Modeling and Analysis of Extrusion-Spin Coating: An Efficient and Deterministic Process for Photoresist Coating Method in Microlithography

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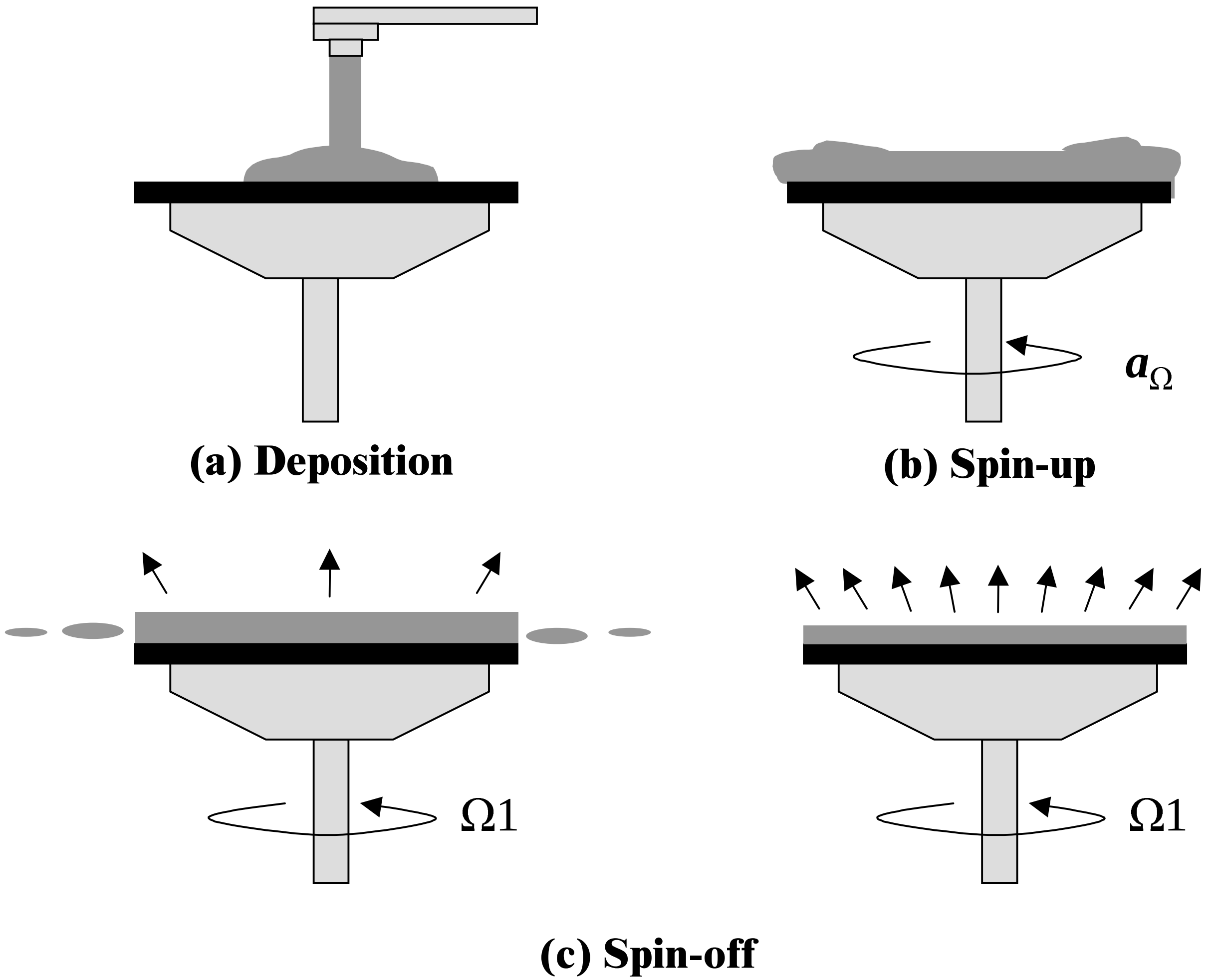
PRESENTATION OUTLINE

- Introduction
- Extrusion-Spin Coating
- Modeling
- Experimental Apparatus
- Process Variables for Extrusion-Spin Coating
- Experimental Results and Analysis
- Conclusions and Future Work

INTRODUCTION

- **Microlithography**
- **Spin Coating**
- **Problems with Spin Coating**
- **Motivation of Research**
- **Goals**
- **Comparison of Spin Coating and Extrusion-Spin Coating**

Spin Coating



Problems with Spin Coating

- An initial coating layer is established using an inefficient coating method (~70% waste)
- Proper amount of photoresist to obtain specific coating thickness and uniformity is unpredictable
  - Photoresist is wasted if too much is applied
  - Incomplete coverage or defects occur if too little is applied *

*: David J. Elliot. Microlithography: Process Technology for IC Fabrication. McGraw-Hill

Motivation of Research

- **Unpredictable coating thickness and uniformity**
- **Increase in cost of photoresist ($500/gallon to $2000/gallon)**
- **Environmental problem**

Goals

- **Improve photoresist coating efficiency (< 1 ml for 200mm wafer)**
- **Maintain coating uniformity (Standard deviation σ of 6 Å within a wafer)**
- **Develop a deterministic process to predict coating results**

Background

- **Key assumptions:**
  - **Wafers are initially entirely covered with photoresist**
  - **Properties of photoresist remain constant during coating process**

- **Spin coating models**
  - **Emslie et al. (without evaporation)**

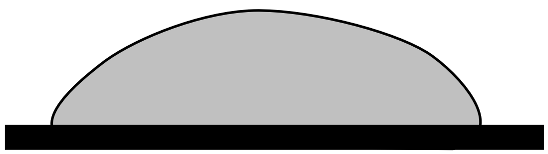
$$h_f \sim \frac{h_0}{[1 + 4(\rho\omega^2/3\mu)h_0^2 t]^{1/2}}$$

  - **Bornside et al. (with evaporation)**

$$h_f = (1 - x_0)\left[\frac{3\mu_{PR}}{2\rho\omega^2}\left(\frac{p^* M}{R_g T}\right)k x_0\right]^{1/3}$$

