Measurement of Grating Structure Evolution Using Off-Normal Spectral Reflectometry

Brooke S. Stutzman, Wei Kong, Hsu-ting Huang, Hunsuk Kim and Fred L. Terry, Jr.

Applied Physics and the Department of Electrical Engineering and Computer Science

University of Michigan, Ann Arbor

Research funded in part by:

AFOSR/DARPA MURI Center for Intelligent Electronics Manufacturing (AFOSR F49620-95-1-0524)

Semiconductor Research Corporation (Contract 97-FC085)

Outline

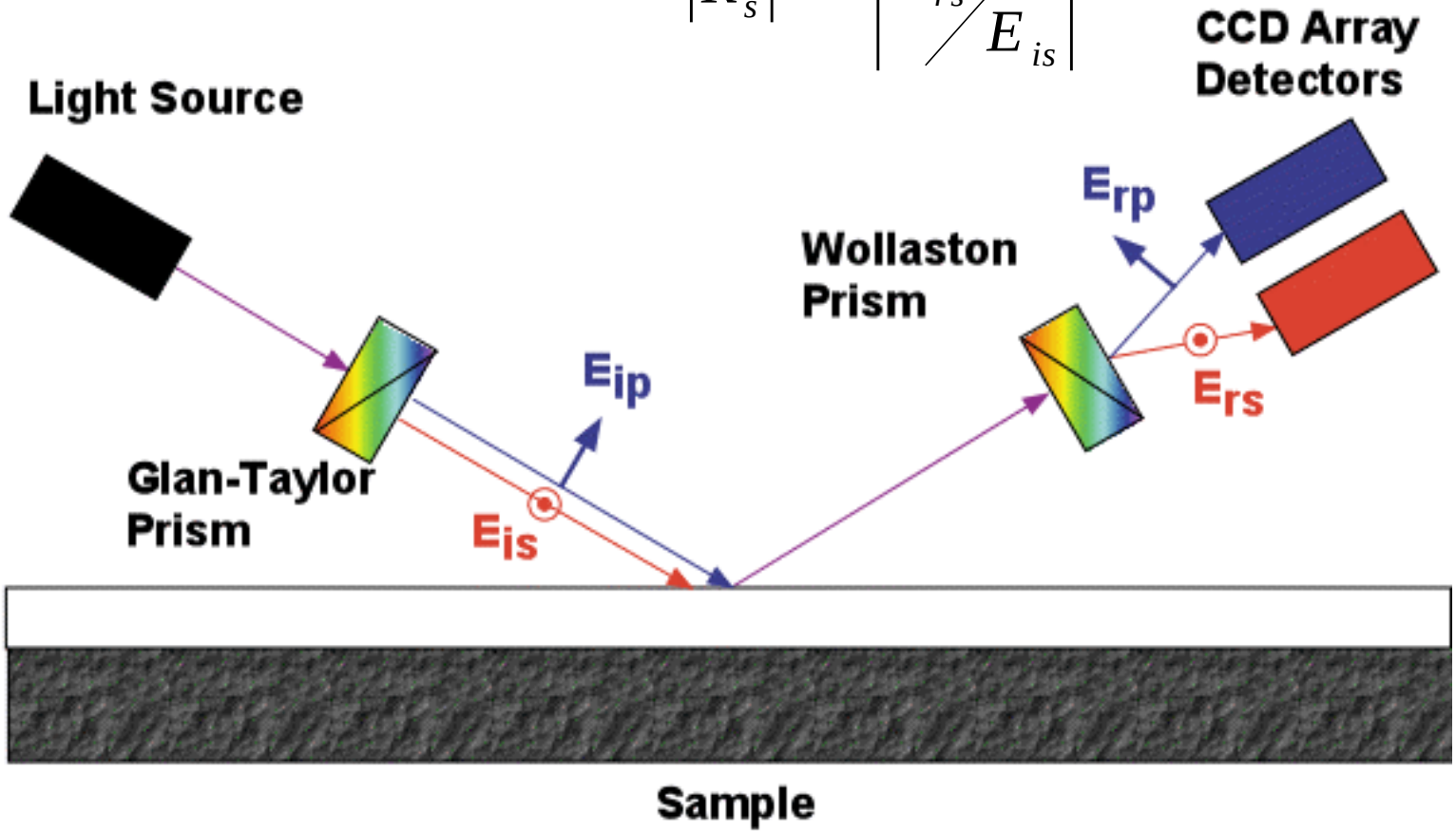
- Motivation
- Comparison of current techniques
- Off-Normal Spectral Reflectometry
- Experiments
- Conclusions
- Future work

