Chemical Vapor Deposition of Organosilicon Composite Films for Porous Low-k Dielectrics

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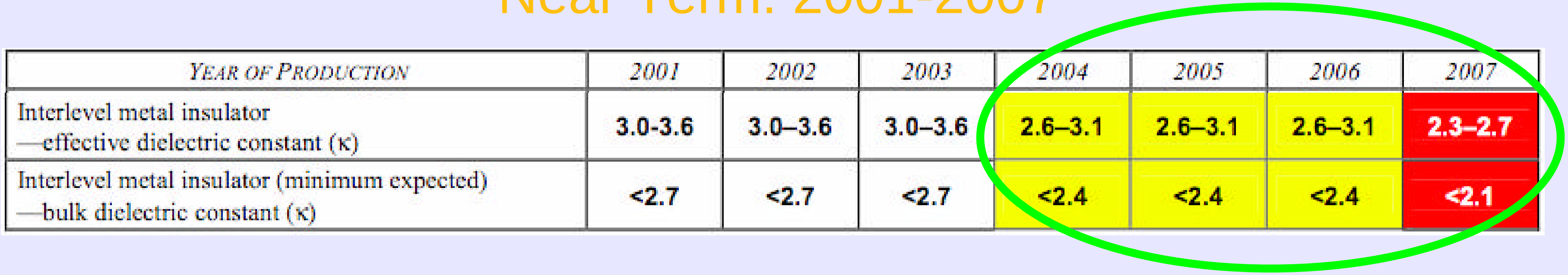
Motivation

Near Term: 2001-2007



YEAR OF PRODUCTION	2001	2002	2003	2004	2005	2006	2007
Interlevel metal insulator —effective dielectric constant (κ)	3.0-3.6	3.0–3.6	3.0–3.6	2.6–3.1	2.6–3.1	2.6–3.1	2.3–2.7
Interlevel metal insulator (minimum expected) —bulk dielectric constant (κ)	<2.7	<2.7	<2.7	<2.4	<2.4	<2.4	<2.1

Source: The International Technology Roadmap for Semiconductors: 2001

☐ **Manufacturable solutions exist**

🟨 **Manufacturable solutions are known**

🟥 **Manufacturable solutions are NOT known**

Motivation

- The widely used ILD material for 0.13μm and older technologies are PECVD SiO_2 and SiOF

Materials/ Technology	0.13μm or 0.09μm	0.07μm	0.05μm
Organic	SiLκ™, Flare™, Paralyne-F(N), αFC, PAE,etc.	Porous SiLκ™, Porous Flare™, OXD, etc	Partial Air Gap, Complete Air Gap
Organosilicates	Carbon Doped Oxide, SOG, etc.	Porous CVD CDO, Porous SOD, CDO, etc.	Partial Air Gap, Complete Air Gap
Range of κ	2.8 to 3.0	1.9 to 2.6	1.0 T to 1.5

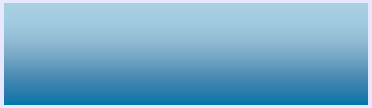
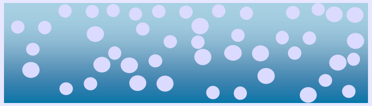
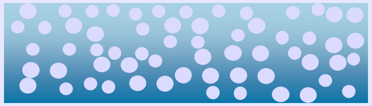
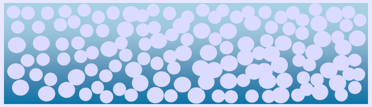
Dr. Eb Andideh, Intel Corporation
(2003, MIT hosted ERC teleconference)

Goals

- Create a Porous, Low-κ Film by CVD
  - Rigid Organosilicon Matrix
  - Thermally Labile Porogen
  - Deposition by Pulsed Plasma Enhanced CVD

Composition	Fully dense κ
SiO_2	4.0
Si:O:C:H (Organosilicate Glass - OSG)	2.7-3.0