Comparison of Spin Coating and Extrusion-Spin Coating

Conventional Spin Coating



Deposition: Deposit resist onto wafer

Spin-up: Accelerate wafer to obtain initial coating thickness

Spin-off: Spin at high speed to final thickness

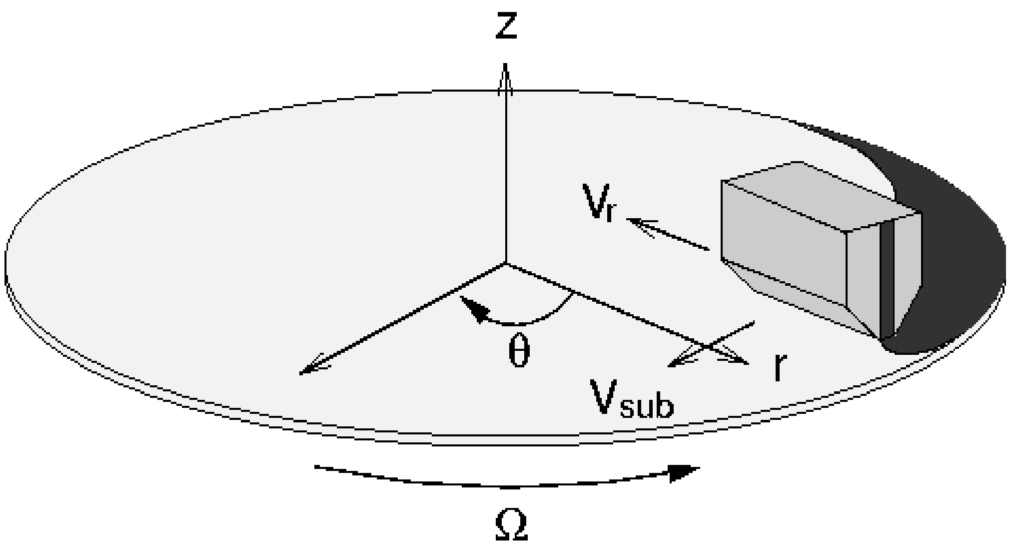
Extrusion-Spin Coating

Deposition: Apply thin layer of resist by extrusion coating

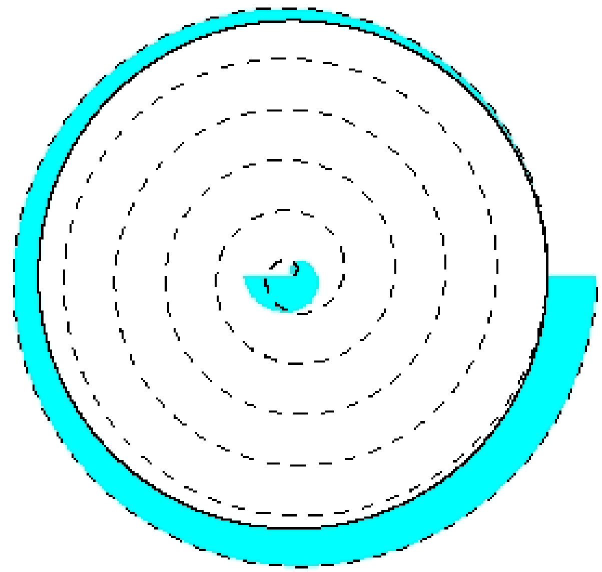
Spin-off: Spin at high speed to final thickness

EXTRUSION-SPIN COATING

Concept of Extrusion-Spin Coating



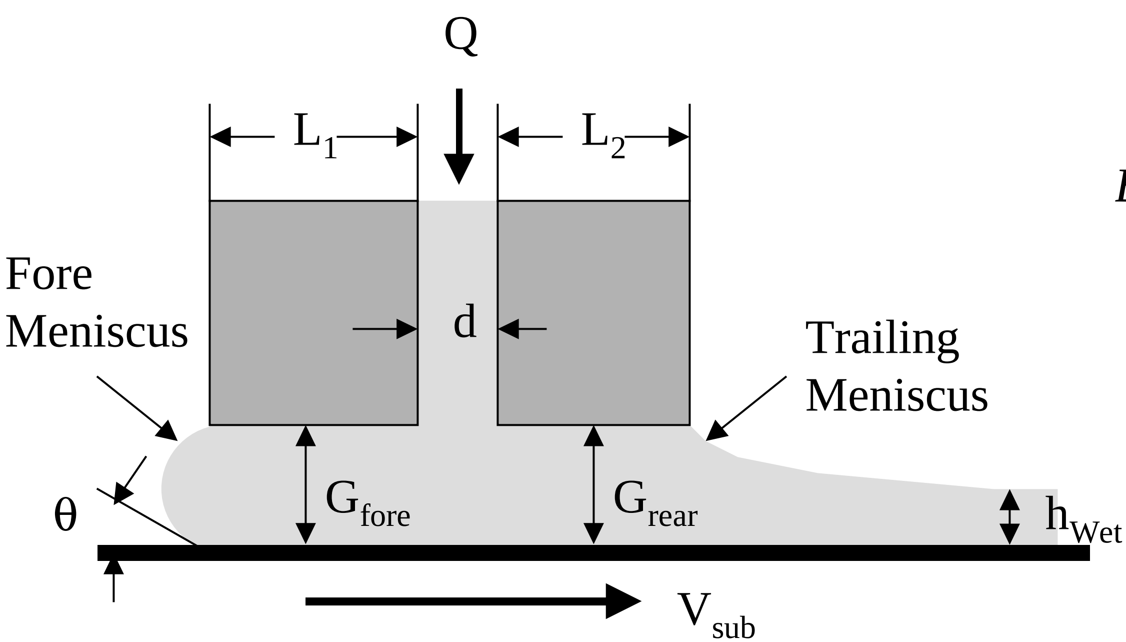
Spiral Coating



MODELING

- **Extrusion Coating**
  - **Schematic diagram of extrusion coating**
  - **Flow over a rotating disk during extrusion-spin coating**
- **Spin Coating**
  - **Coating chamber diagram**
  - **Flow regimes**

Schematic Diagram of Extrusion Coating



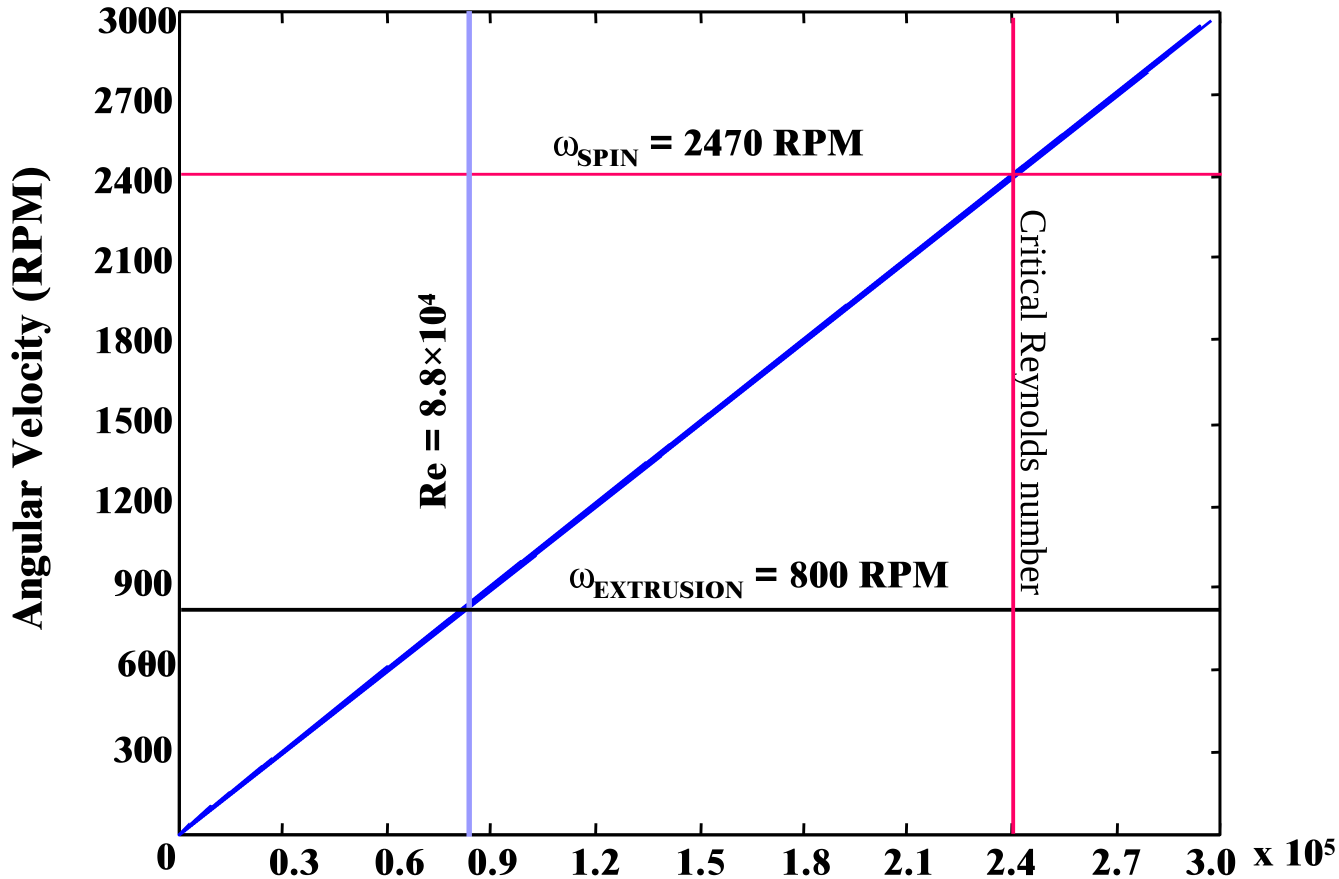
$$Bead\ Coatability \propto h/\mu V_{sub}G^{*}$$