Motivation

- High speed *in situ* film thickness and surface topography measurement system
  - Experimentally relate wafer data to plasma measurements
  - Industrial process control
- Current technology: Spectroscopic Ellipsometry (SE) with array detectors
  - Expensive
  - Slower

Off-Normal Spectral Reflectometry

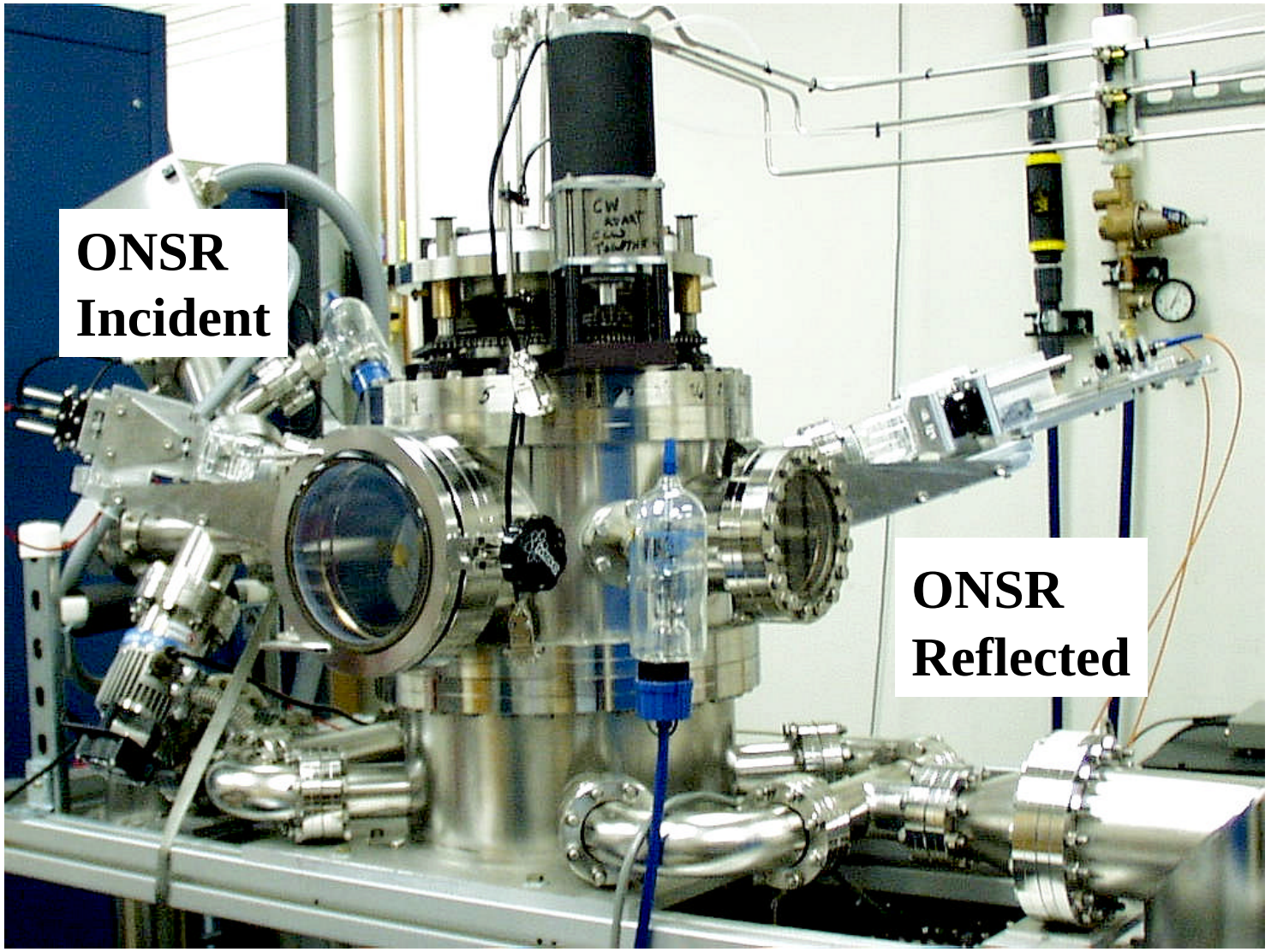
$$\tan(\Psi) = \frac{|R_p|}{|R_s|} = \frac{\left|E_{rp} / E_{ip}\right|}{\left|E_{rs} / E_{is}\right|}$$



