Process Characterization for BTBAS Films

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Presentation by Dr. Robert Herring

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San Jose, California
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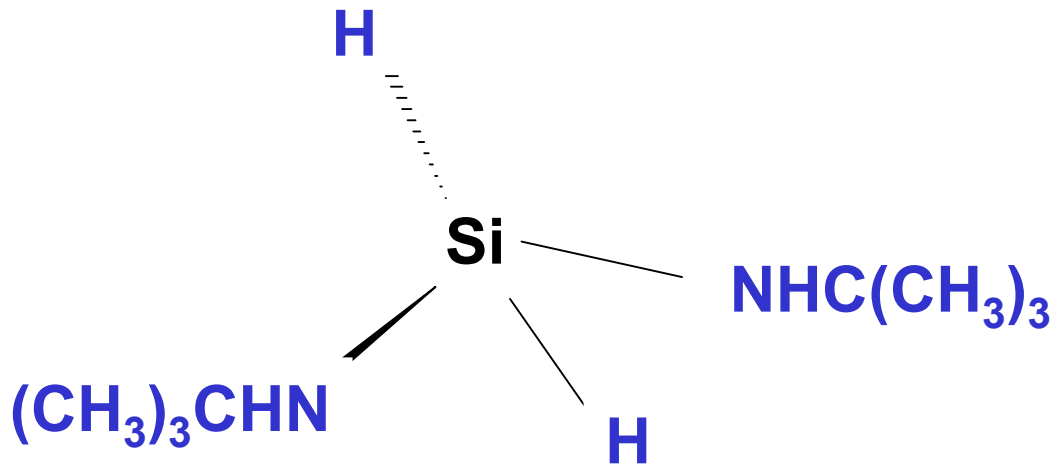
Outline

- BTBAS Background / Properties
- Silicon Nitride
- Silicon Oxide
- Phosphorous doped silicon oxide (PSG)
- Silicon Oxynitride

BTBAS Background

- Developed by Schumacher
- BTBAS = Bis (tertiarybutylamino) silane
- Objective: Lower temperature replacement for Dichlorosilane (without chlorine)
- Testing in the SVG Applications Lab since Jan. 1999
- Dedicated vertical furnace system for BTBAS films
- Several DOE's completed
- Processed wafers for several customer applications

BTBAS Molecule

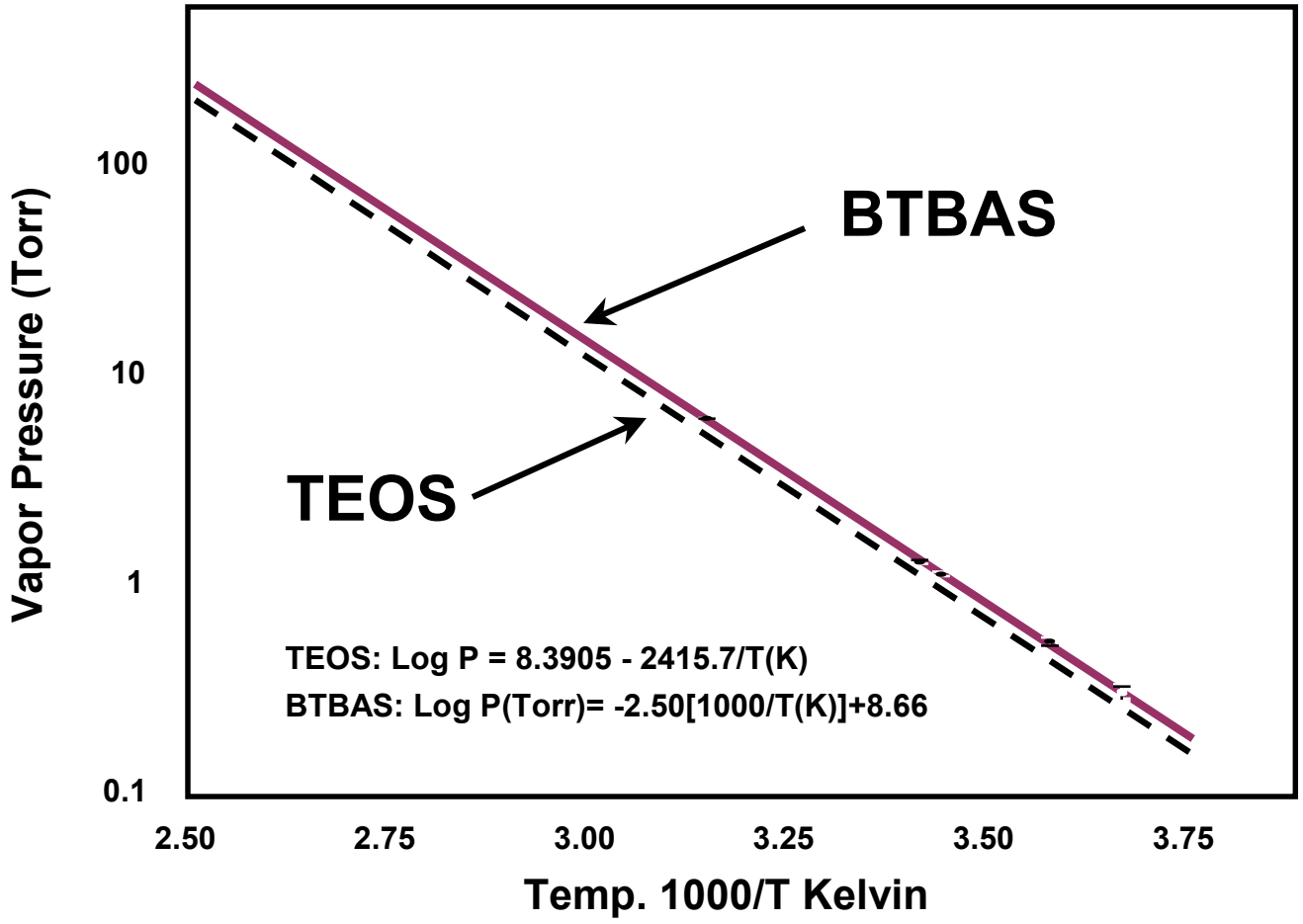


Bis (TertiaryButylAmino) Silane

Physical Properties of BTBAS

Chemical Formula	**$C_8H_{22}N_2Si$**
Molecular Weight	**174.3**
Vapor Pressure @ 20°C	**1.15 Torr**
Specific Gravity @ 22°C	**0.816 g/ml**
Boiling Point @ 760mm Hg	**167°C**
Viscosity @ 22°C	**< 1.5 cPs**
Flash Point	**30°C**
LEL (% in air)	**0.5%**
UEL (% in air)	**Not Available**

Vapor Pressure
BTBAS and TEOS



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BTBAS Applications

Objectives: Decrease of process thermal budget

- Sidewall spacers
  - lower process temperatures
- Etch stop layers
  - Self aligning contacts
- Trench Structure Fill or Liners
  - STI fill (3:1-6:1 aspect ratio)
  - Deep trench liners (>20:1 aspect ratio)

BTBAS Films

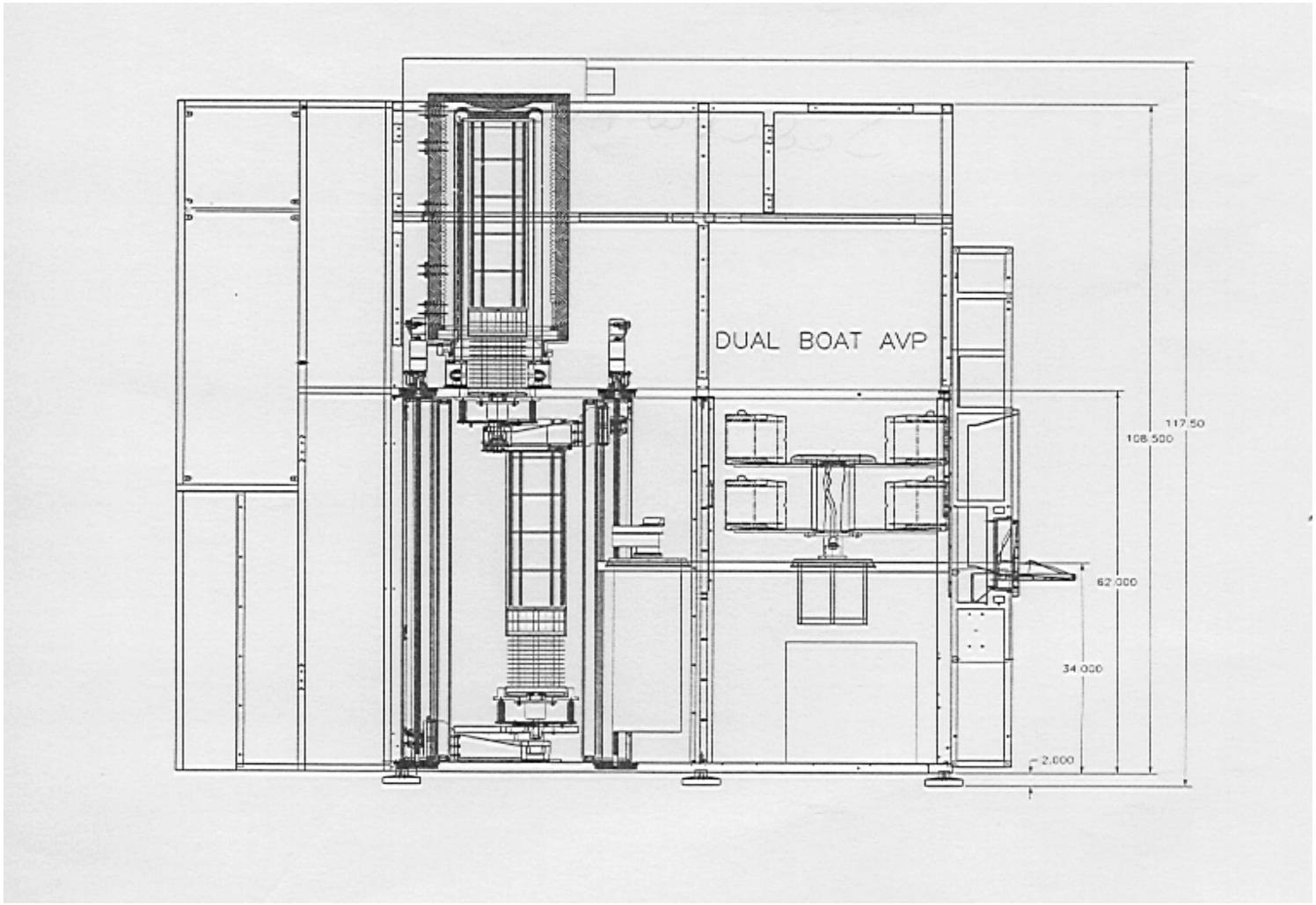
- Films Studied
  - Silicon Nitride
  - Silicon Dioxide
  - Phosphorus Doped Oxides
  - Oxynitrides

BTBAS Films

- Test Methods and Equipment
  - All tests used 200-mm wafers
  - SVG Vertical LPCVD Furnace
    - series 8000 AVP
  - Measured thickness and refractive index by ellipsometry

Front and Rear Views of AVP

Side View AVP Dual Boat System



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BTBAS Films

- Silicon Nitride
  - BTBAS and Ammonia (NH_3)
- Silicon Dioxide
  - BTBAS and Oxygen (O_2)
- Phosphorus Doped Silicon Dioxide (PSG)
  - BTBAS, Oxygen,10% Phosphine in Nitrogen
- Oxynitride
  - BTBAS. Ammonia, Oxygen

  Or
  - BTBAS, Ammonia, Nitrous Oxide (N_2O)

Silicon Nitride BTBAS Films

- Primary Process Window
  - Temperature 500 to 625°C
  - Total Flow 100 to 300 sccm
  - NH3: BTBAS Ratio 1:1 to 12:1
  - Pressure 100 to 600 mT

Figure 1 - BTBAS Nitride
Temperature vs Within Wafer Uniformity for 0.5" Spacing,
100 mTorr, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