$$h_{wet} = \frac{Q}{V_{sub}w}$$

$$h_f = S_f h_{wet}$$

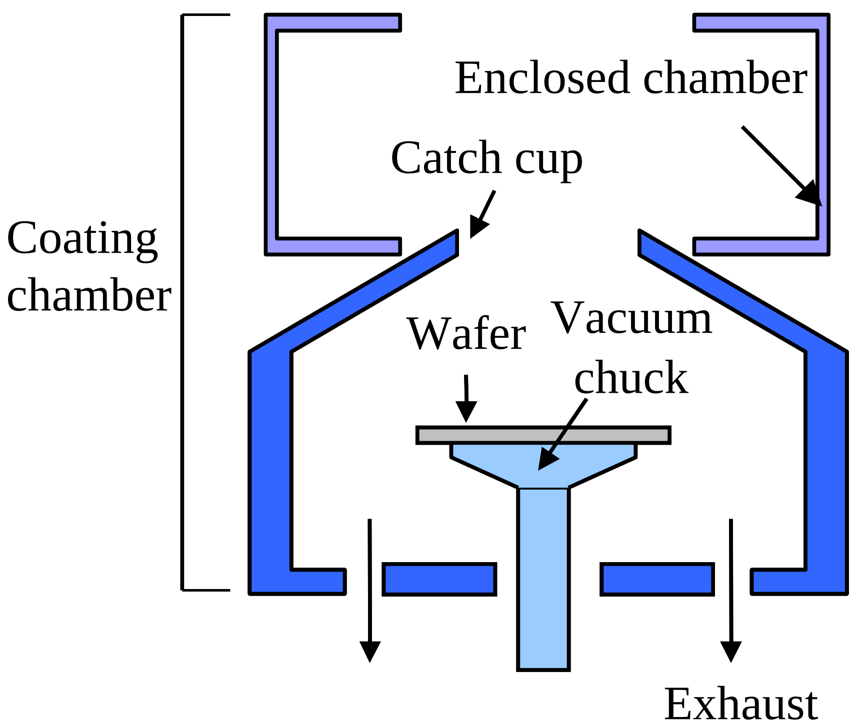
*: Edward J. Choinski. Patch coating: taking the spin out of thin. Information Display, 7(11), 1991

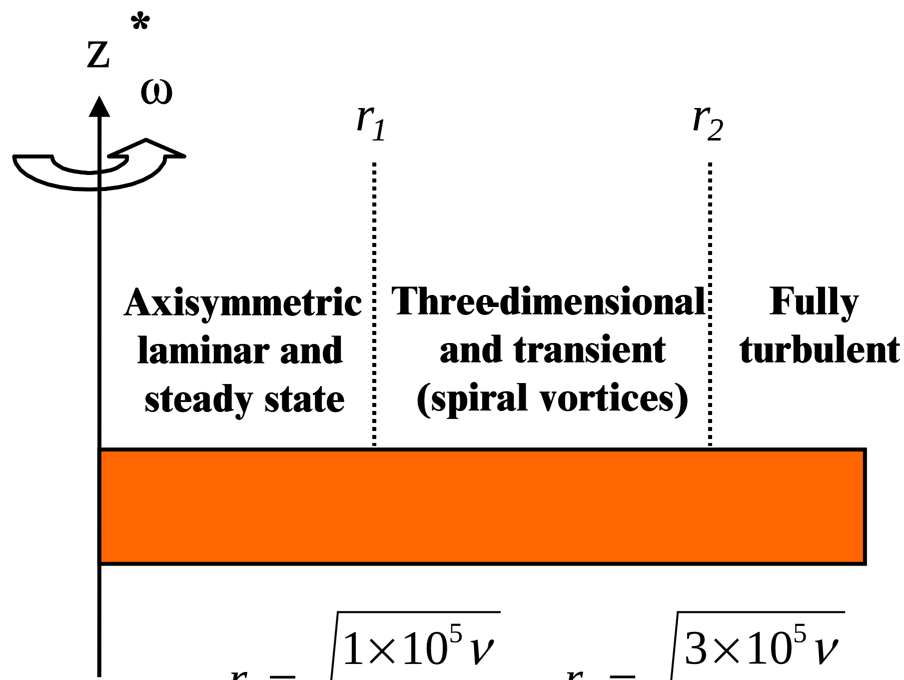
Flow over a Rotating Disk during Extrusion-Spin Coating for 200 mm Wafers



$$\mathrm{Re} = \frac{\rho \omega R}{\mu}$$

Coating Chamber and Flow over a Rotating Disk





$$r_1 = \sqrt{\frac{1\times10^5\nu}{\omega}} \qquad r_2 = \sqrt{\frac{3\times10^5\nu}{\omega}}$$

*: David E. Bornside and Robert A. Brown. The effect of gas phase convection on mass transfer in spin coating. *Journal of Applied Physics*, 71(2), 15 January 1993.

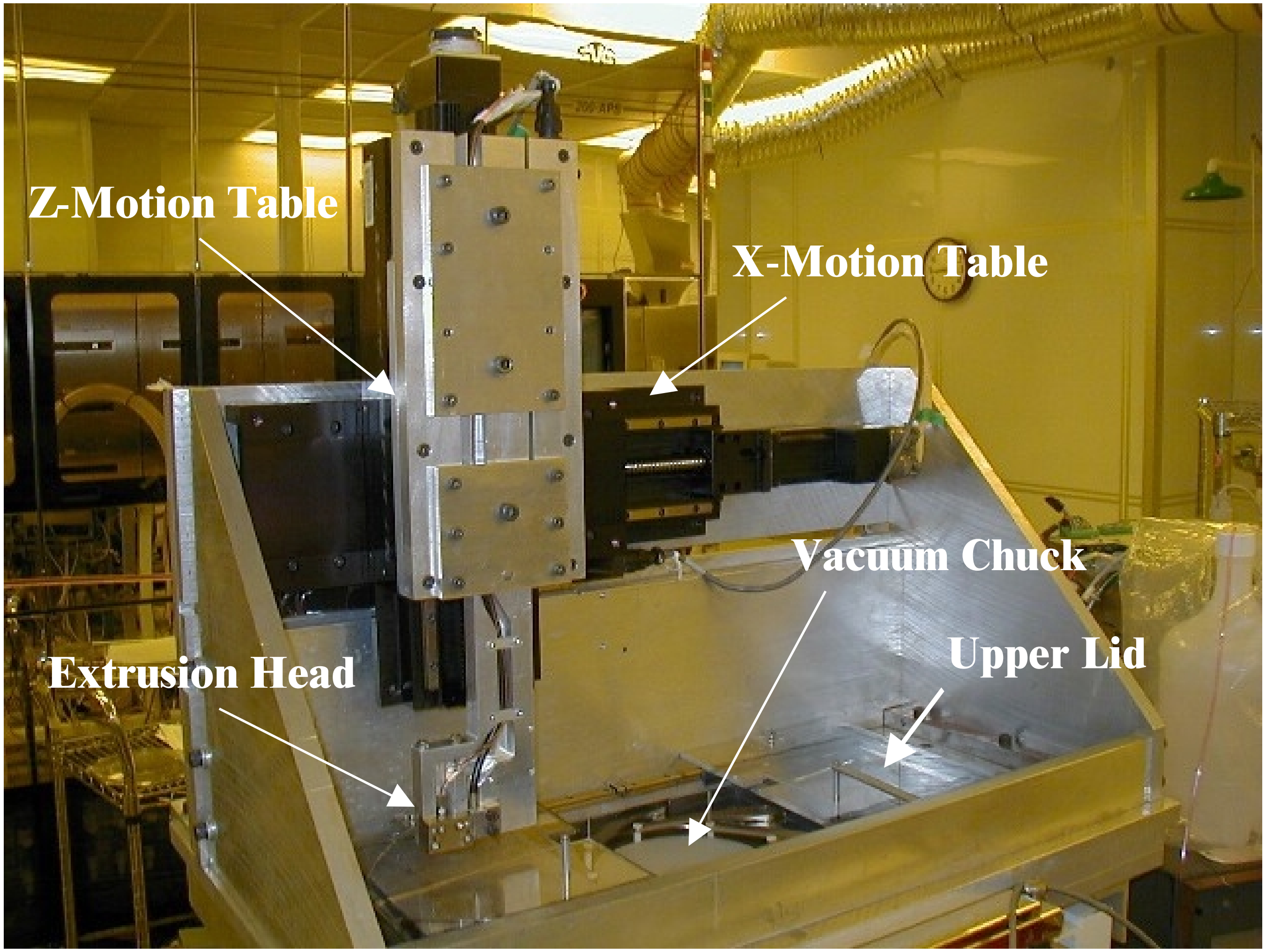
PROCESS VARIABLES FOR EXTRUSION-SPIN COATING

- **Solvent Concentration Degree: 0~100%**
- **Extrusion Coating Speed: 0~150 RPM**
- **Gap Distance: 40~100 μm**
- **Initial Coating Thickness: 10~40 μm**
- **High Spin Speed: 1500~3000 RPM**
- **High Spin Time: 20~50 sec**

