In-situ Semiconductor Process Metrology for Real-Time APC (Advanced Process Control)

Yijun Liu, Laurent Henn-Lecordier, Soon Cho, Yiheng Xu, Carl Gogol(*), Abdul Wajid(*), John N. Kidder, Gary W. Rubloff

UNIVERSITY OF MARYLAND 1856

* INFICON

The Institute for Systems Research

Department of Materials and Nuclear Engineering

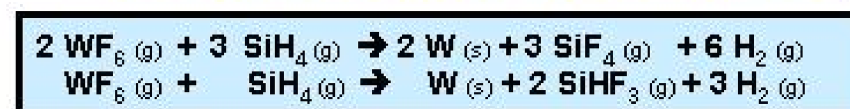
Real-time APC in 0.5 torr SiH4/WF6 Process

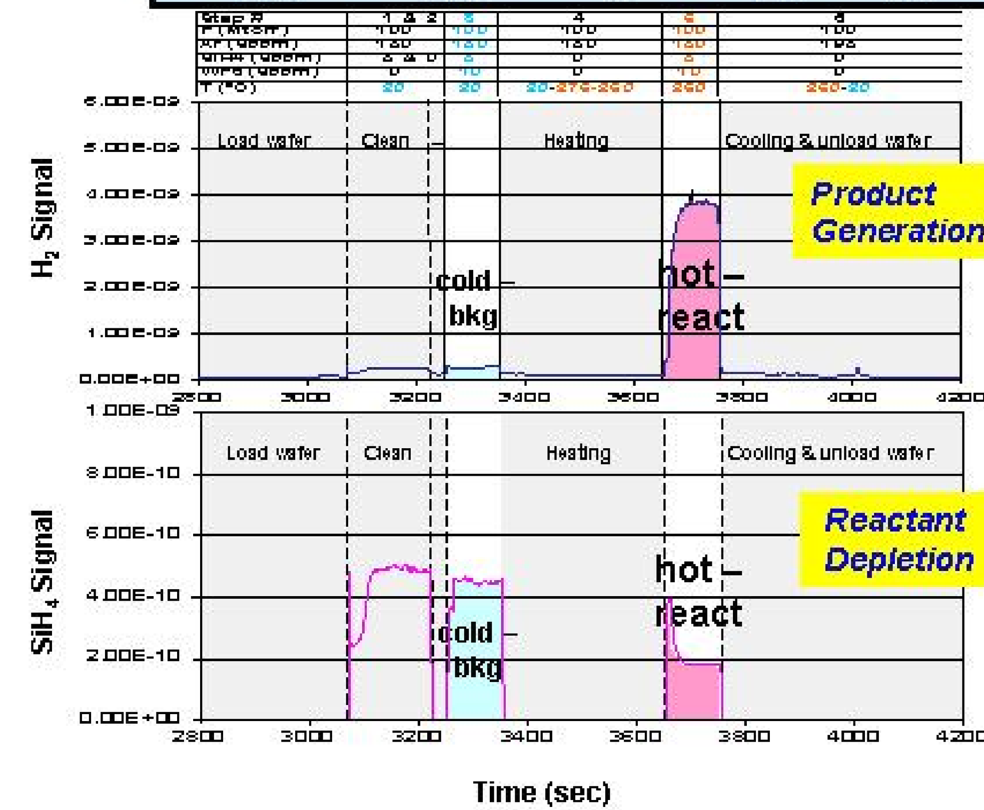
Real-Time Advanced Process Control (APC)

Current Industry status
- Run to Run drift correction using post-process
- Real-time fault detection for major equipment failures

Research for real-time APC
- Real-time, in-situ sensors for quantitative process/wafer metrology
- Real-time course correction for systematic drift and random variations