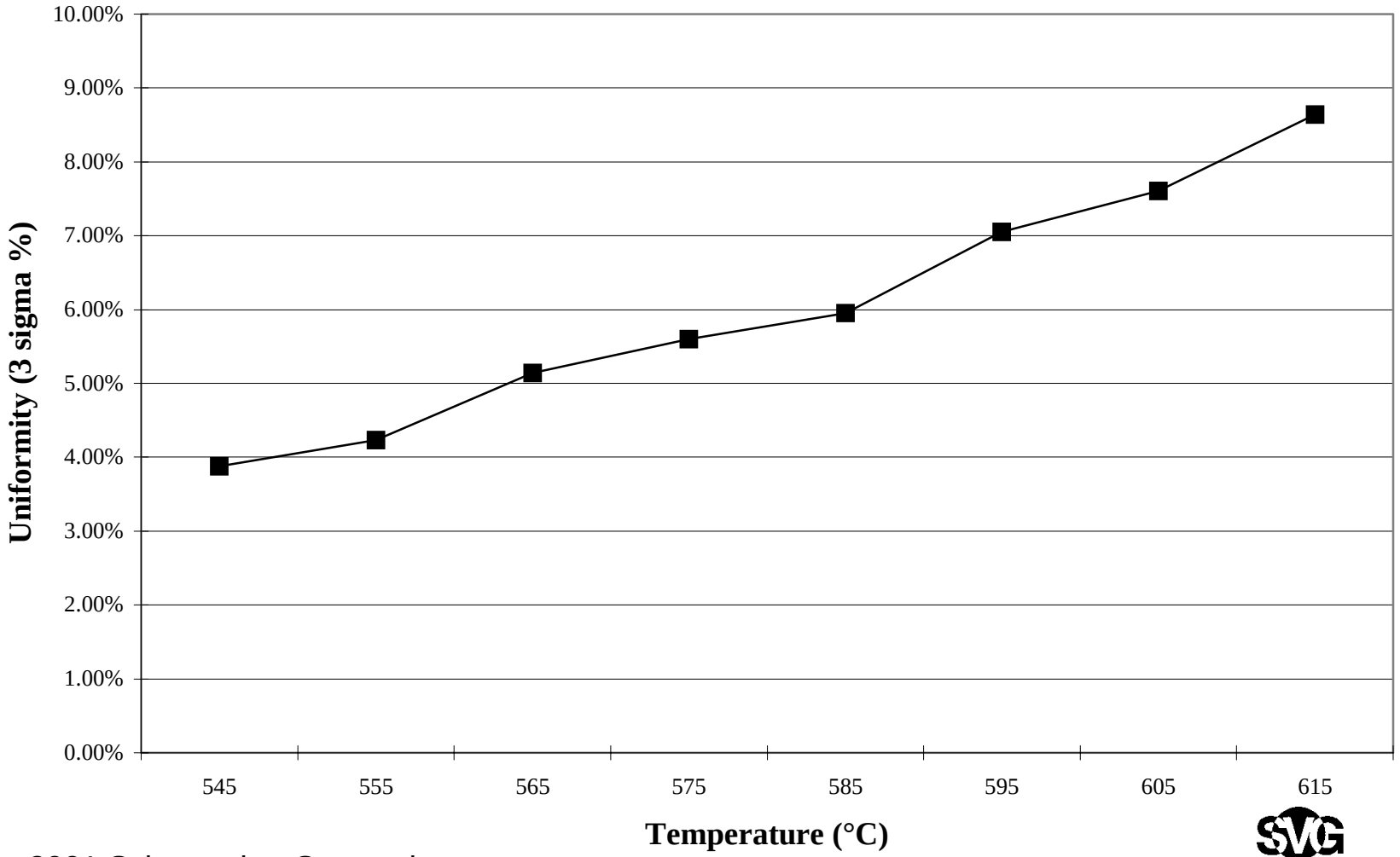

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Figure 2 - BTBAS Nitride
Temperature vs Deposition Rate for 0.5" Spacing, 100 mTorr Pressure, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

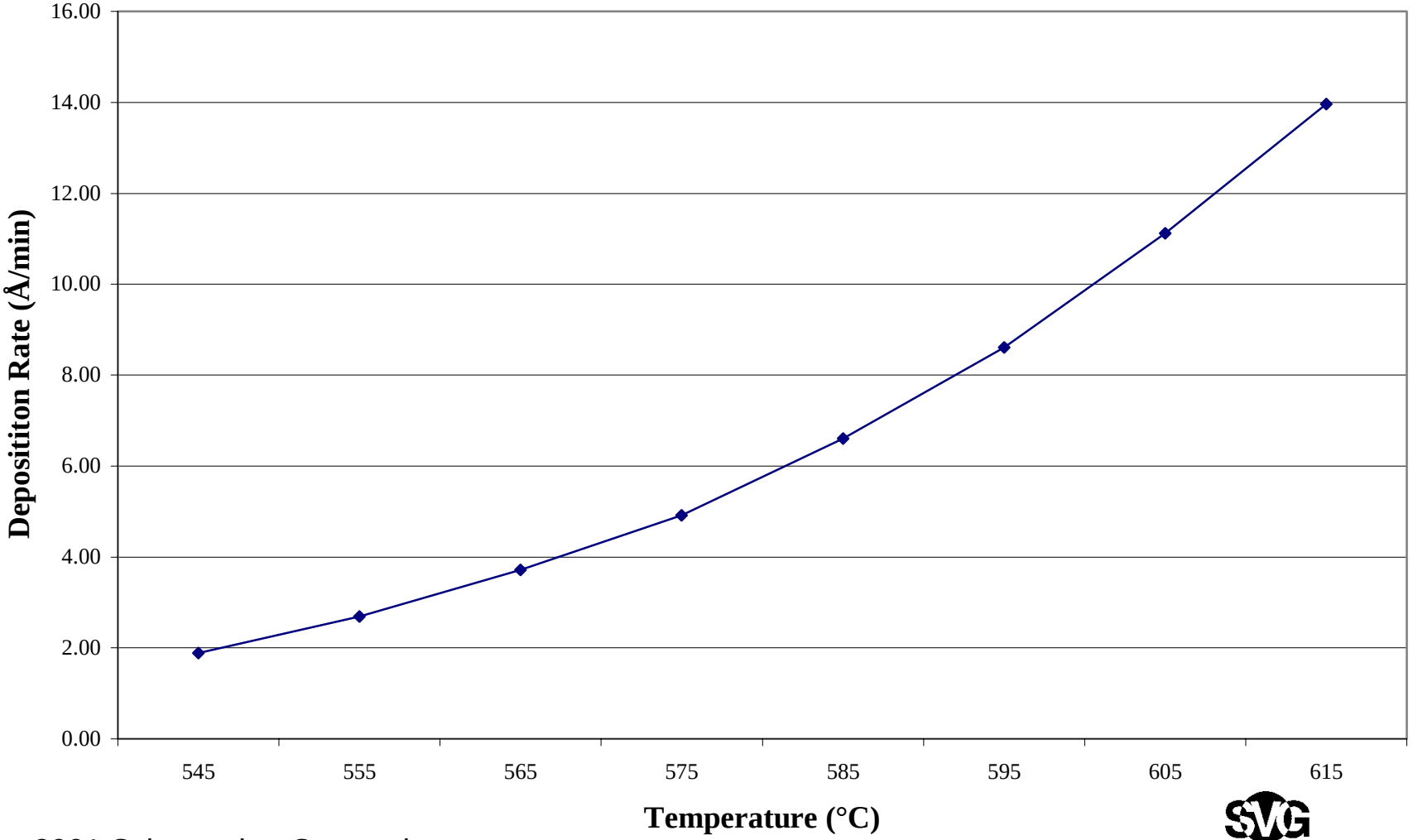

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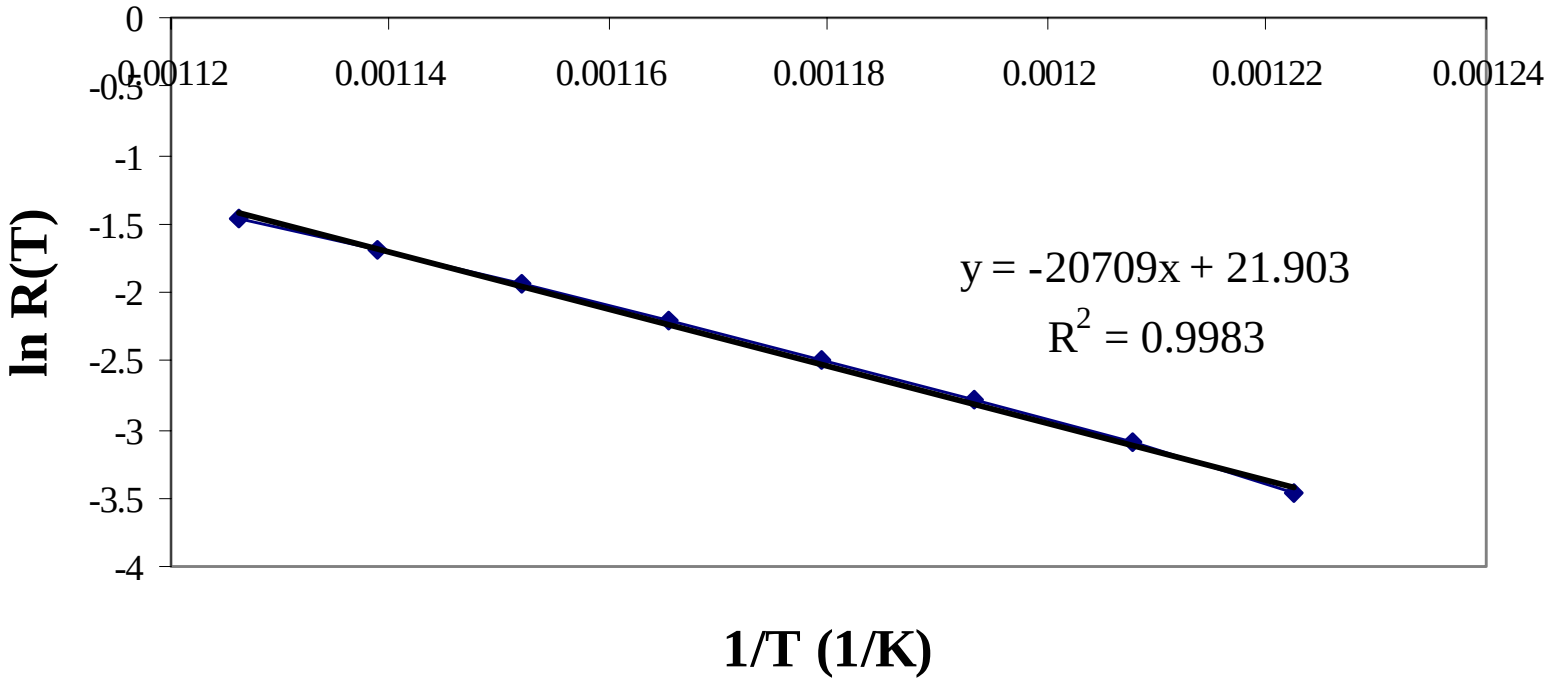
Figure 3 - Arrhenius Plot for BTBAS Nitride



Activation energy = 1.5489 eV
= 149.46 kJ/mol

Figure 4 - BTBAS Nitride
Temperature vs Refractive Index for 0.5" Spacing,
100 mTorr Pressure, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