EXPERIMENTAL RESULTS AND ANALYSIS

- Properties of Photoresist
- Initial Experiments without Solvent Concentrated Environment
- Effect of Solvent Concentration on Coating Results
- Experimental Results with Solvent Concentrated Environment

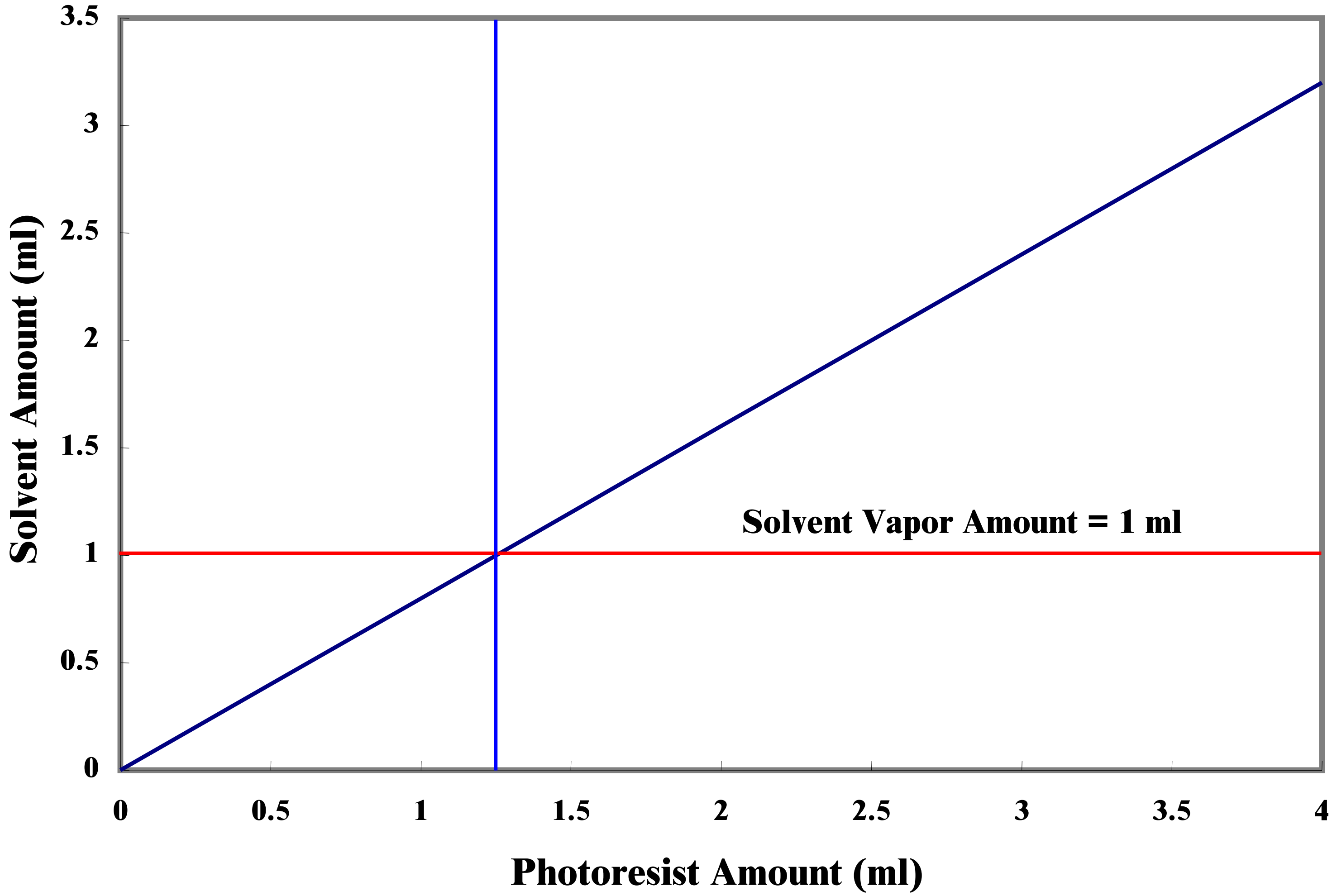
Prototype Extrusion-Spin Coater



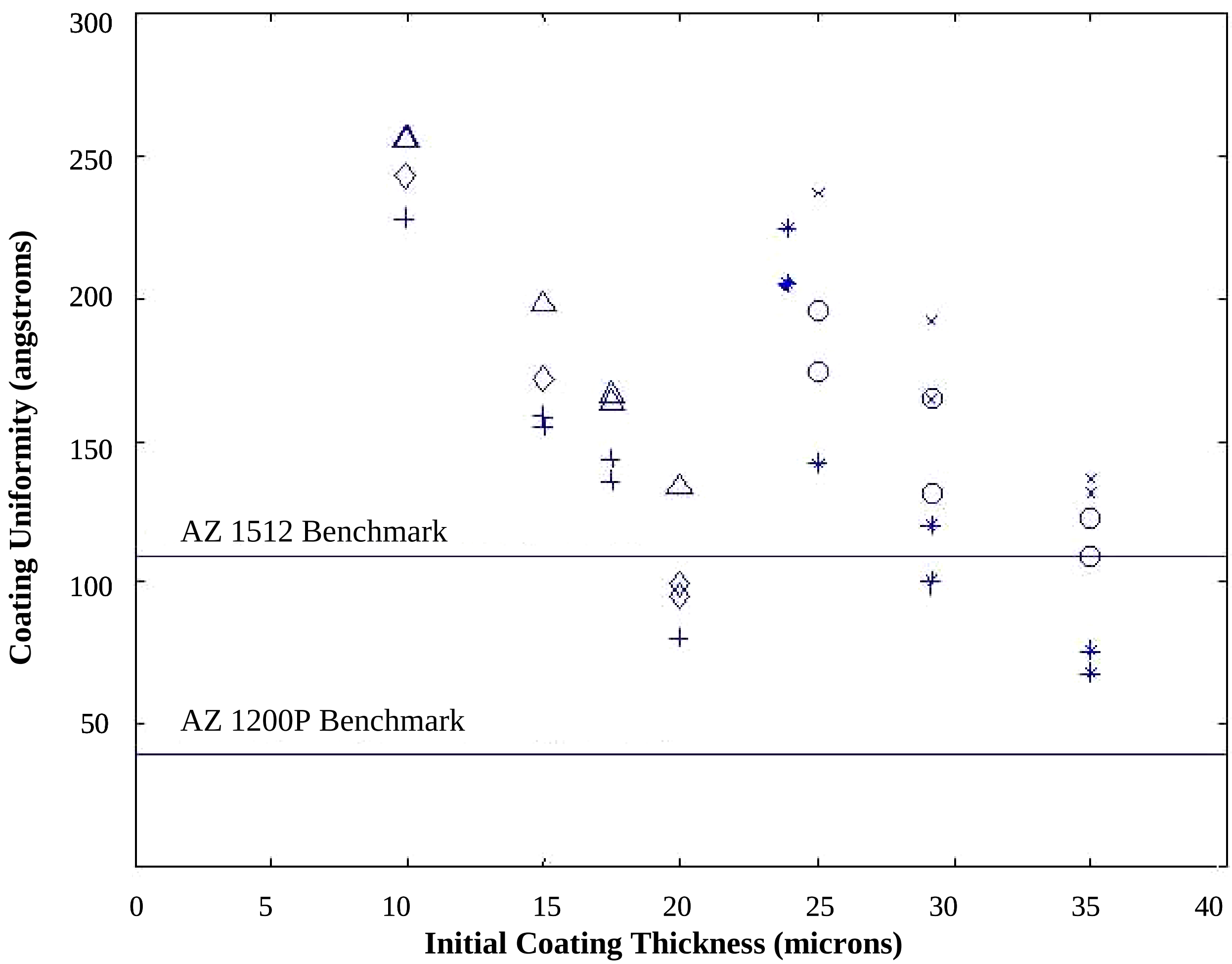
Properties of Photoresist

	AZ1512	AZ 1200P	Water
Density (kg/m^3)	1040	1000	1000
Viscosity (mPA-sec)	19	11	1
Surface Tension (N/km)	32	30	74
Solid Contents (%)	26	20	NA
Price/Gallon ($)	500	2000	

Solvent Amount vs. Photoresist Amount



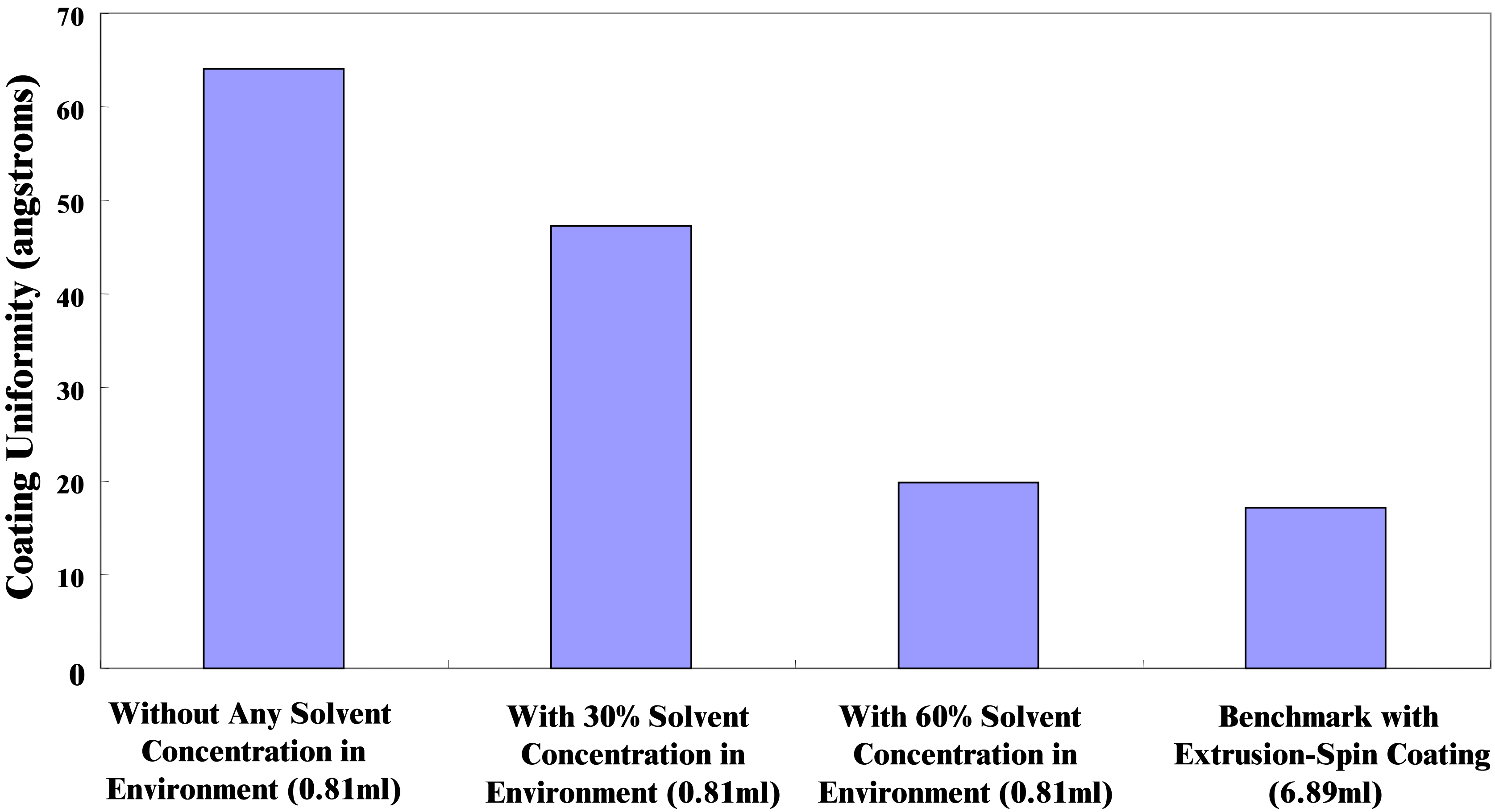