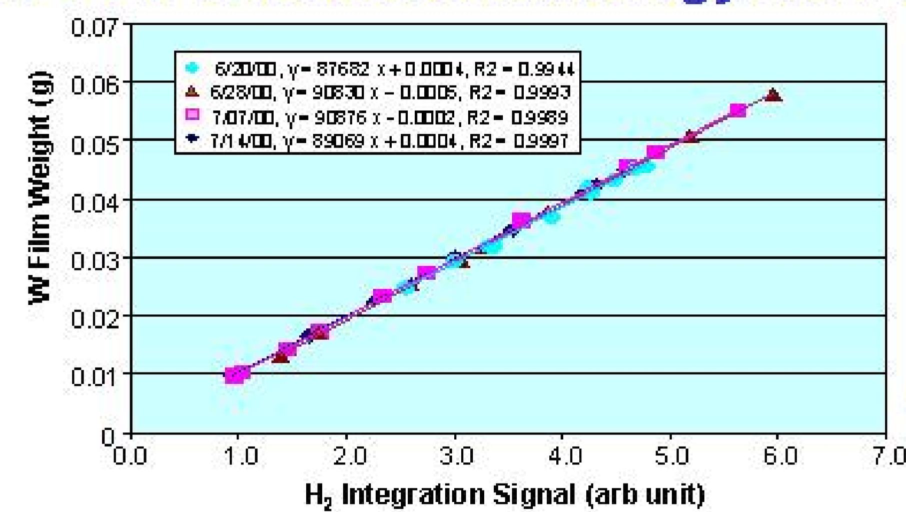
Real-time in-situ Chemical Sensor (Mass Spectrometry) in 0.5 Torr SiH_4/WF_6 Process





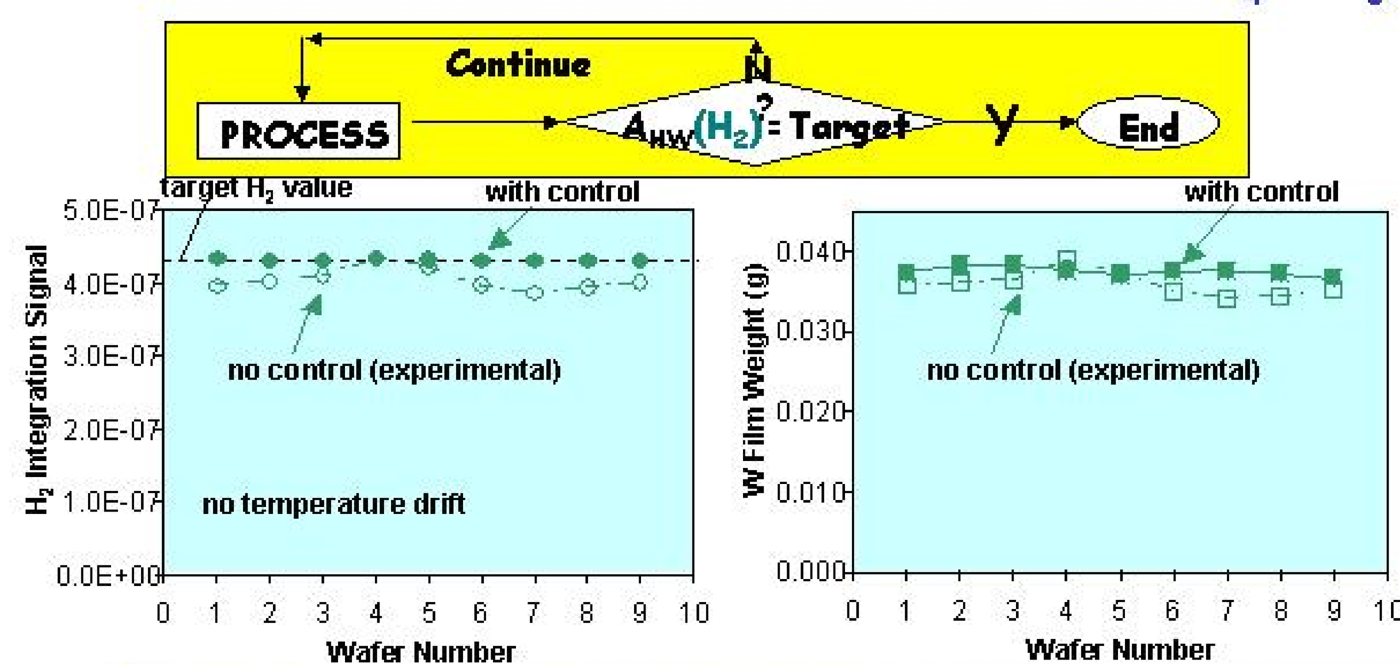
- *Readily observe & measure Product Generation and Reactant Depletion*
  - *H_2 Product Generation*
  - *SiH_4 Reactant Depletion*
- *Use Product Generation and/or Reactant Depletion time-integrated signals for film thickness metrology*