Air
$\kappa = 1.0$

	% Porosity	k
	0	2.7
	20	2.3
	50	1.75
	90	1.15

Solventless Low k Dielectrics

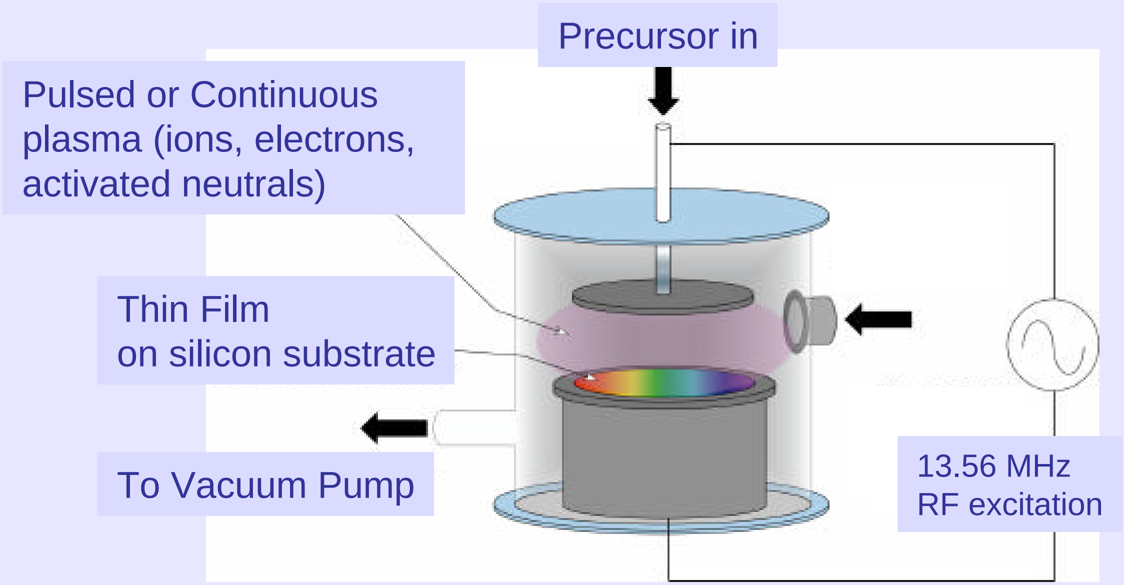
A. Manufacturing Metrics (Effect on Performance, Yield, and Cost)

Replacing the silicon dioxide (SiO_2) interlevel dielectric layers in microprocessors with films of lower dielectric constant, κ, increases the speed, reduces the power consumption, and decreases the crosstalk between adjacent metal lines. The lowest dielectric constant leads to the fewest levels of interconnect, resulting in an economic and environmental "win-win". Spin-on process for low κ dielectrics such as SIlk (Dow) have the potential for high waste and solvent-related ESH concerns. Plasma CVD process are another possible candidate for the manufacture of low κ dielectrics.

B. ESH Metrics

	Usage Reduction			**Emission Reduction**			
Goals / Possibilities	**Energy**	**Water**	**Chemicals**	**PFCs**	**VOCs**	**HAPs**	**Other Hazardous Wastes**
Hot Filament CVD for $\kappa < 2.2$	HFCVD uses 5-60% less power than plasma CVD	NA	2.2% utilization for HFCVD >> plasma CVD or spin on	TBD {reduction compared to plasma CVD (fewer chamber cleans may be required)}	Great reduction vs spin-on ~ same as plasma CVD	Some reduction in acid vapors	NA

Pulsed Plasma Enhanced CVD



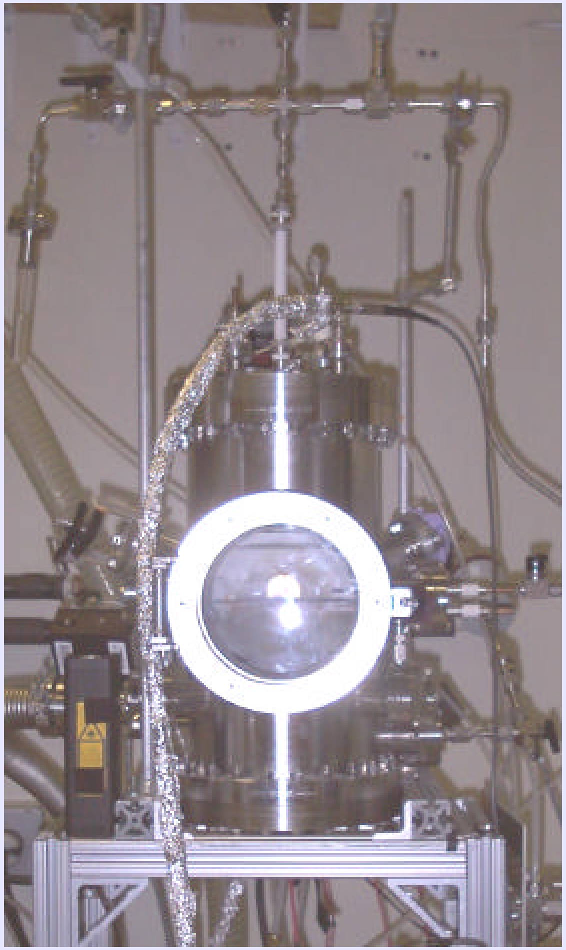
Precursor in

Pulsed or Continuous plasma (ions, electrons, activated neutrals)