Coating Uniformity without Any Solvent Concentrated Environment



AZ1512 (19cp)
***: Initial coating time (~21 sec)**
o: ~3 sec delay time
x: ~5 sec delay time

AZ1200P (11cp)
+: Initial coating time (~17 sec)
◊: ~3 sec delay time
Δ: ~5 sec delay time

Effect of Solvent Concentration on Coating Uniformity: Initial Test (1998)

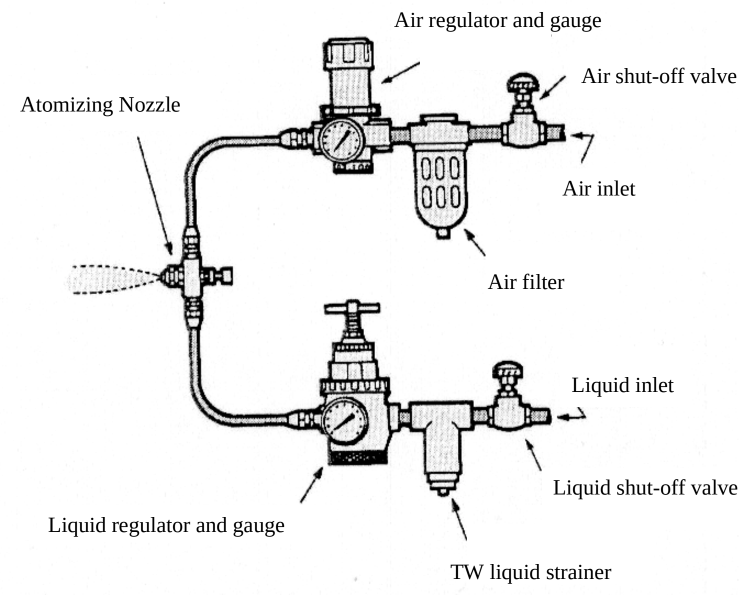


Solvent Concentrated Environment

- **Solvent: Propylene Glycol Mono-methyl Ether Acetate (PGMEA)**
  - **Molecular weight: 132.2**
  - **Density: 0.00543 g/cm^3**
  - **Viscosity: 62 μP ***
  - **Vapor pressure at 20˚C: 3.7 mm HG**
  - **Diffusion coefficients:**
    - **$D_{PGMEA>Air}$=6.67×10^{-6} m^2/sec**