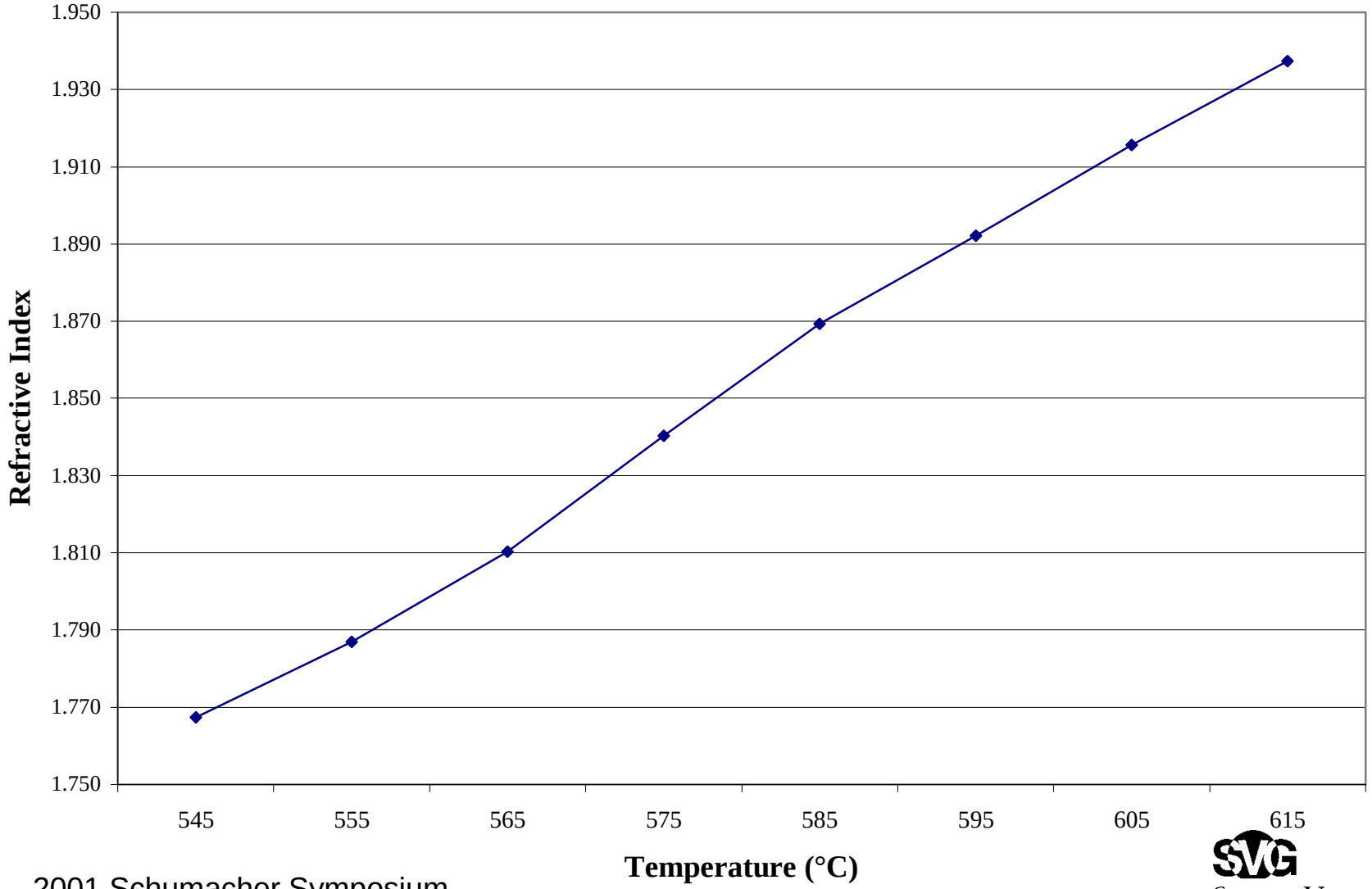


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Figure 5 - BTBAS Nitride
Pressure vs Within Wafer Uniformity for 0.5" Spacing, 575°C, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

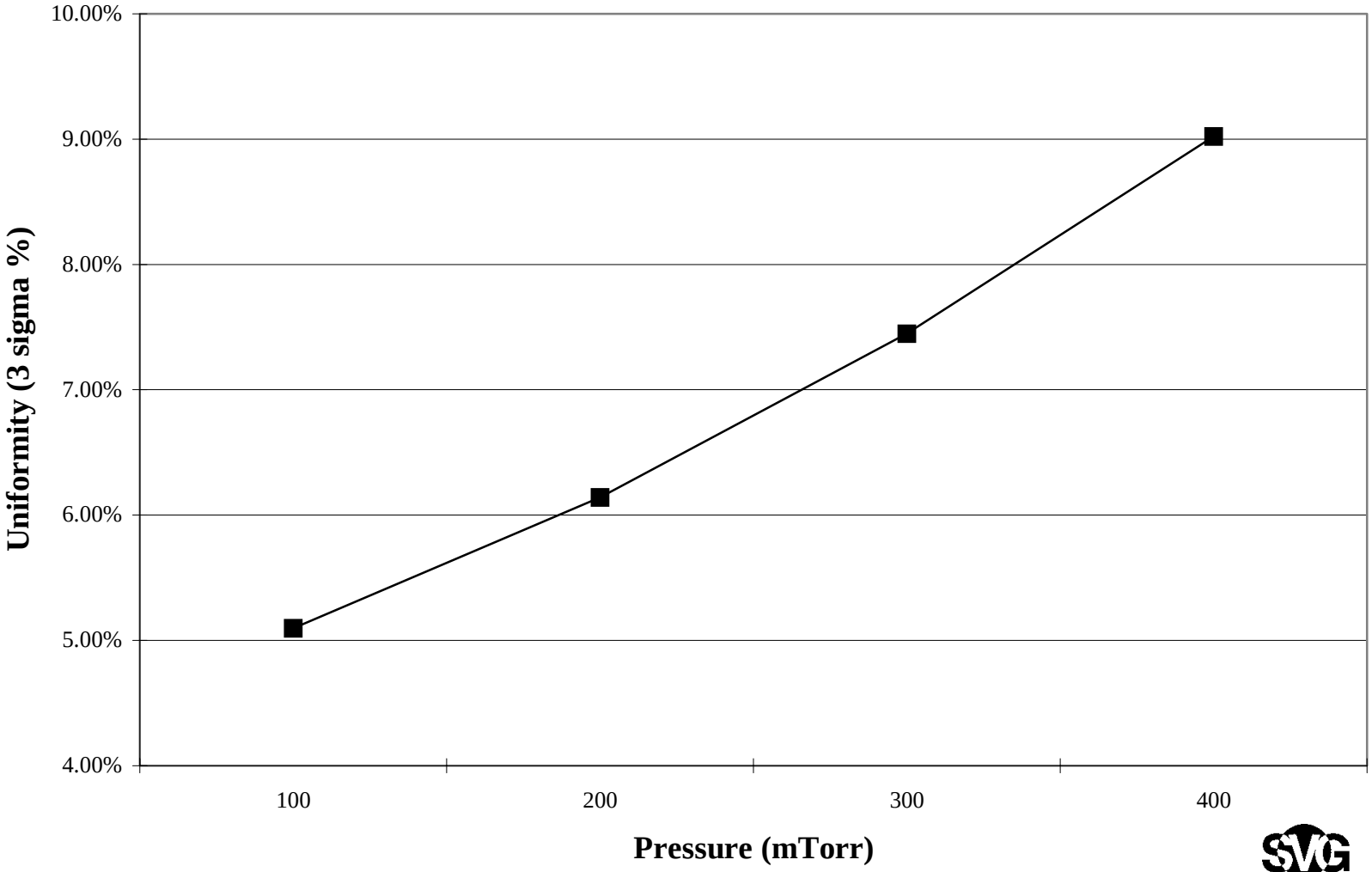

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Figure 6 - BTBAS Nitride
Pressure vs Deposition Rate for 0.5" Spacing,
575°C, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

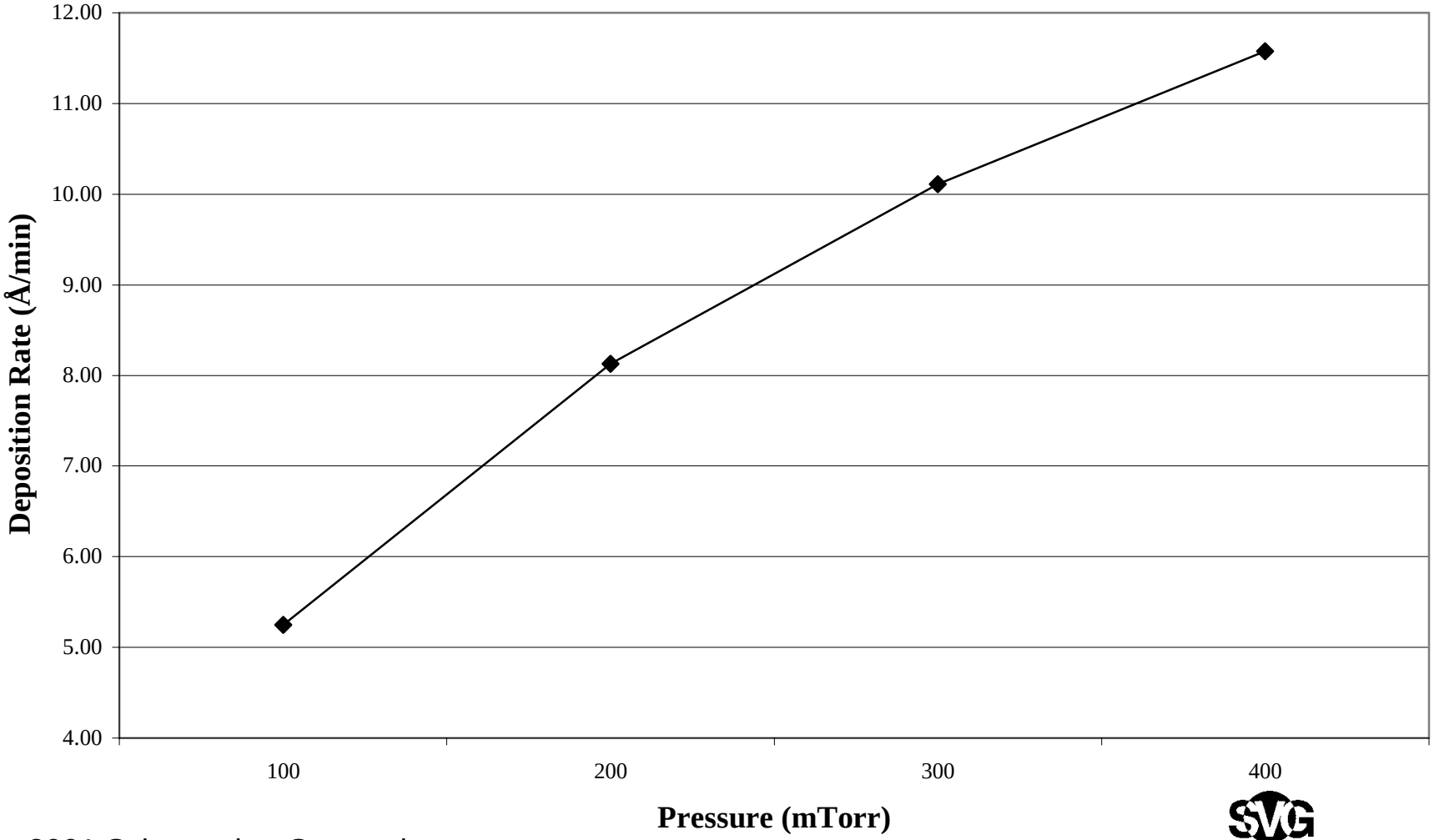

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Figure 7 - BTBAS Nitride
Pressure vs Refractive Index for 0.5" Spacing,
575°C, 2:1 Ratio NH3:BTBAS, 200 sccm Total Flow