W Film Thickness Metrology from RT In-situ Sensing



- *1.25% average uncertainty and 1.09% standard deviation from linear fit*
- *Viable for manufacturing*
- *Real time end-point process control for film thickness*

RT End-Point Control of W Film Thickness in SiH_4/WF_6 Process



- *Real-Time End-Point Control is capable of handling BOTH: RANDOM VARIATION AS WELL AS SYSTEMATIC PROCESS DRIFTS (Run-to-Run)*
- *Real-Time End-Point Control to ~ 3%, but open-loop wafer-to-wafer thickness variation ~ 10%*

1

In-situ Sensing-based Metrology in 10 torr H2/WF6 Process

Application to Processes

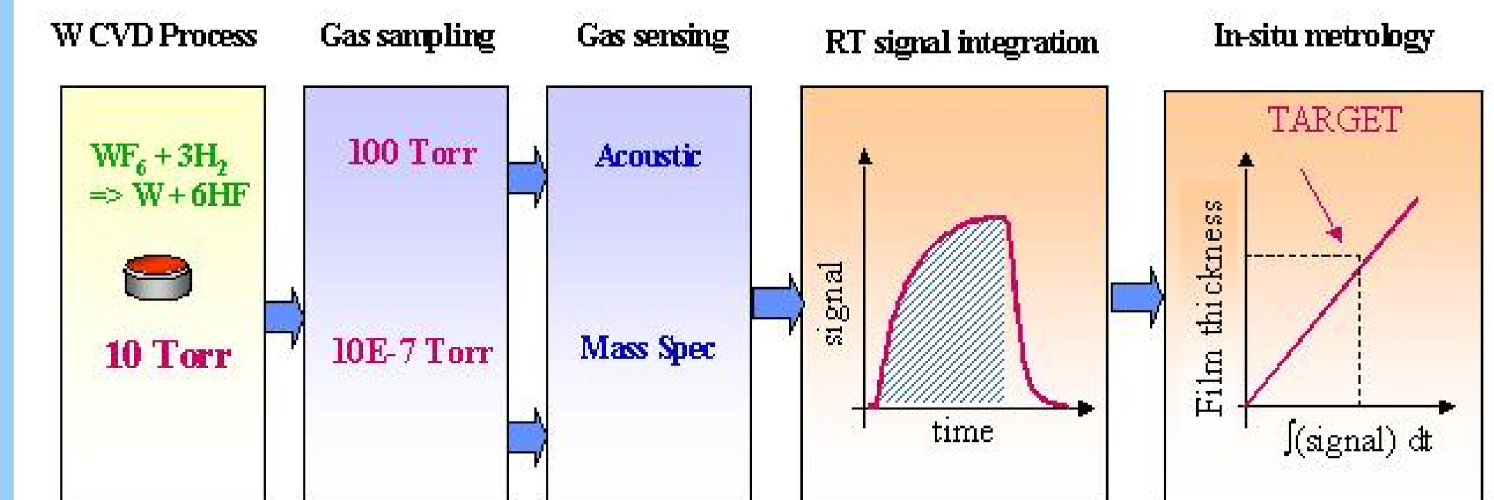
- Low pressure selective W CVD using
  - H2/WF6 500 mtorr
  - SiH4/WF6 500 mtorr
- Higher pressure blanket W CVD using
  - H2/WF6 10 torr