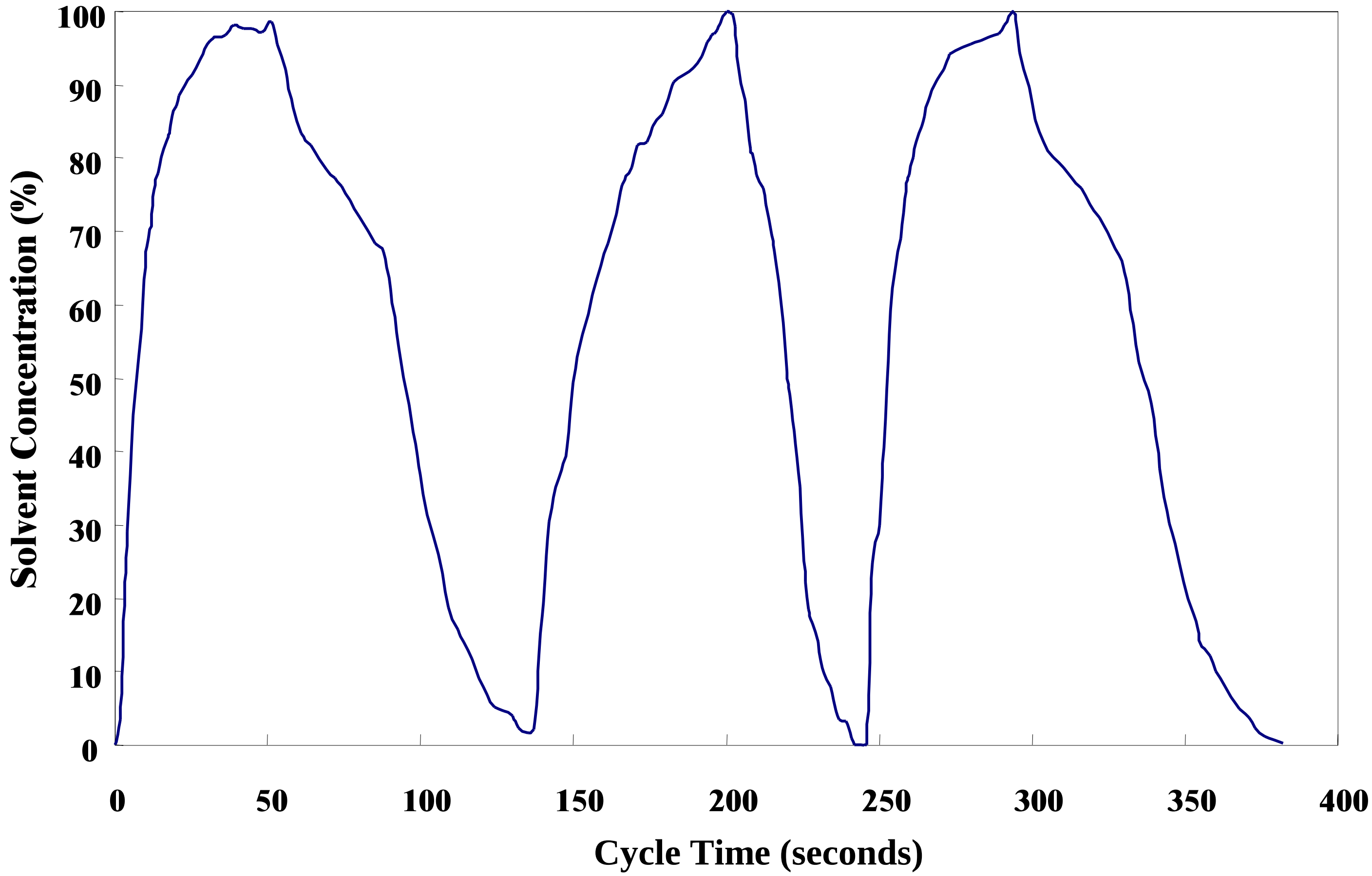
*: R. Reid, Properties of Gases and Liquids, McGraw Hill

- **Solvent Vaporizing Equipment: Atomizer**



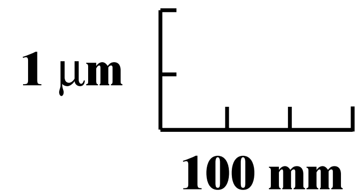
- **Metrology tool: Berkeley Micro Instruments BMC200 Chemical Vapor Sensor**

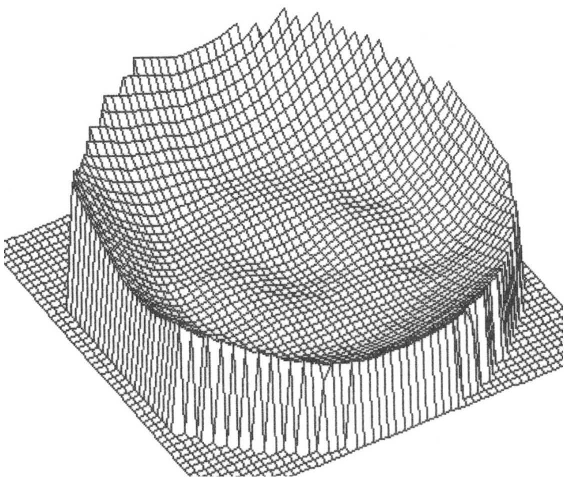
Solvent Concentration Measurements



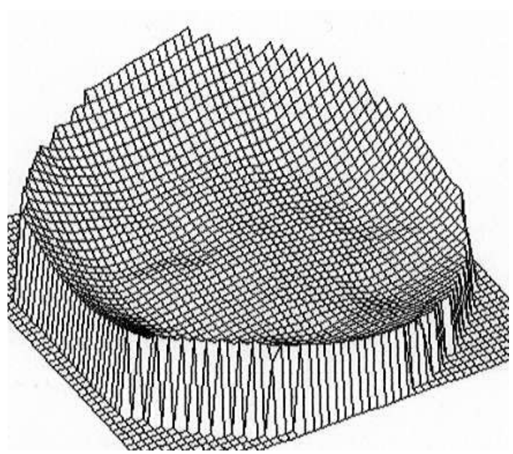
Exhaust valve was maintained closed throughout the entire coating cycle (extrusion + spin coating) in first and third experiments. Exhaust valve was closed during extrusion coating and turned open during the spin coating cycle in second experiments.

Coating Thickness Profile

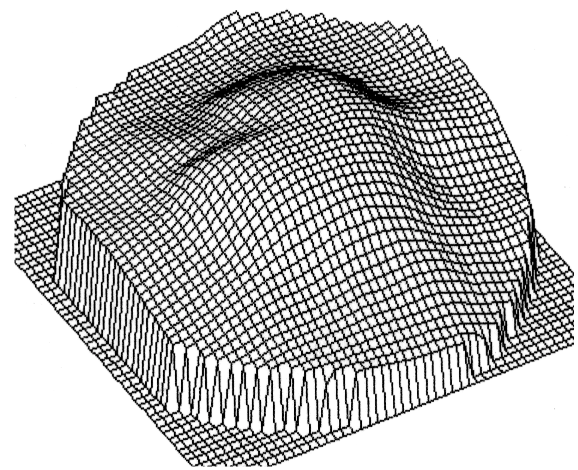




Spin coated at 3000 RPM
in 0% solvent
concentrated environment:
7718 μm with 78 Å