Thin Film
on silicon substrate

To Vacuum Pump

13.56 MHz
RF excitation

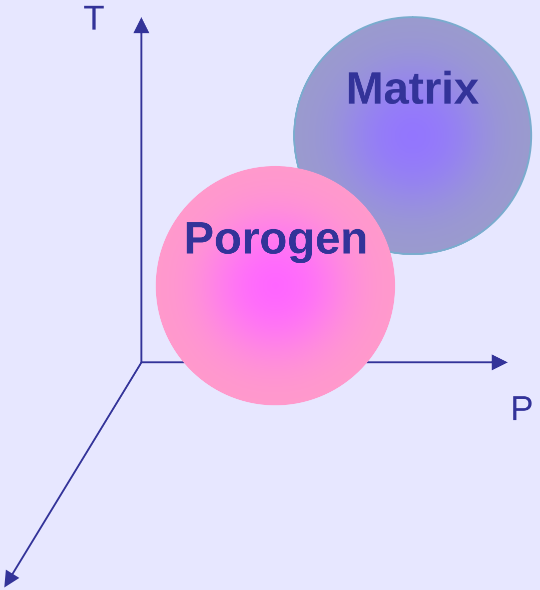


Typical Operating Parameters

pressure	*300 mTorr*
peak power	*100-300 W*
duty cycle	10-25%
substrate temp	*cooling water*
precursor flow rate	*0 - 20 sccm*