Plans:

- Diffusion barrier layers by CVD and ALD
  - WN_x, TaN, TiN…
- Cu CVD interconnects

2

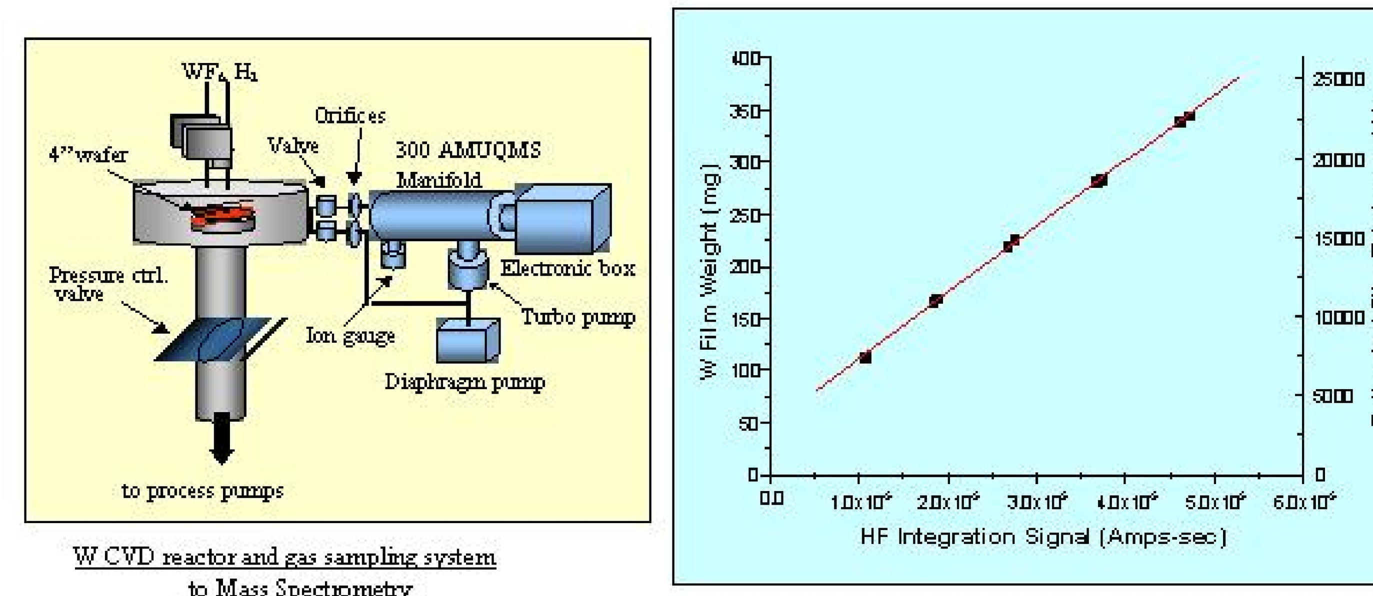
Real Time in-situ Chemical Sensor-based Metrology in 10 Torr H2/WF6 Process



- *Process time varies from 318 to 968 s. over 10 wafers*
- *Fixed temperature 390°C*