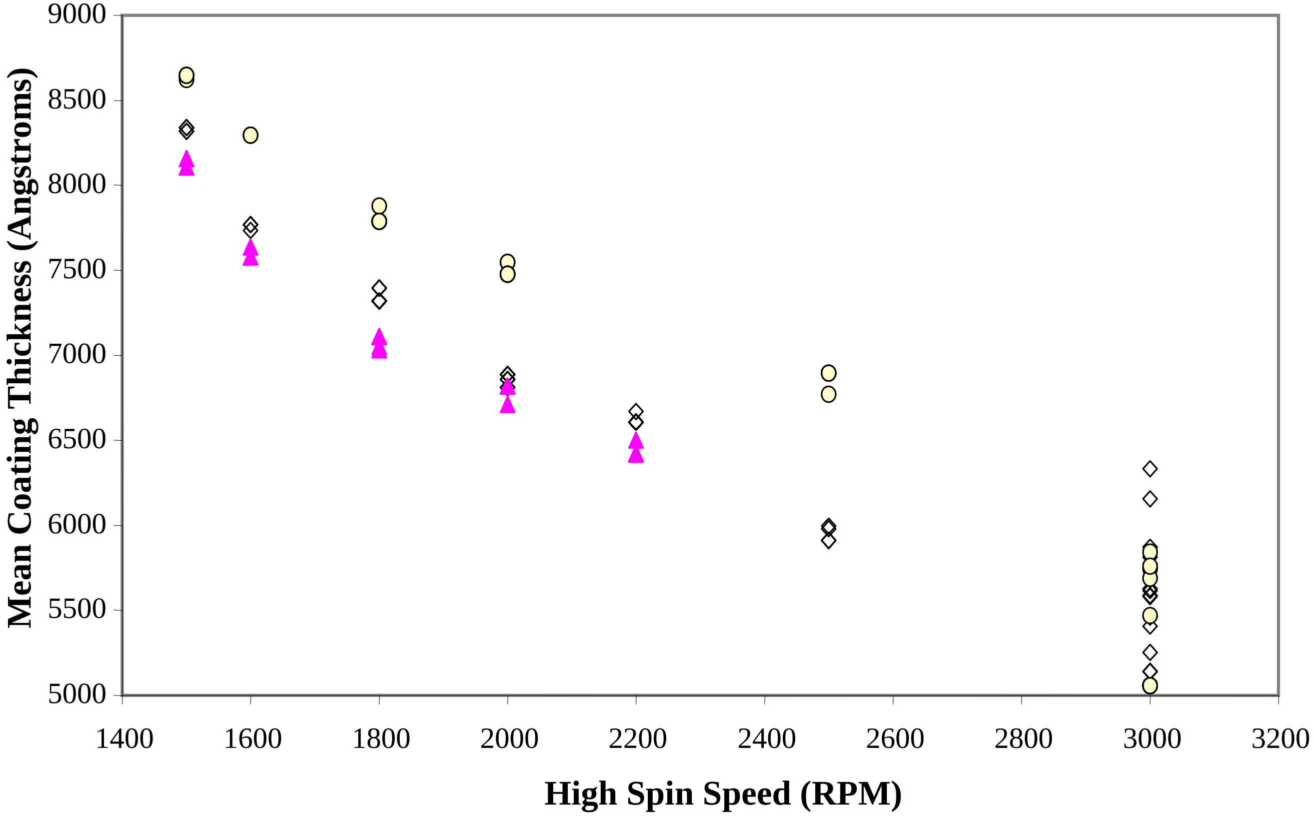


Spin coated at 3000 RPM
in 100% solvent
concentrated environment:
6215 μm with 12 Å



Spin coated at 1500 RPM
in 100% solvent
concentrated environment:
8414 μm with 6 Å

Mean Coating Thickness



Emslie et al.'s predictive model of coating thickness without evaporation

$$h_f \sim \frac{h_0}{\left[1+4\left(\rho\omega^2/3\mu\right)h_0^2 t\right]^{1/2}}$$

Proportional Coefficient

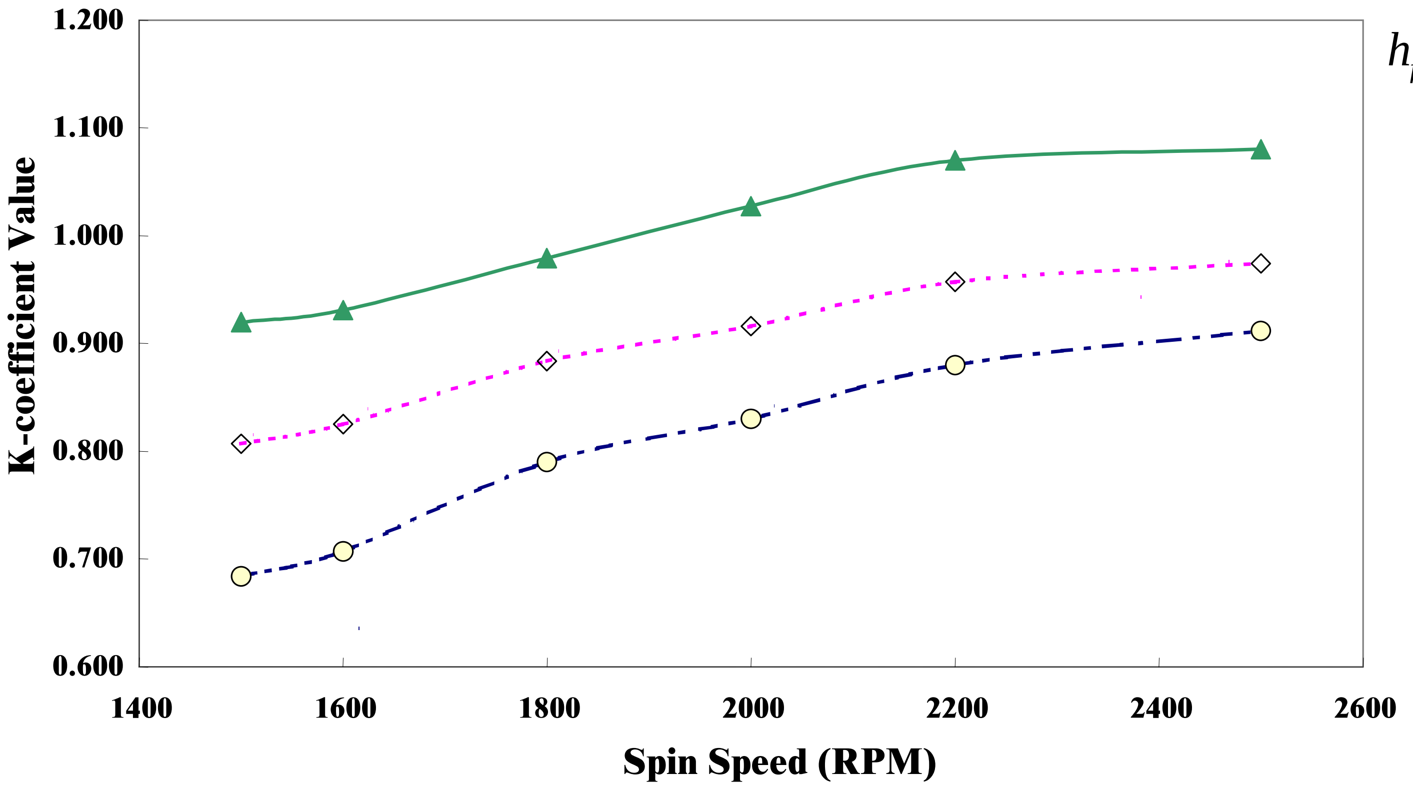
K(c, H, ω,t)