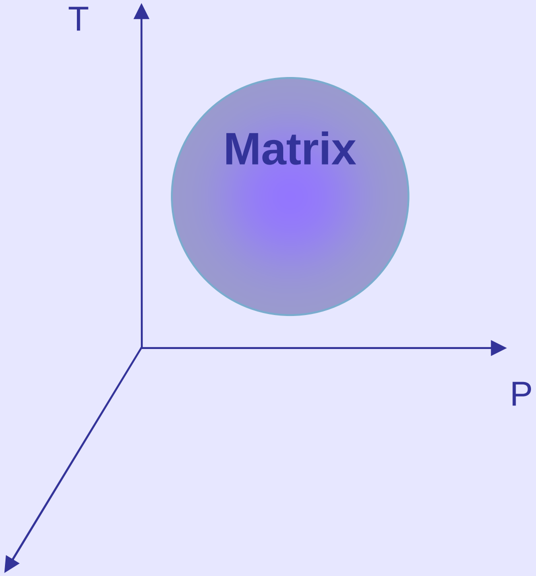
Composite Materials

Co-deposition of Porogen and Matrix Materials



Processing Conditions

Polystyrene Beads as Porogen–Matrix Deposition Independent

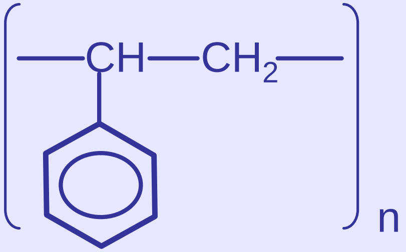


Processing Conditions

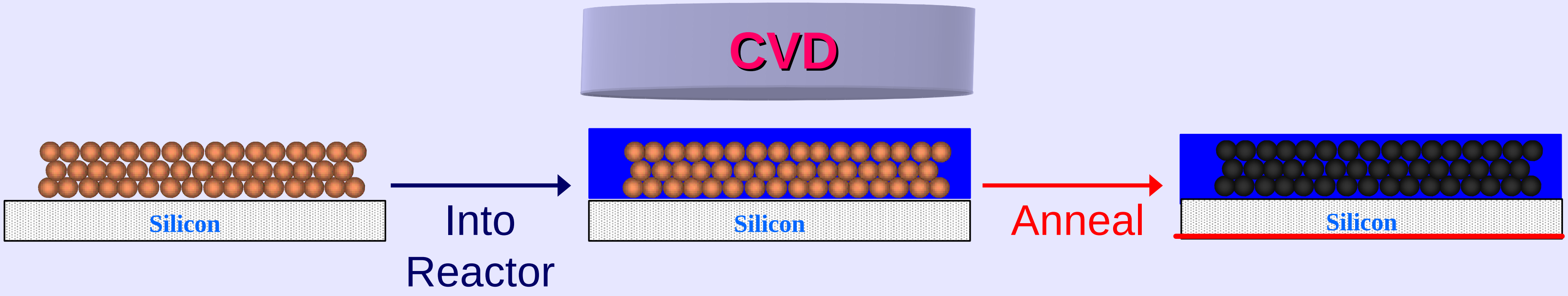
Decouple Processing Windows

Porogen: Polystyrene Beads

- Controlled Pore Size & Distribution
- Distributed Over Large Area
- Bead Diameters: 15nm (std = 3), 96nm (std = 9)
- No Covalent Bonding
- Decompose under 400°C
- Health=0, Flammability=1, Reactivity=0
- 1% Styrene in Air: Health=1, Flammability=0, Reactivity=1