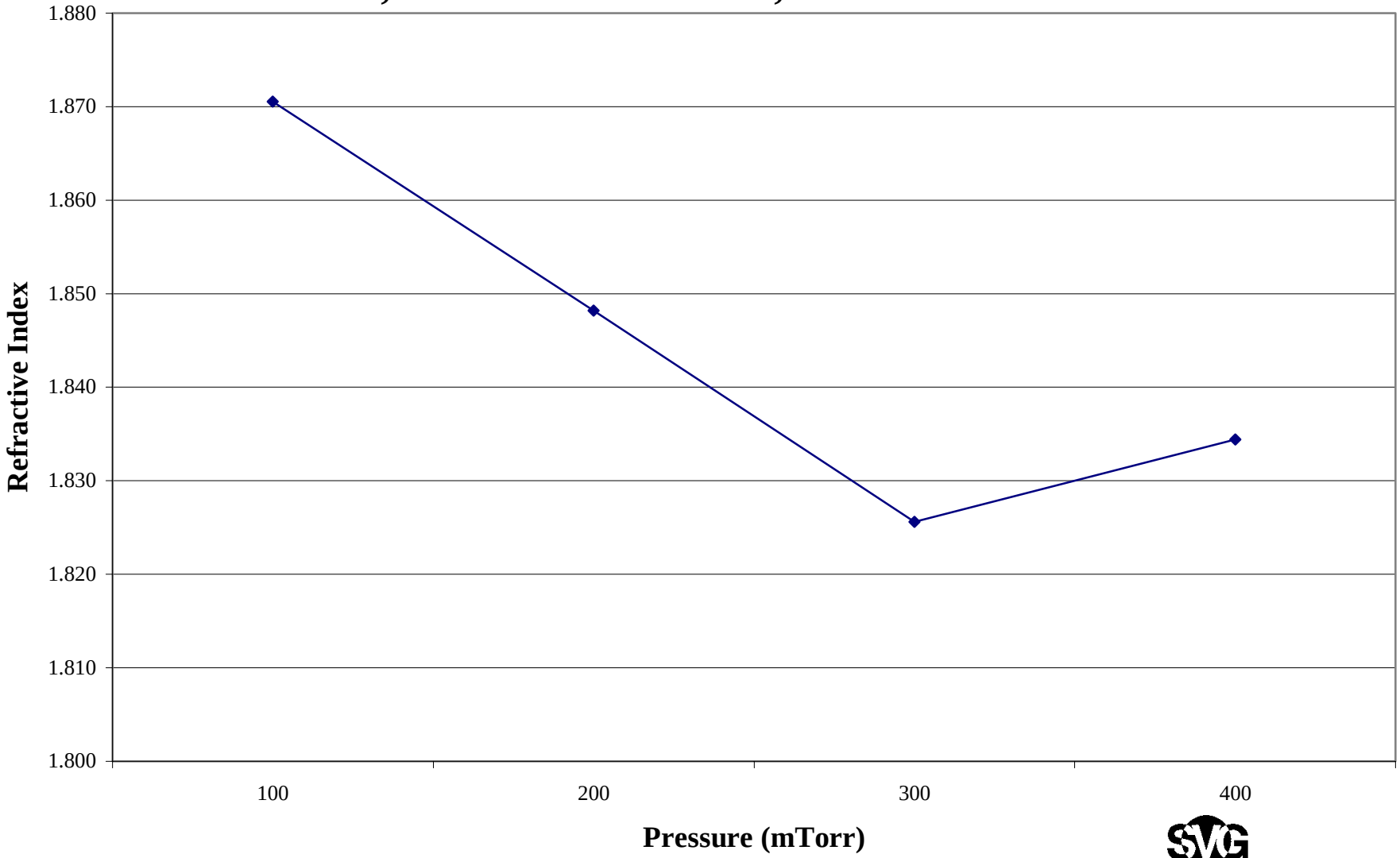

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Figure 8 - BTBAS Nitride
Total Flow vs Within Wafer Uniformity for 0.5" Spacing,
575°C, 2:1 Ratio NH3:BTBAS, 100 mTorr Pressure

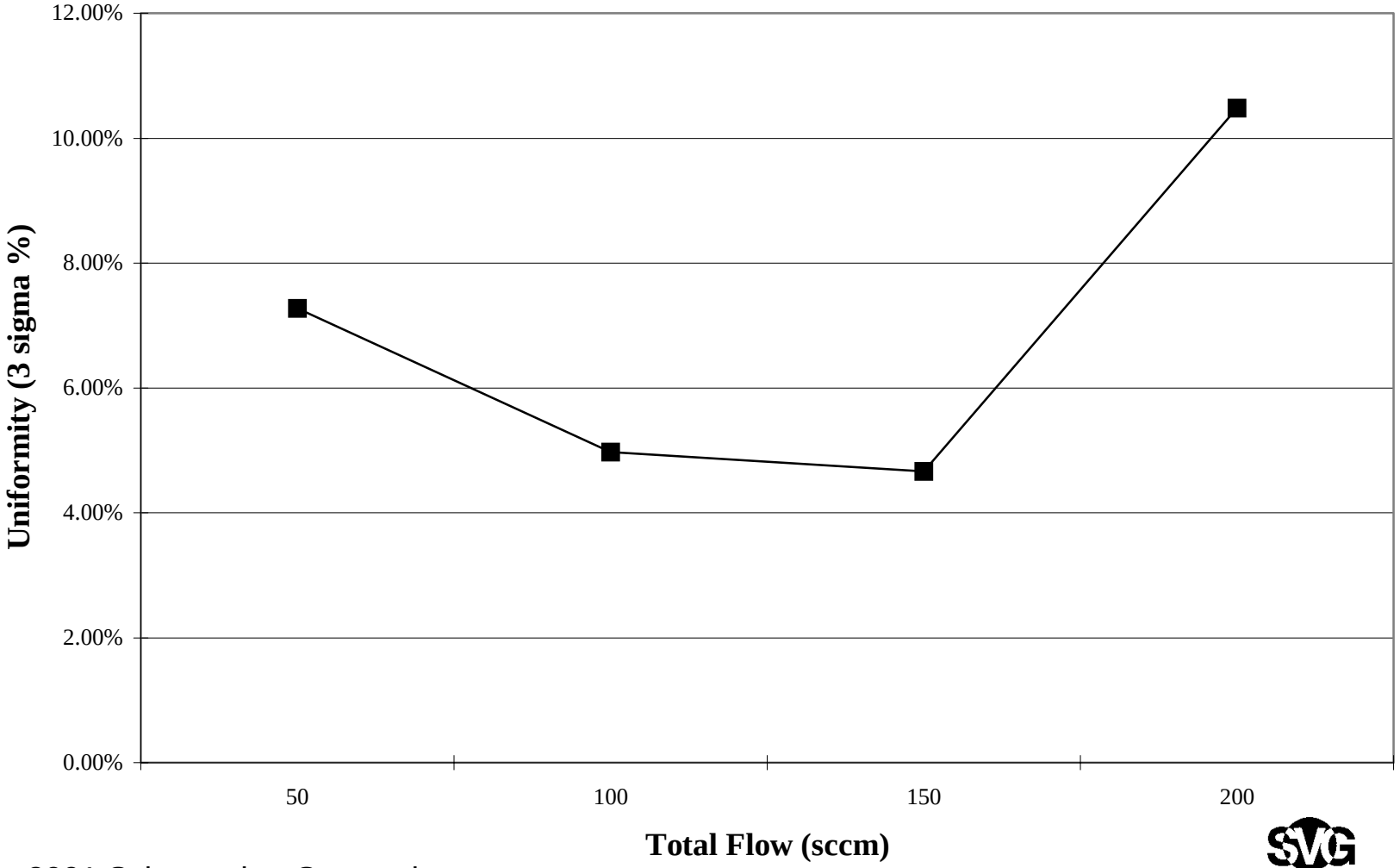

Figure 8 - BTBAS Nitride
Total Flow vs Refractive Index for 0.5" Spacing,
575°C, 2:1 Ratio NH3:BTBAS, 100 mTorr Pressure

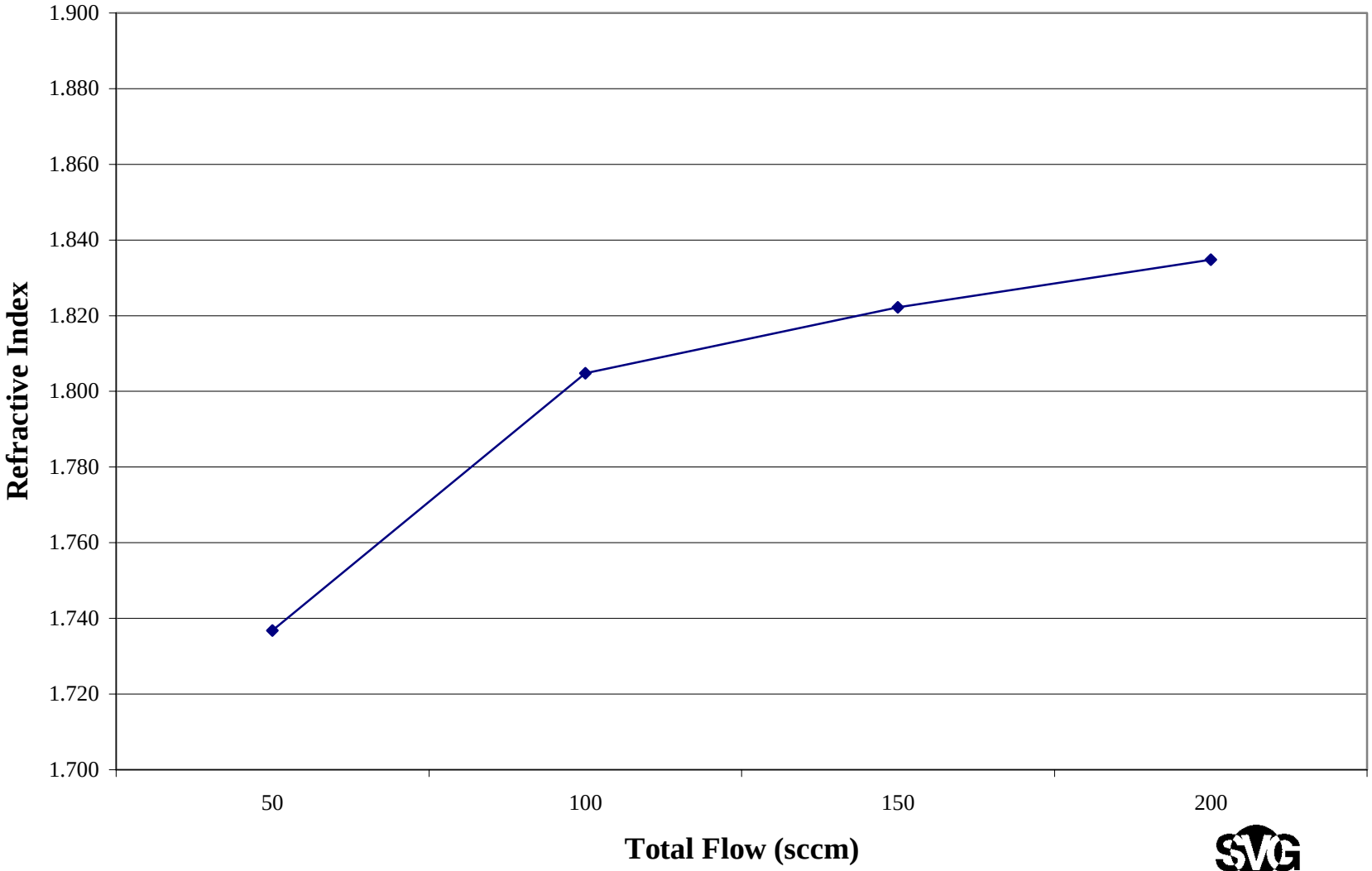

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Figure 10 - BTBAS Nitride
Total Flow vs Deposition Rate for 0.5" Spacing,
575°C, 2:1 Ratio NH3:BTBAS, 100 mTorr Pressure