"o": 20 seconds spin coating time

"◇" : 30 seconds spin coating time

"△": 40 seconds spin coating time

Experimental Estimation of Coefficient *K(c, H, ω,t)*

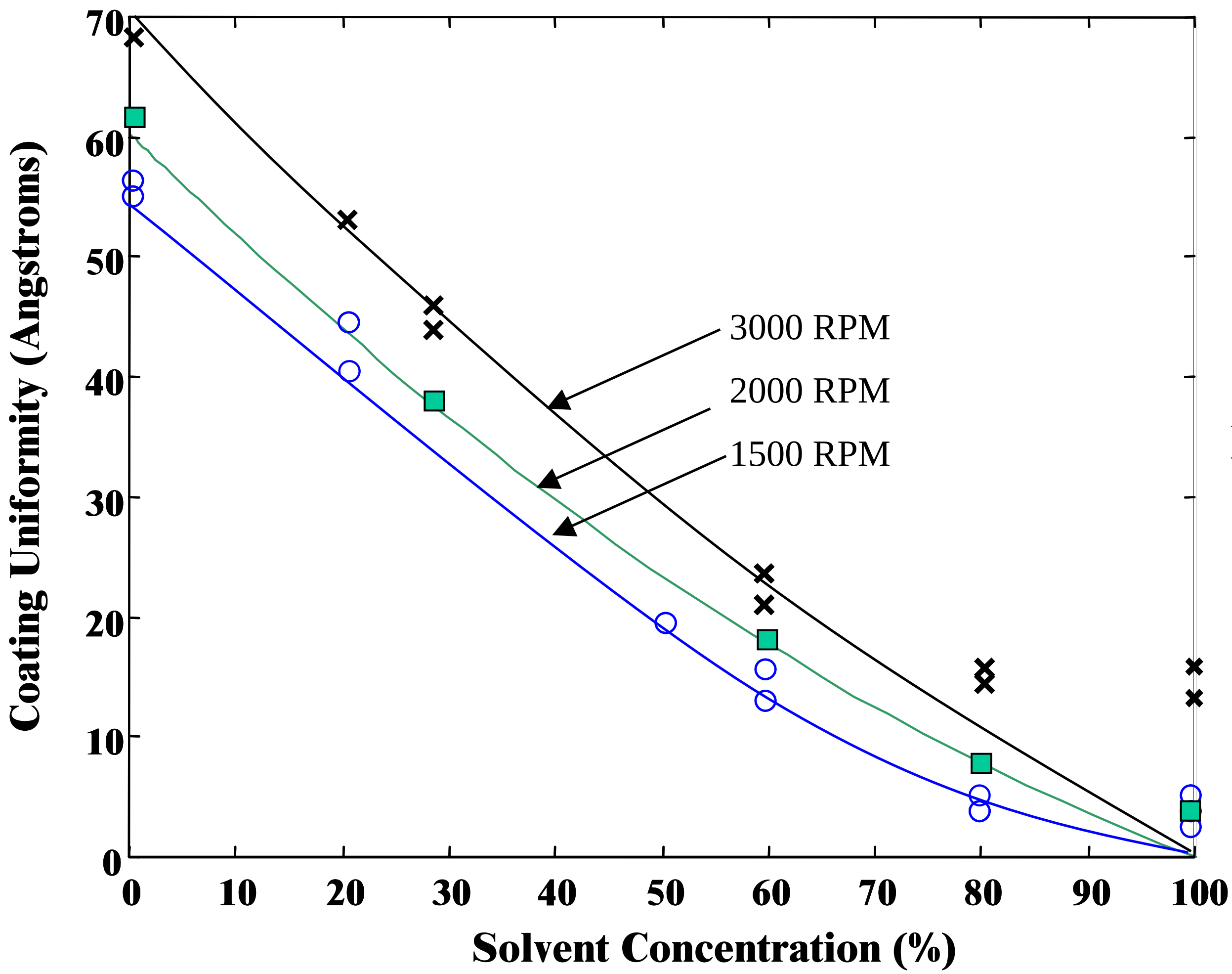


$$h_f = \frac{K(c,H,\omega,t)h_0}{\left[1+4\left(\rho\omega^2/3\mu\right)h_0^2 t\right]^{1/2}}$$

***K*(*c*, *H*, ω, *t*)**
***c* = 100%**
***H* = 43~46%**

"o": 20 seconds spin coating time
"◇" : 30 seconds spin coating time
"△": 40 seconds spin coating time

Prediction of Coating Uniformity



Bornside et al.'s predictive model of coating thickness with evaporation

$$h_f \sim \left[k(c, H, r, \omega)\right]^{\frac{1}{3}}$$

Mass Transfer Coefficient

$k(c, H, r, \omega)$

with: H = 43~46%

"×": 3000 RPM

"□": 2000 RPM

"O": 1500 RPM

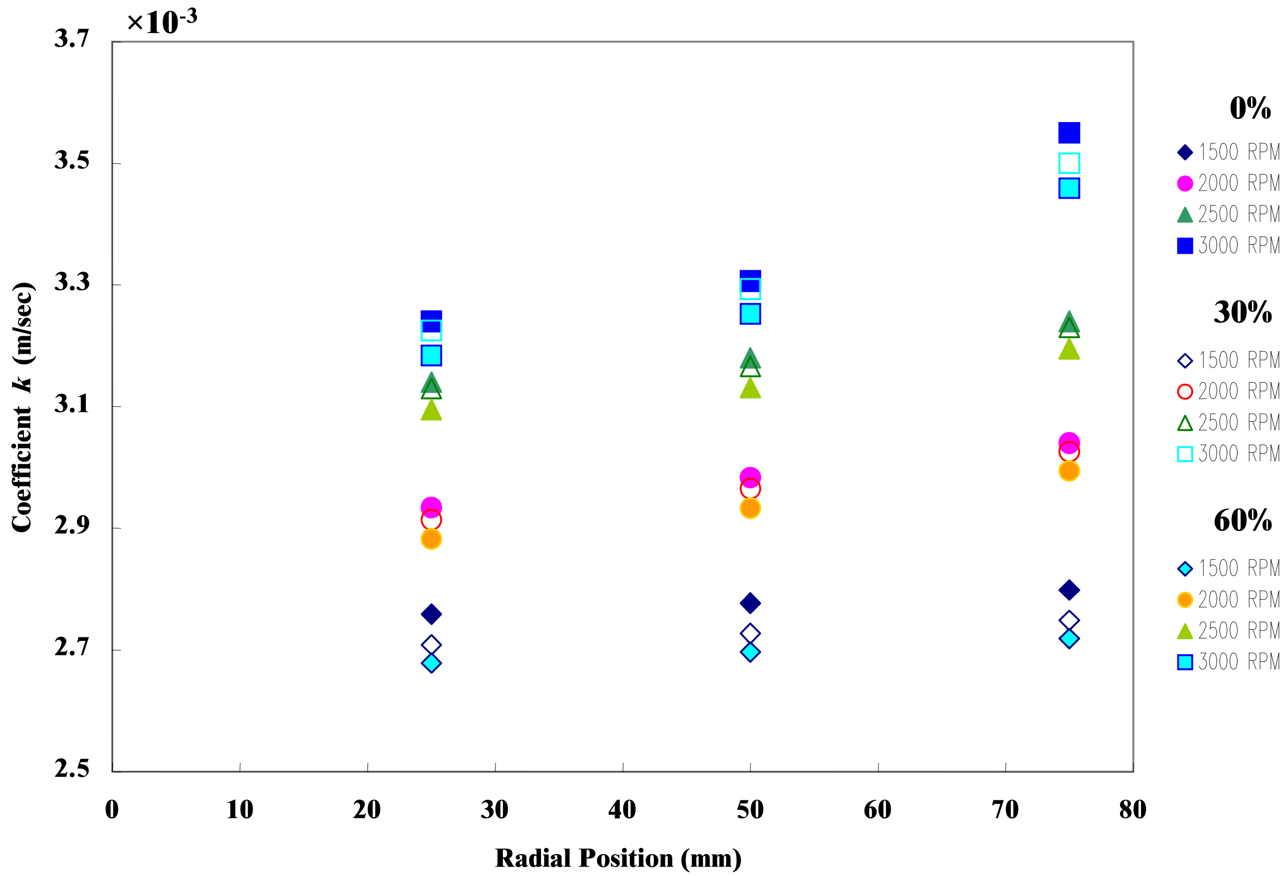
Experimental Estimation of Coefficient *k(c, H, r, ω)*

$$h_{mean} = \frac{1}{N}(1-x_0)\left[\left(\frac{3\mu}{2\rho^2\omega^2}\right)\frac{p^*M}{RT}x_0\right]^{1/3}\sum_{n=1}^{N}k_n^{1/3}$$

***N*: Number of measured points**

$$\sigma = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(h_{mean}-h_f\right)^2}$$

σ: Coating uniformity



CONCLUSIONS

- **Extrusion-spin coating can minimize amount of photoresist and solvent use and meet desired coating uniformity**
- **Coating thickness and uniformity can be predicted by analyzing $K(c, H, \omega, t)$ and $k(c, H, r, \omega)$, respectively**

FUTURE WORK

- Improve design of solvent vapor generating system to minimize use of solvent
- Improve design of coating chamber to maintain 100% solvent concentration