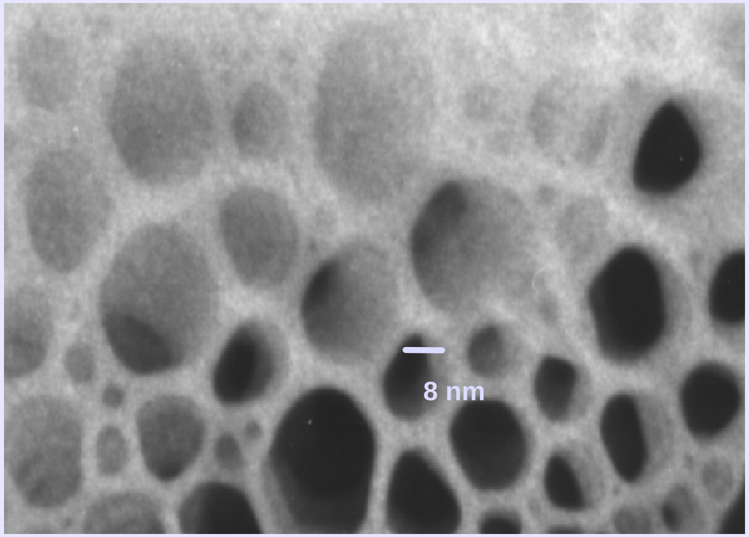


Proof of Concept



Into Reactor

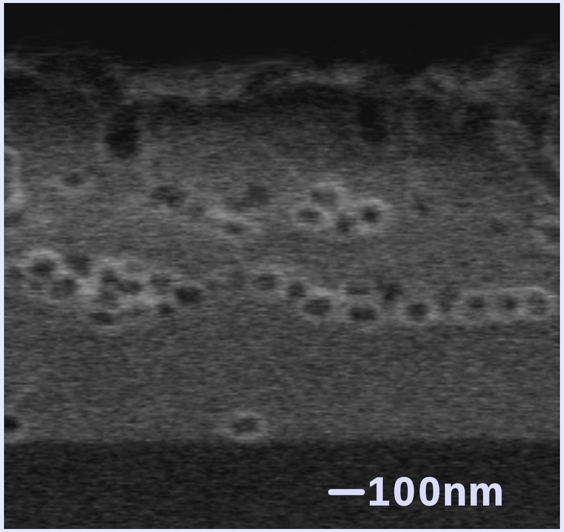
Anneal

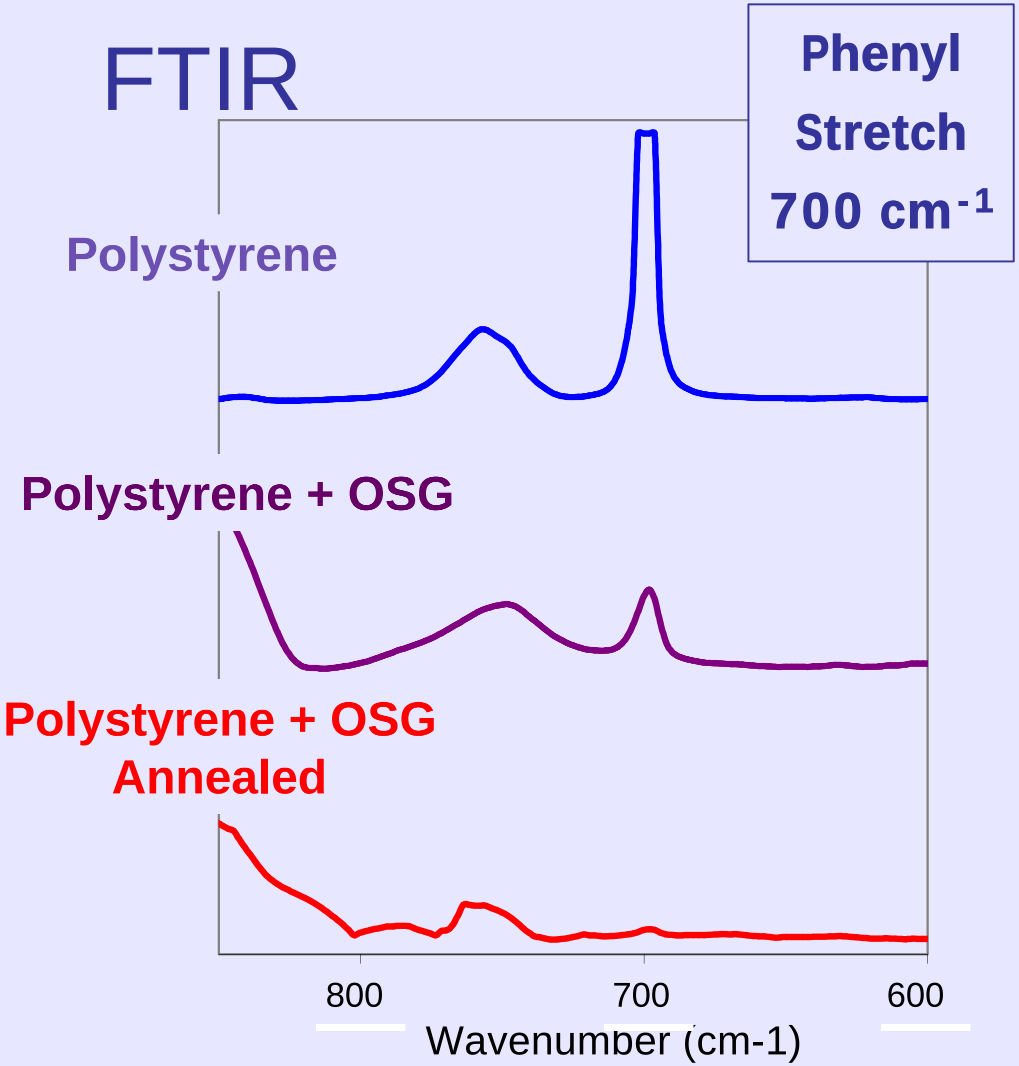


dielectric constant 1.4
refractive index 1.067
(Qingguo Wu)

