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

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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/parameter metrology
- Real-time coarse correction for systematic drift and random variations

Real-time In-situ Chemical Sensor (Mass Spectrometry) in 0.5 Torr SiH4/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 mtorr

Plans:
- Diffusion barrier layers by CVD and ALD
  - W, TaN, TiN...
- Cu CVD interconnects

W Film Thickness Metrology from RT In-situ Sensing

- 1.25% average uncertainty and 1.0% standard deviation from linear fit
- Usable for manufacturing
- Real-time end-point process control for film thickness

RT End-Point Control of W Film Thickness in SiH4/WF6 Process

- Real-time End-Point Control is capable of handling R3/R2
  - Random/Random as well as systematic process drifts (Run-to-Run)
- Real-time End-Point Control is ~ 3% better open-loop wafer-to-wafer thickness variation ~ 15%

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

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

- W CVD/Pretreatment
- Gas sampling
- Gas sampling
- Retention integration
- Ion conductance

W Film Thickness Metrology using in-situ Mass Spectrometry

- Measurable metrology from linear regression fit
  - Average uncertainty: 1.5%, standard deviation: 1.5%
- 2nd-order polynomial fit
  - Average uncertainty: 0.5%, standard deviation: 0.5%
- Local range metrology more robust and viable for manufacturing application

CONCLUSIONS

Successful demonstration of real-time end-point control for W thickness in 0.5 Torr SiH4/WF6 process using in-situ chemical sensors (Mass Spectrometry)
- Ozone selectivity/W thickness variation ~ 10%
- Real-time End-Point Control in ~ 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
- 1.5% 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: 1.5% average metrology error from wafer to wafer
- Acoustic sensor: 1.5% average metrology error from second order polynomial fit

Real-time APC is viable for semiconductor manufacturing application

Acknowledgements