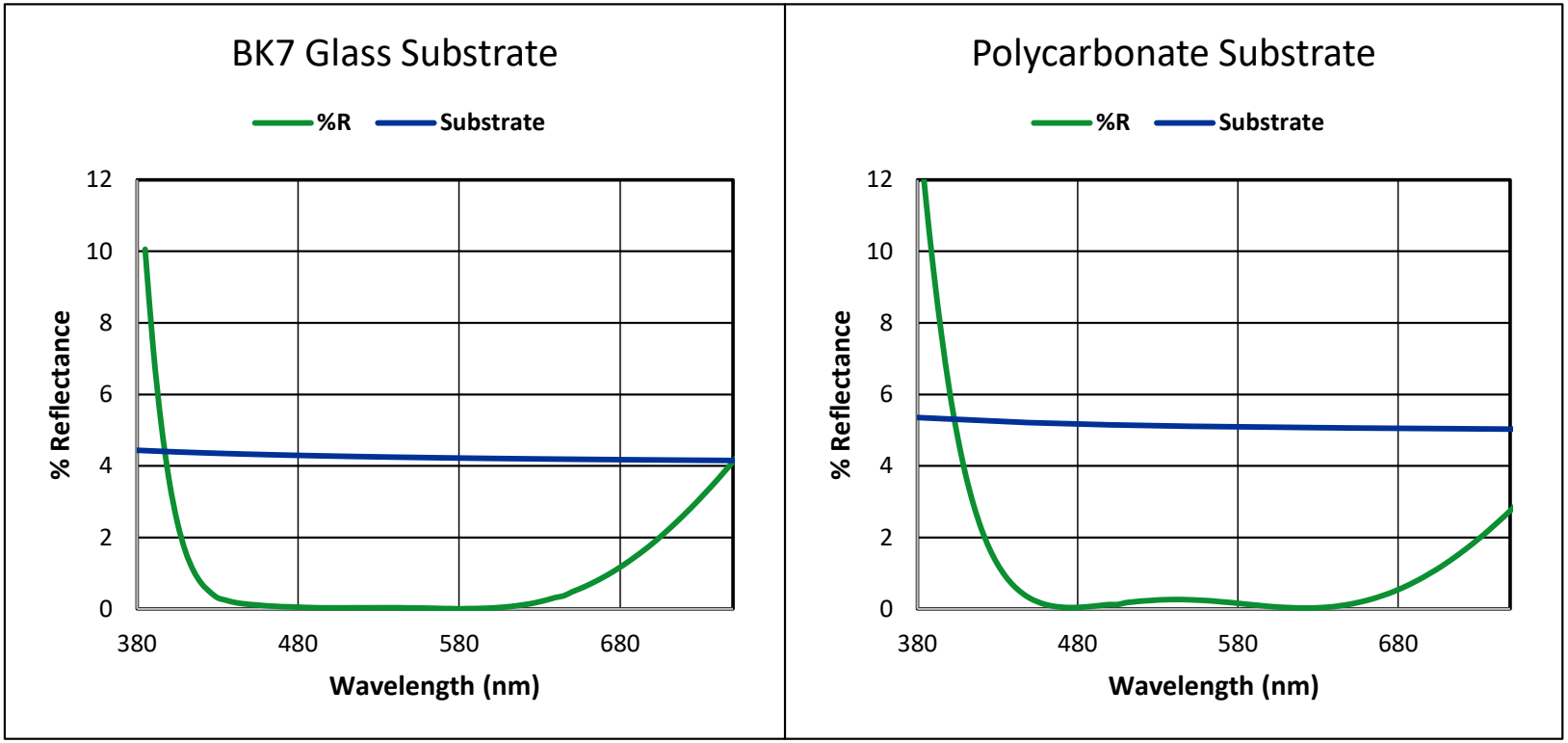


200mm wafers	R11	T2S	TFS 200
Batch size	10	25	1
Process type	PEALD	Thermal	Thermal/PEALD
Capacity (wph)			
10nm Al_2O_3	30	39	8
100nm Al_2O_3	27	9	1.6
1000nm Al_2O_3	13	1.0	0.18



Case example: Deposition of an Anti-Reflective Coating

- SiO_2 and TiO_2 , 4-layers, total thickness ~250nm
- Polycarbonate and BK7 glass substrate
- Process temperature 90˚C
- Rotation speed of 200 RPM (200 ALD cycles per minute)



- Reflectance of about 0.07% for AR on glass
  - R < 0.1% for range of 460nm to 615nm

Summary

- Rotary Spatial PEALD technology offers extremely high ALD deposition rates (in µm/h scale)
- Good conformality can be achieved at high deposition rate
- DC plasma process enables low temperature processing and stress control
- The optimal choice for applications requiring µm-scale film thickness, *e.g.*
  - optical coatings
  - insulators for high voltage applications
  - TCO layers

Thank you!

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