3

W Film Thickness Metrology using in-situ Mass Spectrometry

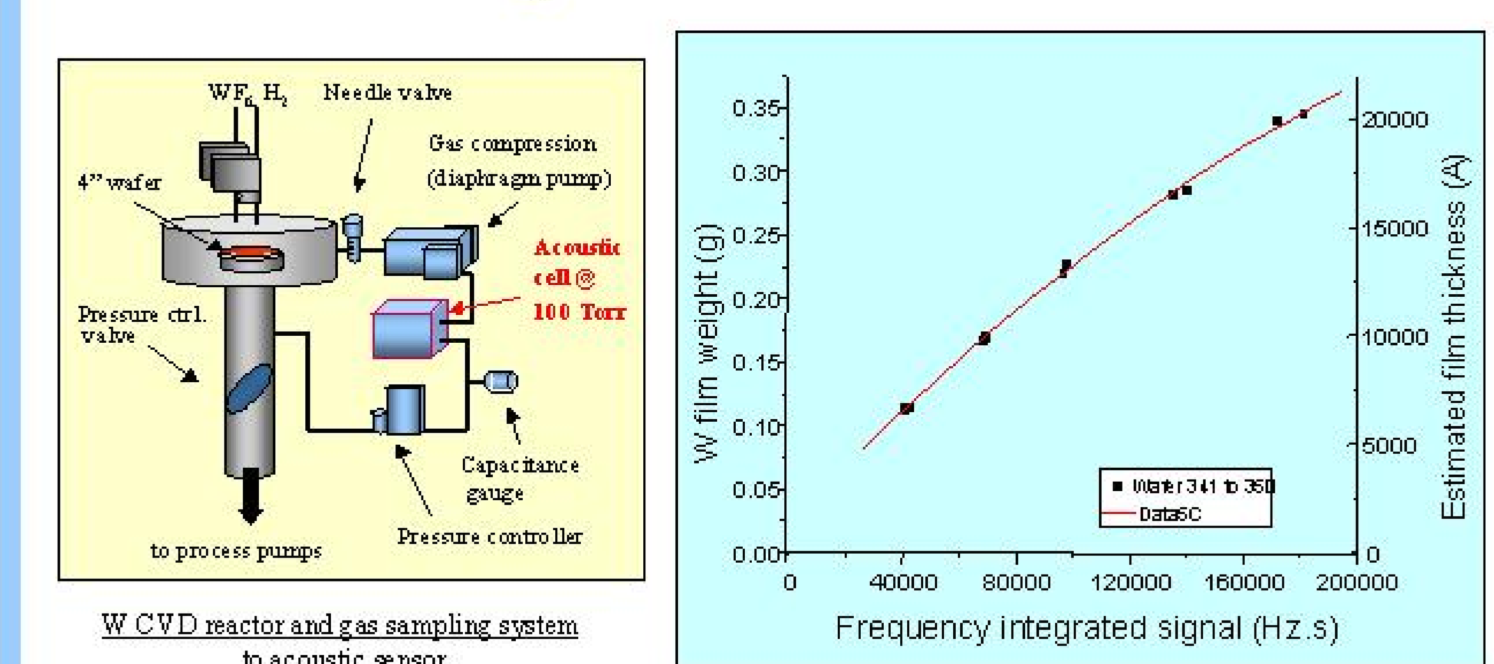


W CVD reactor and gas sampling system to Mass Spectrometry

- *Reasonable metrology from linear regression fit*
  - *Average uncertainty 1.19%, standard deviation 1.59%*
- *2nd-order polynomial fit*
  - *Average uncertainty 0.48%, standard deviation 0.57%*
- *Local range metrology more likely and viable for manufacturing application*

4

W Film Thickness Metrology using in-situ Acoustic Sensor



W CVD reactor and gas sampling system to acoustic sensor

- Metrology error to second order polynomial fit = 1.0%

5

CONCLUSIONS

Successful demonstration of real-time end-point control for W film thickness in 0.5 Torr SiH4/WF6 process using in-situ chemical sensor (Mass Spectrometry)
- *Open-loop wafer-to-wafer thickness variation ~ 10%*
- *Real-Time End-Point Control to ~ 3%*
- *in presence of random variation as well as systematic drifts*

In-situ sensing-based real-time metrology is essential for implementation of real-time APC

1.25% average metrology error ⇒ 3% real-time end-point film thickness control

Successful implementation of W film thickness metrology in 10 Torr H2/WF6 process using in-situ Mass Spectrometry and Acoustic sensor
- *Mass Spectrometry: 1.19% average metrology error from linear fit*
- *Acoustic sensor: 1.0% average metrology error from second order polynomial fit*

Real-time APC is viable for semiconductor manufacturing application

Acknowledgements

INFICON

National Institute of Standards and Technology NIST

6