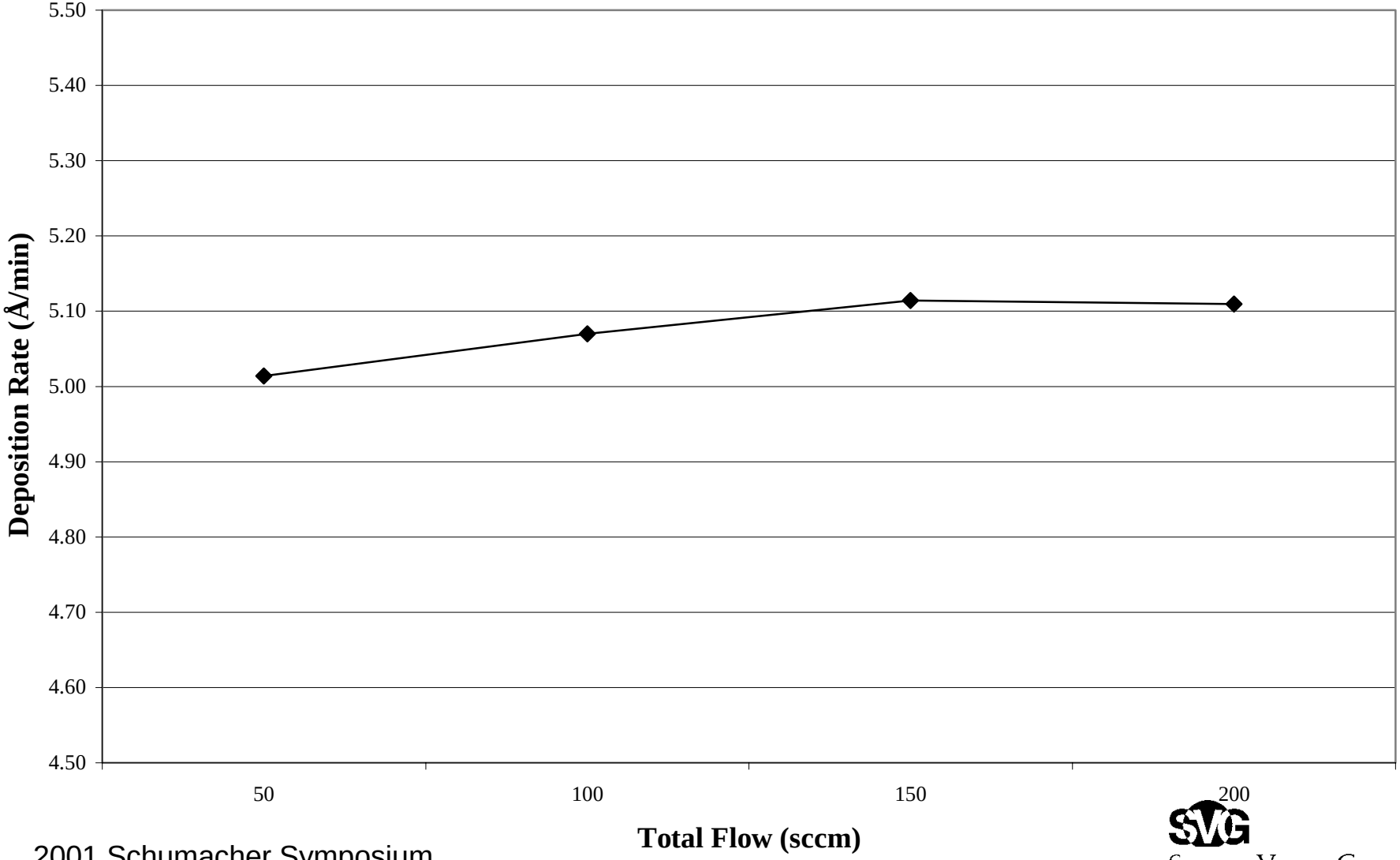

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Figure 11 - BTBAS Nitride
Ratio NH3:BTBAS vs Within Wafer Uniformity for 0.5" Spacing, 575°C, 100 mTorr Pressure, 150 sccm Total Flow

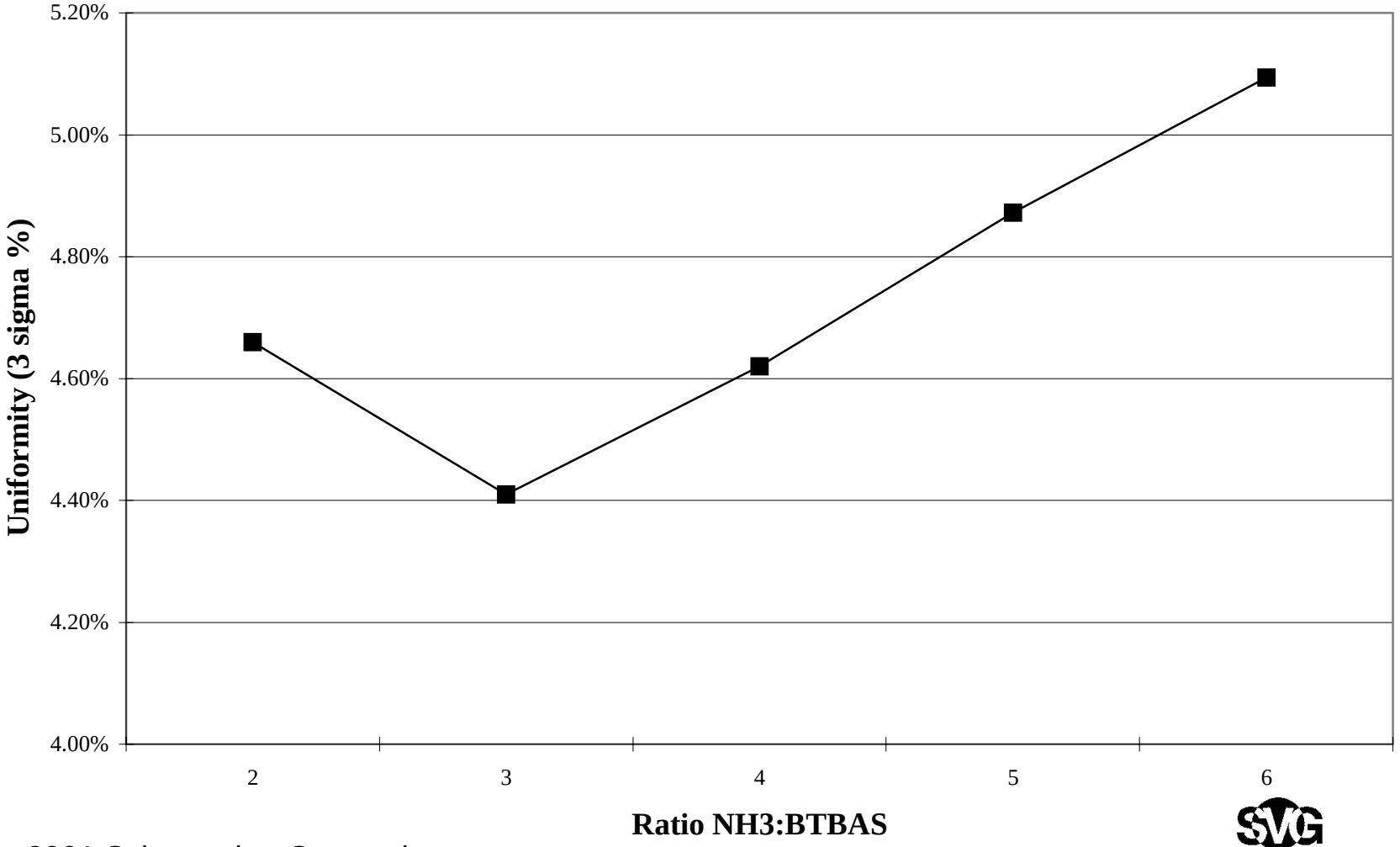

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Figure 12 - BTBAS Nitride
Ratio NH3:BTBAS vs Deposition Rate for 0.5" Spacing,
575°C, 100 mTorr Pressure, 150 sccm Total Flow