- ☑ Non-collapsing Structure
- ☒ Variable Porosity
- ☒ Manufacturable Process

Alternating Bead-Matrix Deposition

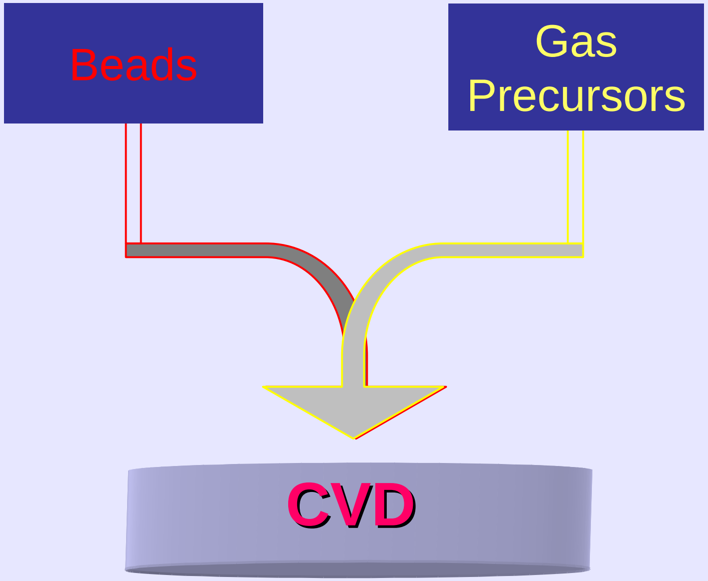




- ☑ Non-collapsing Structure
- ☑ Variable Porosity
- ☒ Manufacturable Process

Sequential Vacuum Deposition

- ☑ Non-collapsing Structure
- ☑ Variable Porosity
- ☐ Manufacturable Process

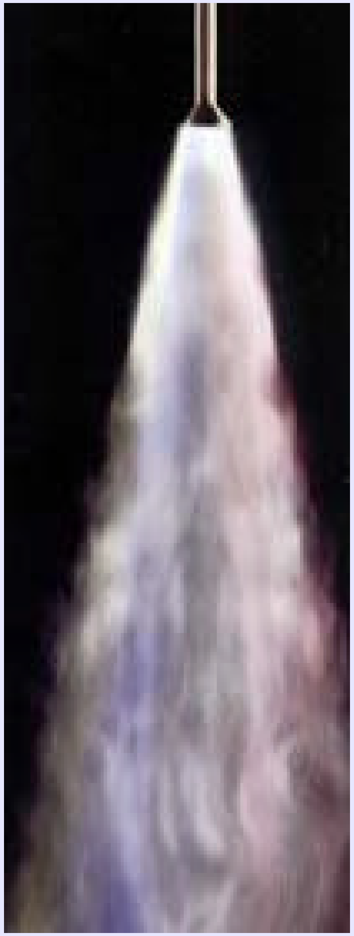

Beads

Gas Precursors

CVD

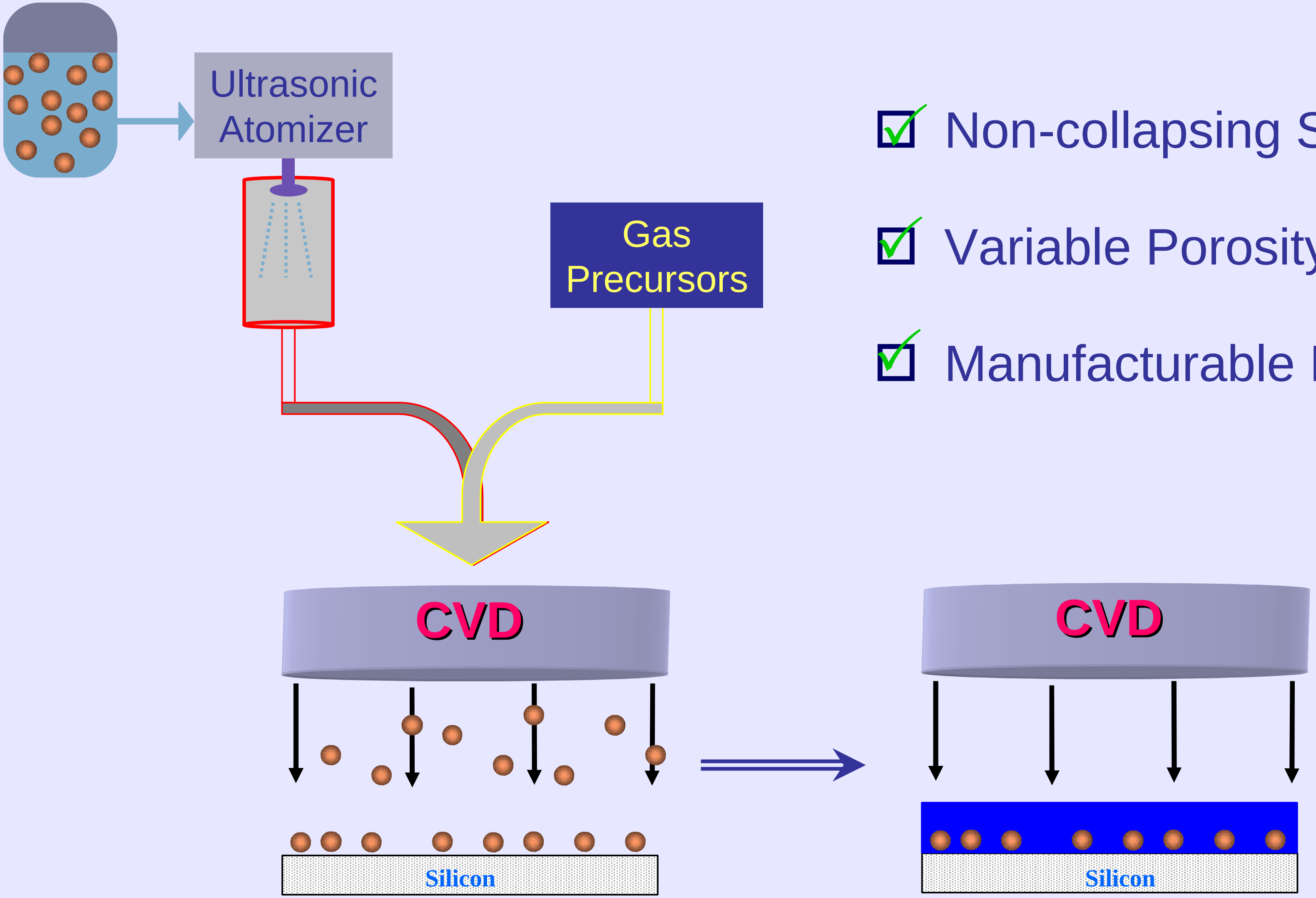
Sequential Vacuum Deposition

Ultrasonic Atomizer