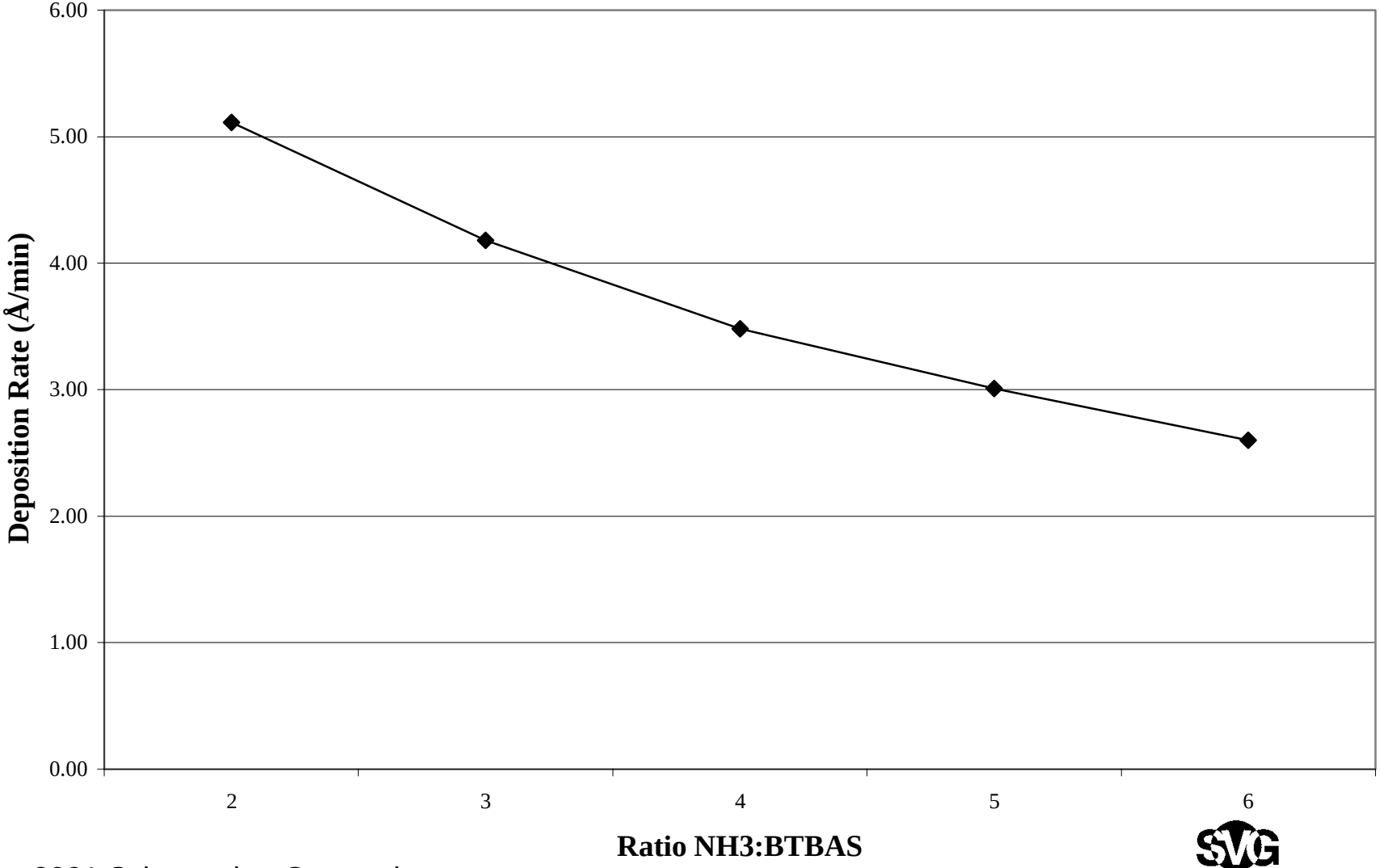

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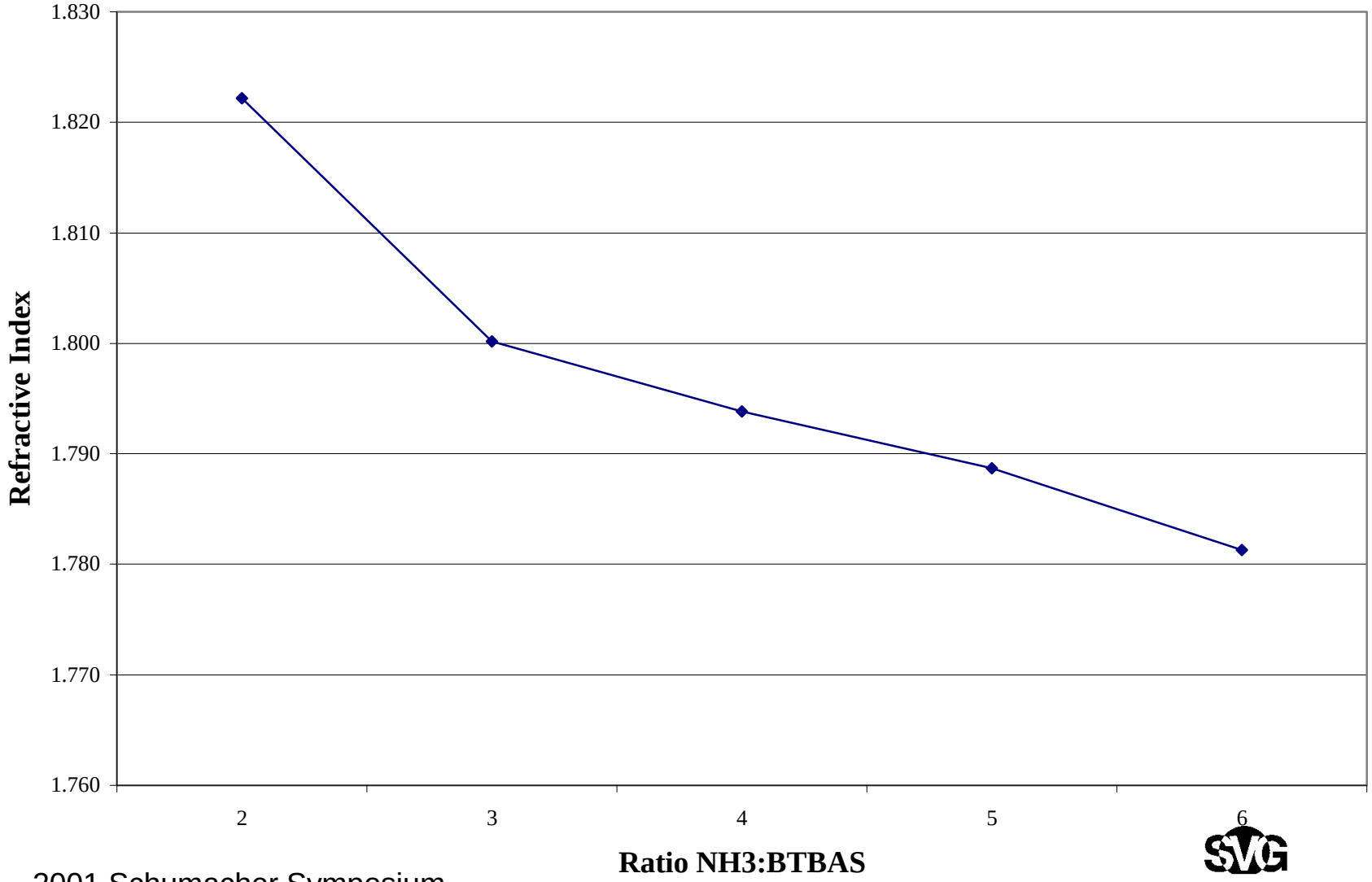
Figure 13 - BTBAS Nitride
Ratio NH3:BTBAS vs Refractive Index for 0.5" Spacing,
575°C, 100 mTorr Pressure, 150 sccm Total Flow



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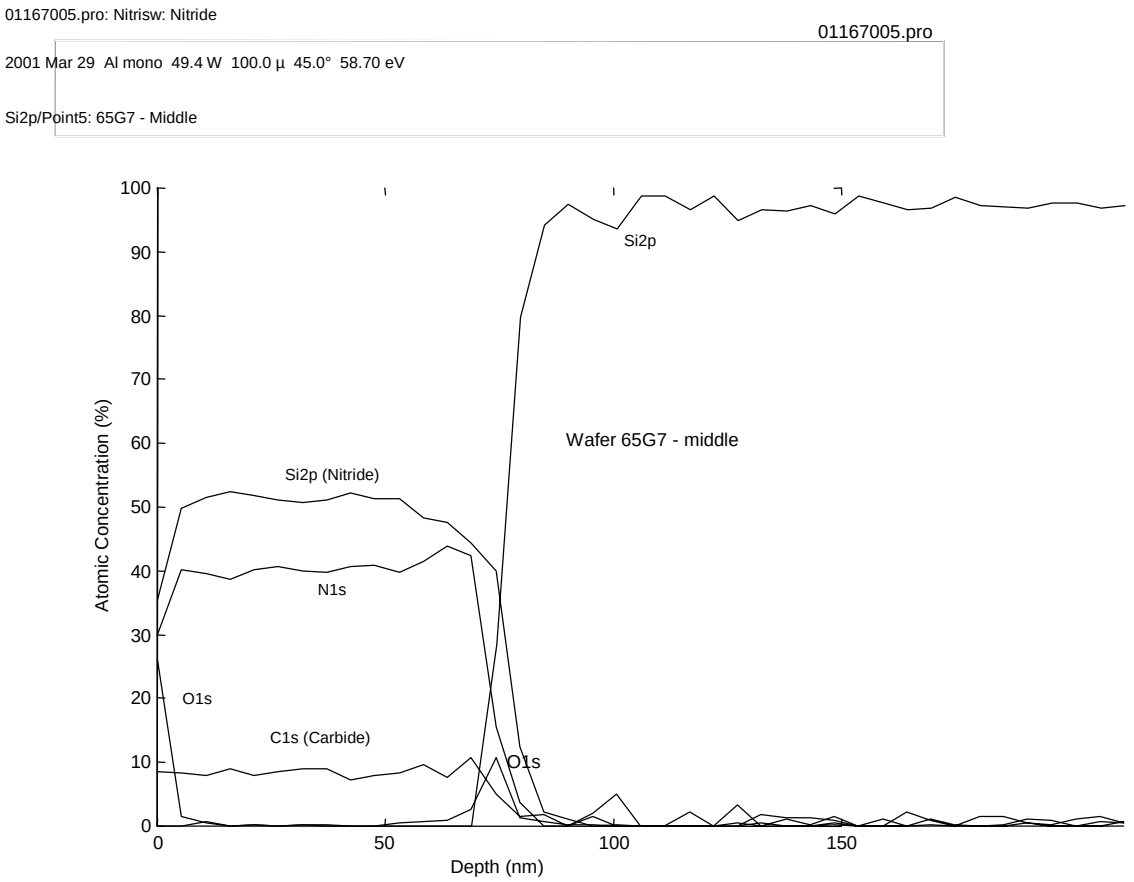
BTBAS Nitride 100 Wafer Loads (0.25 inch Wafer Pitch)

- Using previous knowledge from 0.5 inch wafer pitch tests
- Added new reduced diameter tube liner (240mm ID)
- Added Boat Rotation to improve uniformity within wafer
- "Best Process Conditions"
  - Temperature 560°C
  - Pressure 100 mT
  - Flows 150 BTBAS, 150 NH3
- Best Results:
  - Within Wafer <5% 3σ
  - Wafer to Wafer <3% 3σ
  - Refractive Index 1.91 to 1.93
  - Deposition Rate 3.3 Å/minute

Figure 14 X-ray Photoelectron Spectroscopy



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X-ray Photoelectron Spectroscopy

- Films deposited at 560°C and 610°C
- Thin oxide layer at the Si-SiN interface.
- Surface of the films have a thin oxide layer
  - may be adsorbed surface oxygen
- Si:N ratio in all the samples is near 5:4
  - films are silicon rich
- ~10% Carbon detected in all the SiN films
  - Carbon is present as a carbide (probably SiC)

BTBAS Nitride Advantages

- Liquid source
- Similar to TEOS - delivery, handling
- Vapor pressure of ~ 6.5 Torr at 45°C
- Reacts with Ammonia to form Silicon Nitride
- Temperature of deposition 550°C to 650°C
- More conformal than DCS or SiH_4 Silicon Nitride

BTBAS Nitride Limitations

- Best within wafer uniformities at lower temperatures
- Lower temperature = lower deposition rates
- Spacing is important -
  - (wafer pitch and wafer edge to liner)

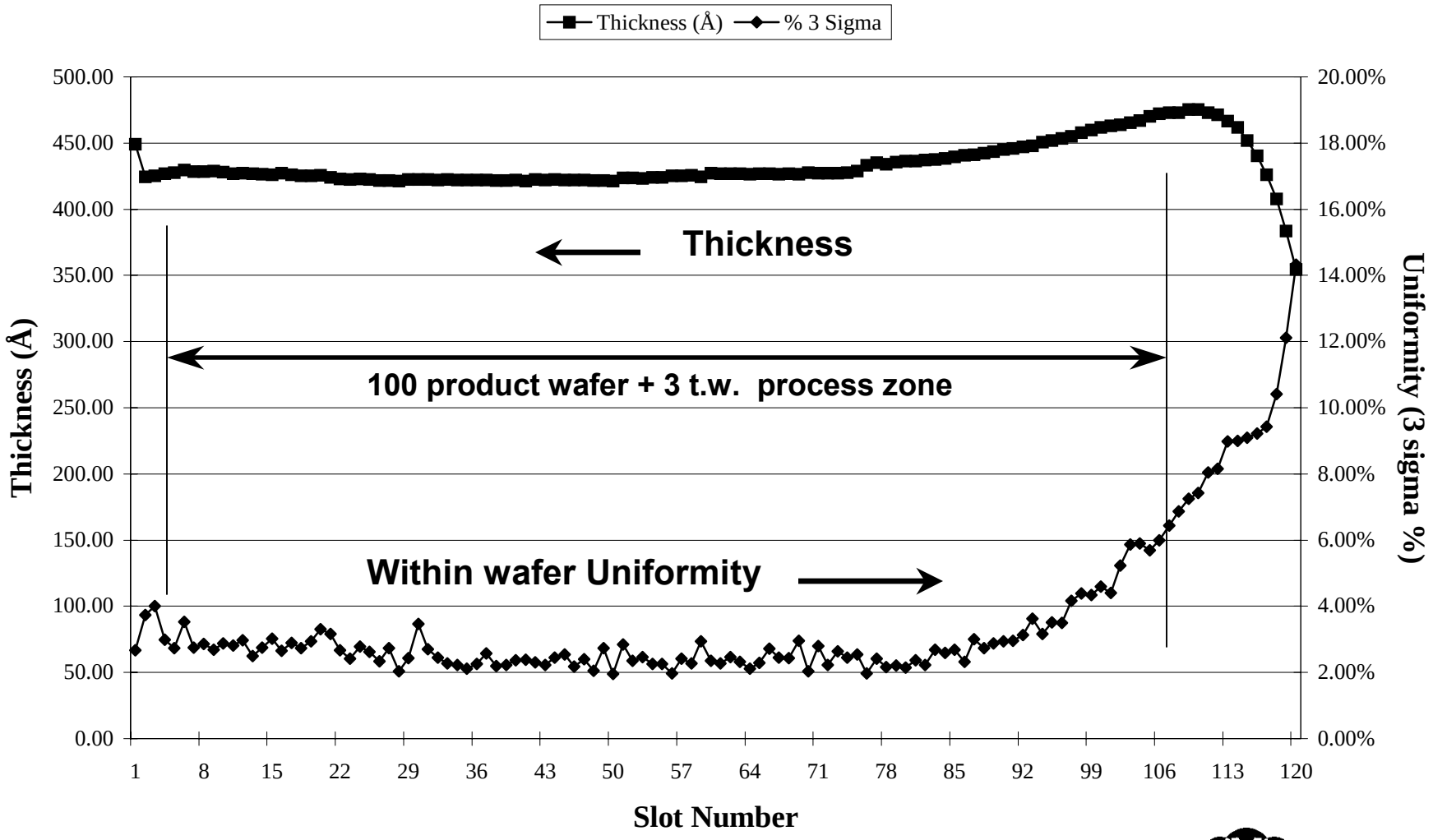
Wafer pit	**Loadsize**	**WIW Uniformity**
0.50 inch	50 product	< 4.5 % 3σ (std. Liner)
0.25 inch	100 product	< 6.5 % 3σ (std. Liner)
0.25 inch	100 product	< 5.0 % 3σ (reduced liner)

- Refractive Index 1.8-1.95 typical in these tests
- Refractive index decreases toward better WIW Unif.