- Uses low ultrasonic vibrational energy for atomization
- Dispenses microliters/min
- Continuous or intermittent spray
- Pressureless atomization
- Can handle up to 30% solids

Sequential Vacuum Deposition



- ☑ Non-collapsing Structure
- ☑ Variable Porosity
- ☑ Manufacturable Process

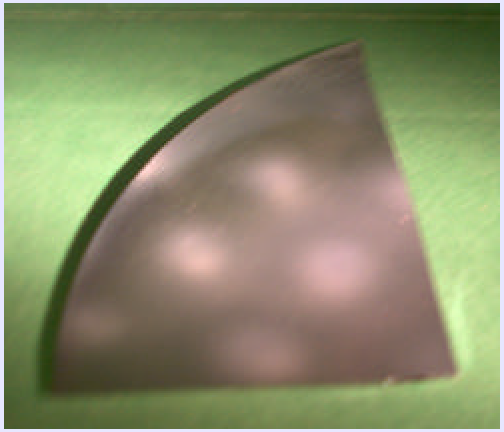
Processing Conditions

- Gas flowrate (20-100 sccm)
- Liquid flowrate (100-5000 µL/min)
- Chamber pressure (3 – 5 torr)
- Temperature (20 – 30°C)
- Bead Concentration (0.0005 – 0.05% solids)