Silicon Dioxide BTBAS Films

- Primary Process Window
  - Temperature 500 to 600°C
  - Total flow 200 to 500 sccm
  - O2: BTBAS Ratio 2:1 to 10:1
  - Pressure 150 to 450 mT
- Area of best results
  - Temperature 500°C
  - Total Flow 200 sccm
  - O2: BTBAS Ratio 2:1
  - Pressure 150 mT

Figure 15 - BTBAS Oxide - 120 Wafer Load (0.25" Spacing) - Not Optimized



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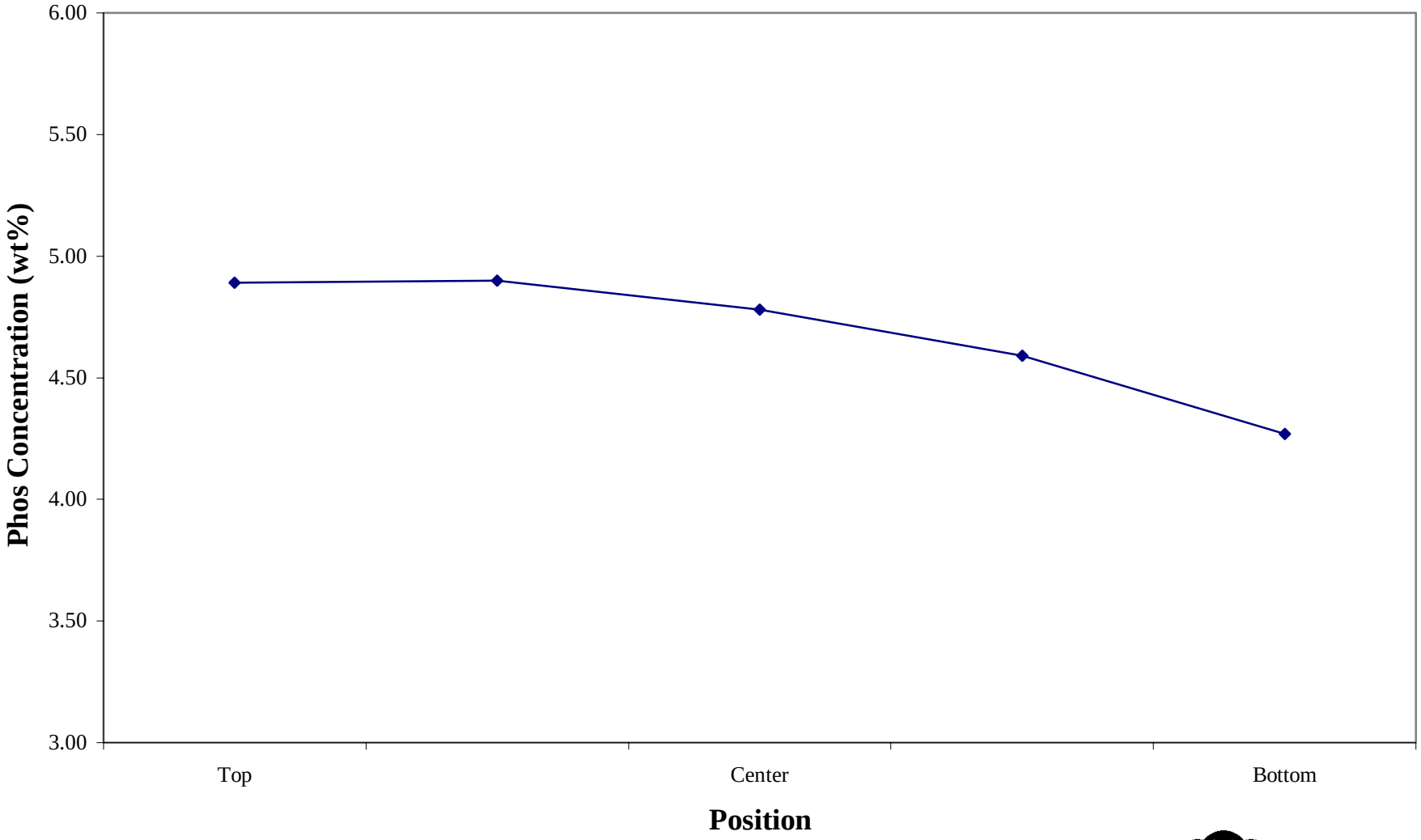
BTBAS Oxide
Etch Rate Comparison – 40:1 BOE

Run	Etch Rate Å/minute	Relative to Thermal Oxide	Deposition Temperature °C
BTBAS Ox1	6.17	2.32	575
BTBAS Ox5	6.18	2.32	575
BTBAS Ox7	6.00	2.25	575
TEOS	6.80	2.55	650
TEOS	6.50	2.44	650
Thermal Ox	2.66	1.00	NA

Phosphorus Doped Silicon Dioxide BTBAS Films

- Primary Process Window
  - Temperature 450 to 500°C
  - Total Flow 525 to 1600 sccm
  - O_2: BTBAS Ratio 2:1
  - PH3 mole ratio 1.4 to 5.0 E-2
  - Pressure 300 to 1000 mT
  - Phosphine Mixture 10% PH_3 in N_2

Figure 16 - Phosphorus Concentration Down Load For BTBAS Oxide



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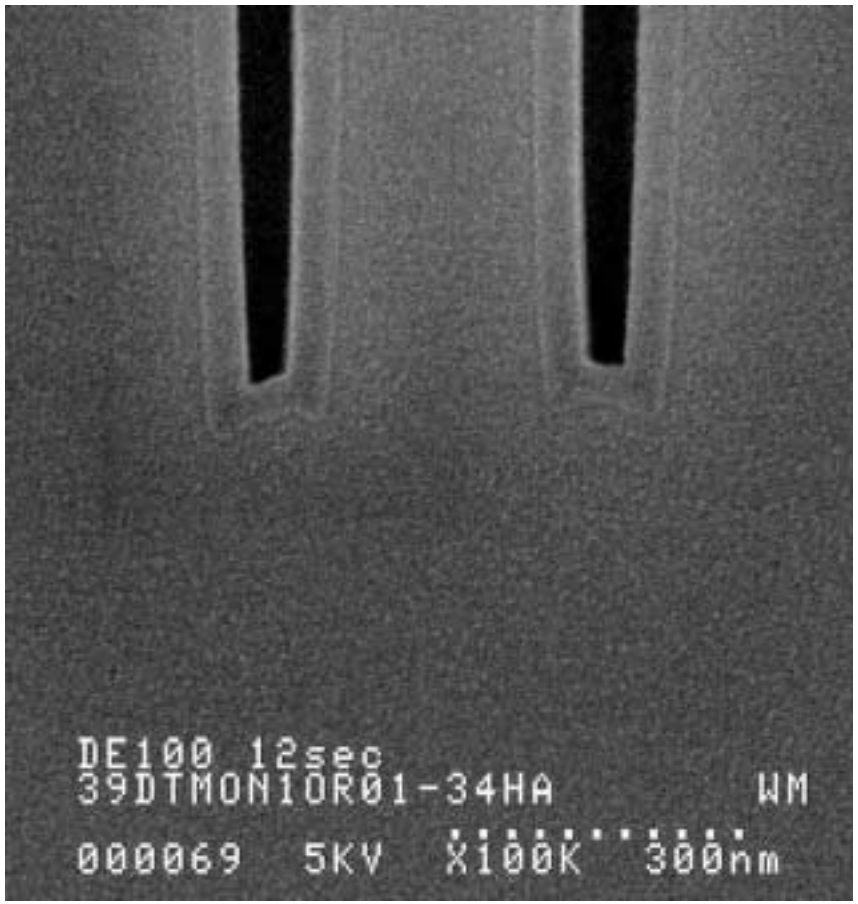
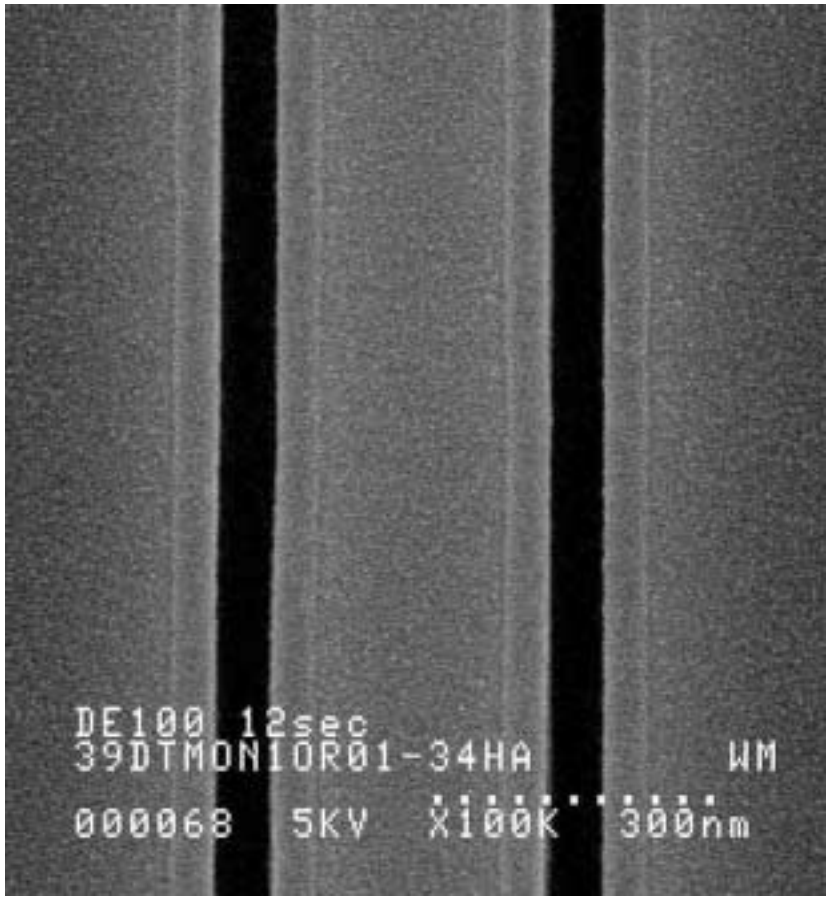
BTBAS Phos Doped Oxide Etch Rate Comparison – 40:1 BOE

Run	Etch Rate Å/minute	Relative to Thermal Oxide	Deposition Temperature °C
4.3 Wt%	7.84	2.94	500
5.5 Wt%	8.85	3.32	500
4.8 Wt%	10.48	3.94	475
6.4 Wt%	10.01	3.76	475
Thermal Ox	2.66	1.00	NA