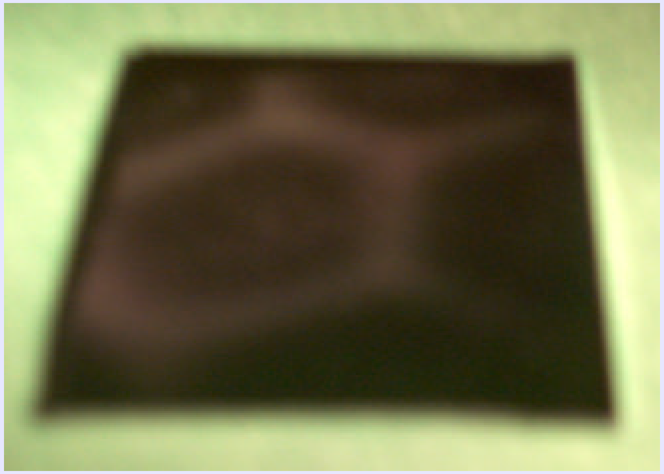
Bead Distribution

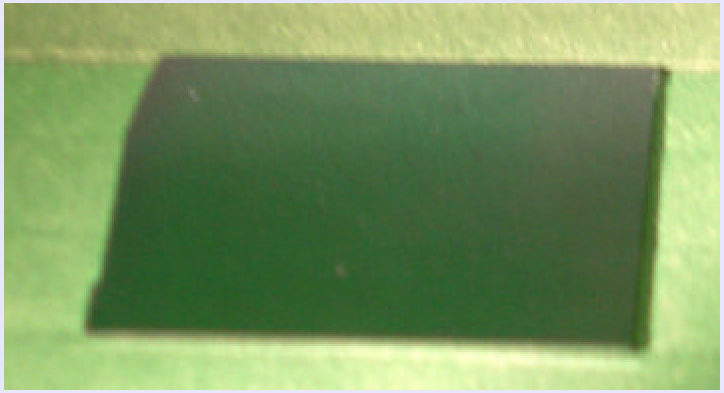
- Effect of Gas Flowrate

Low Gas Flowrate

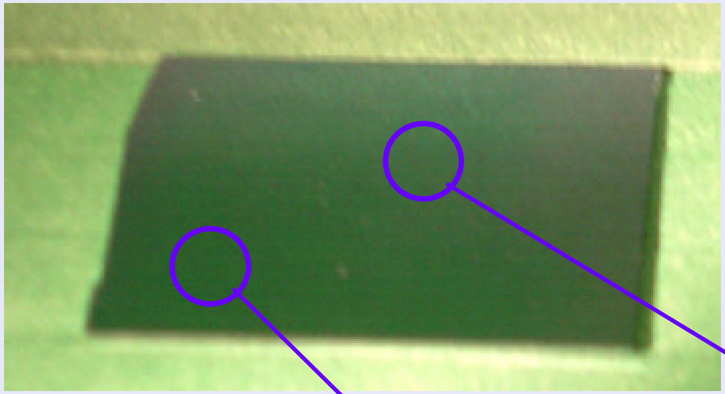


High Gas Flowrate

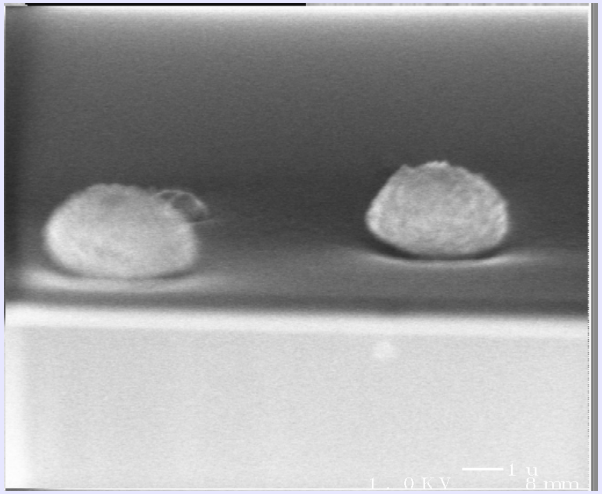


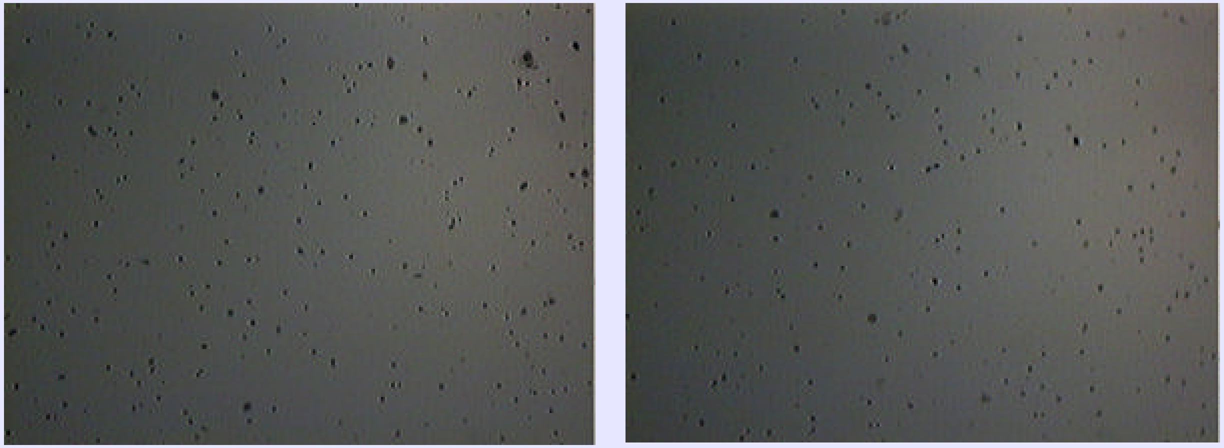


Bead Distribution



SEM





Optical Microscopy
Magnification: 500x
~4% beads by area

Conclusions

- Polystyrene beads viable porogen
  - Spherical voids created in CVD films
  - Dielectric constant = 1.4

- Sequential Vacuum Deposition
  - Ultrasonic Atomization
  - Compatible with current CVD process
  - Controlled Degree of Porosity

Acknowledgments

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- MIT MRSEC Shared Facilities supported by the NSF
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- Gleason Research Group