BTBAS Oxide Step Coverage
Deep Trench Oxide Liner





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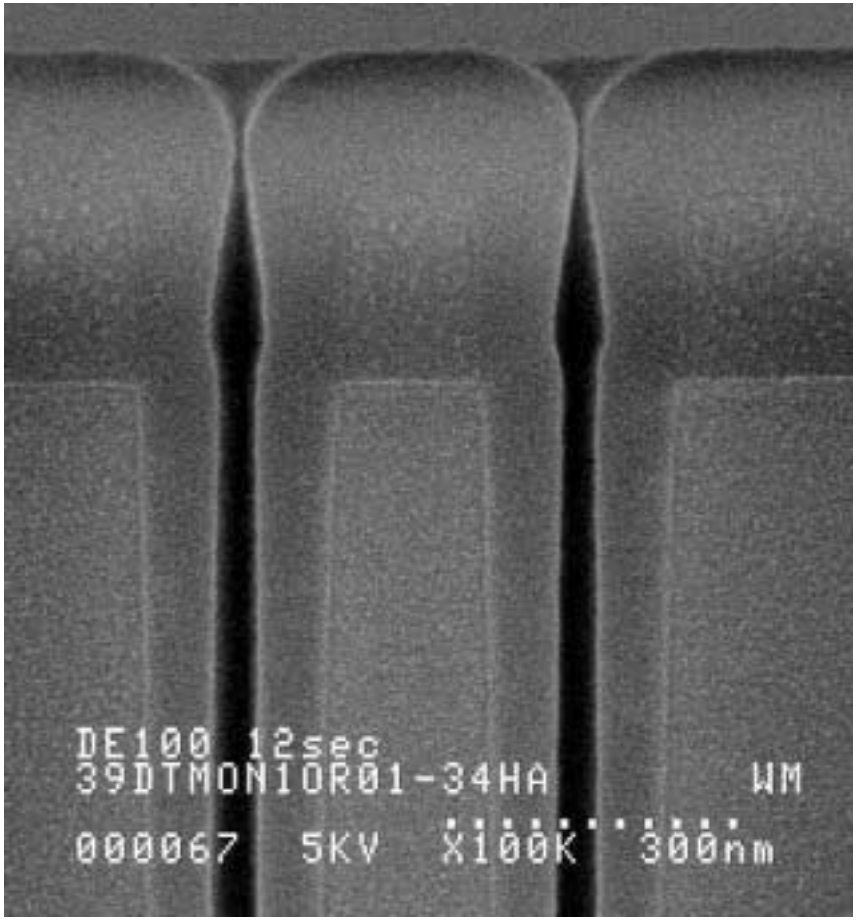
Step Coverage – Deep Trench



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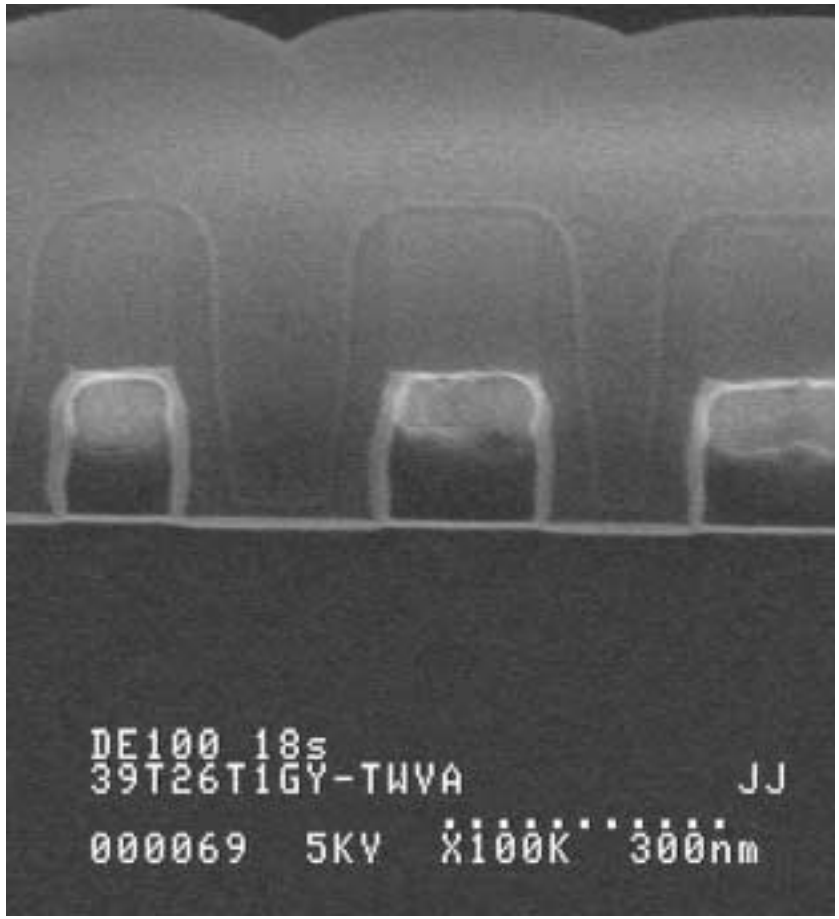
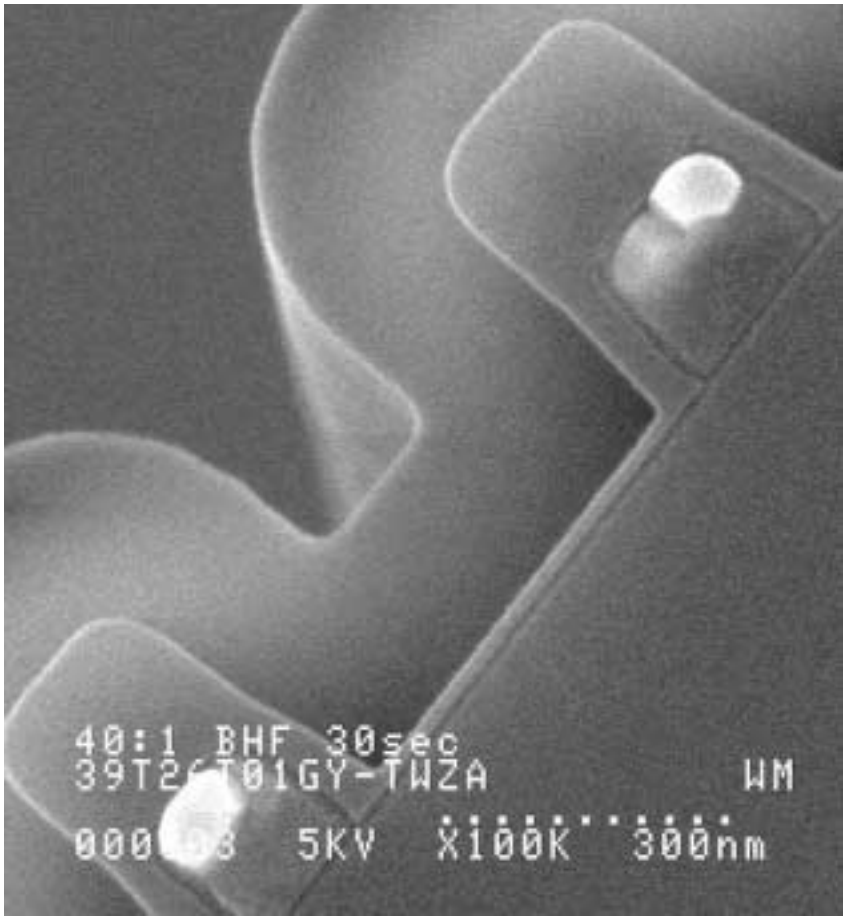
Step Coverage – Shallow Trench Isolation
BTBAS Oxide





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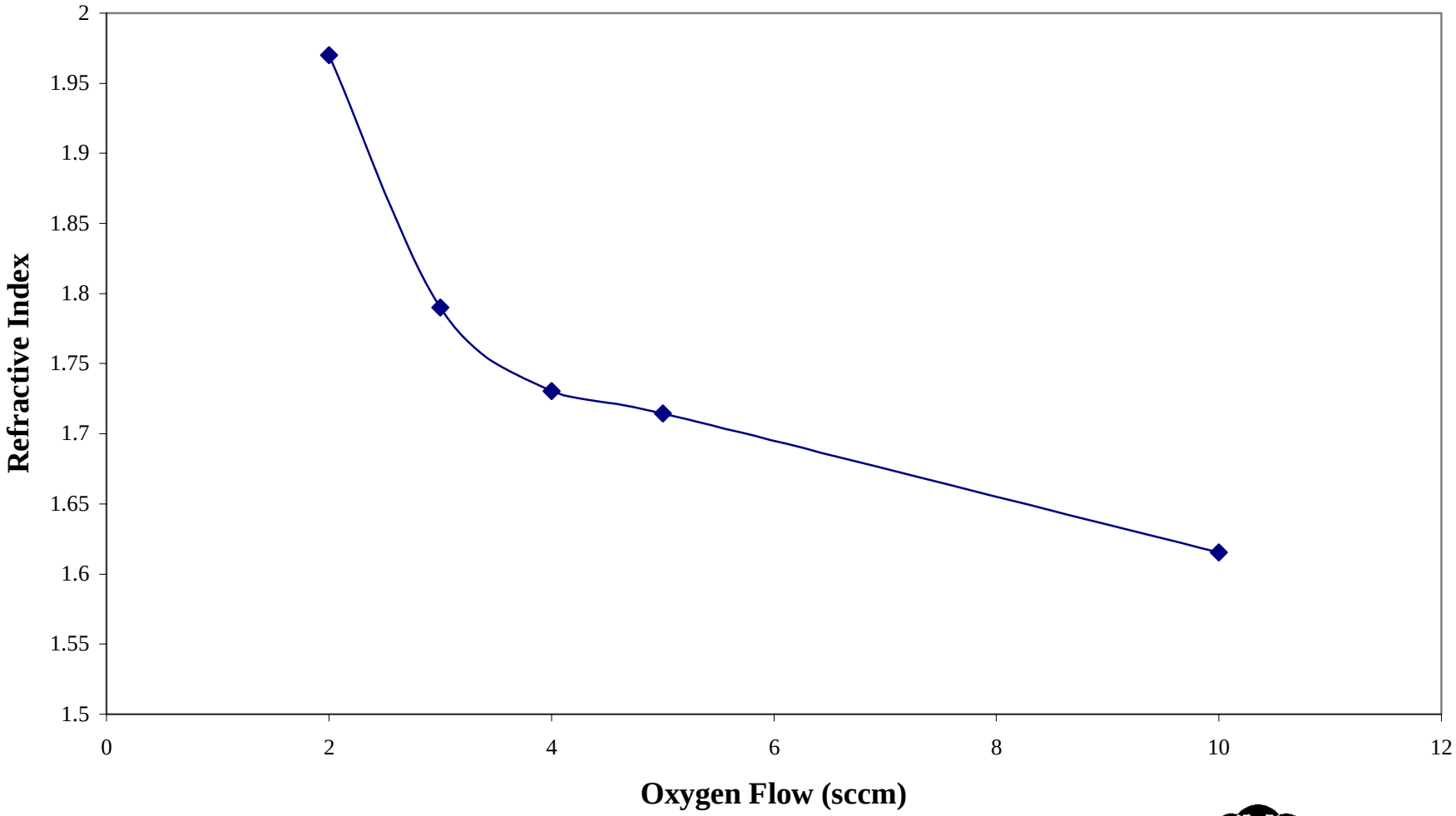
BTBAS Oxynitride

- BTBAS + NH_3 + O_2 or N_2O
- Tests run with O_2 only
  - N_2O not currently available on our system
- Standard BTBAS/NH_3 flows
  - Added very small amounts of O_2 (2 to 10 sccm)
- Pressure at 150 mTorr
- Refractive index = 1.62 to 1.97
- Index Uniformity = < 3% 3σ all points
- Wafer pitch = 0.5 inch
- Using Boat Rotation

Figure 17 - BTBAS Oxynitride Refractive Index vs Oxygen Flow
2:1 NH3:BTBAS, 560°C, 150 mT



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Conclusions

- **BTBAS films:**
  - **Nitrides, Oxides, Phosphorus Doped Oxides, and Oxynitrides can be produced in a Vertical Batch Furnace with good load size and uniformity**
- **Many device applications can be developed**
- **The SVG Apps Lab has a system dedicated to BTBAS film process demonstration and application development.**
- **We are willing to work with interested companies on potential device applications.**

Acknowledgements

We thank --

- Dr. David Brown at AMD Austin for XPS work on nitride
- BJ Park at IBM for Oxide and PSG etch rate and dopant analysis results
- Helen Marsh at the San Jose Applications Lab for running most of the experiments and making the film measurements