ONSR Vs SE

ONSR	SE
High Signal to Noise Ratio & Fast Sampling Times with Inexpensive Spectrometers	More Expensive Detectors Needed to Get Equivalent S/N Performance {tan(ψ)}
More Than Half of SE Data $\|Rp\|^2$, $\|Rs\|^2 \Rightarrow$ tan(ψ)	Both tan(ψ), and Phase {cos(Δ)}
No Moving Parts	Moving Parts, More Complex Electronics ⇒ More Likely to Break
Construction Cost ~$7K	Commercial Systems ~$100K
Need to Calibrate for Absolute Intensity	Insensitive to Absolute Intensity

GEC Reference Cell and ONSR

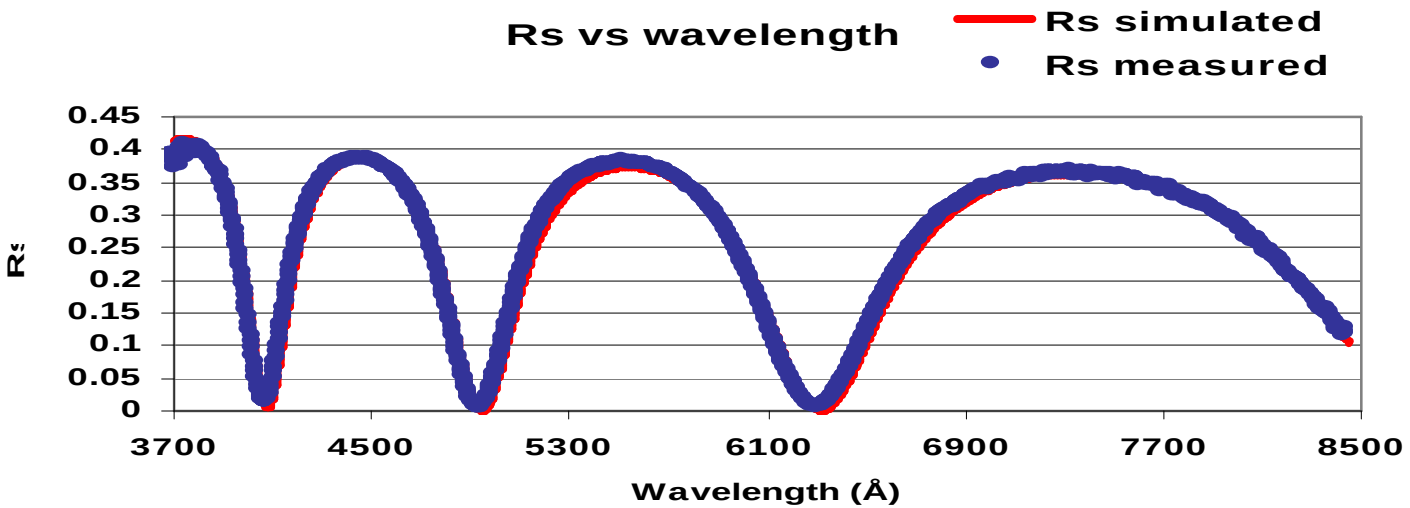


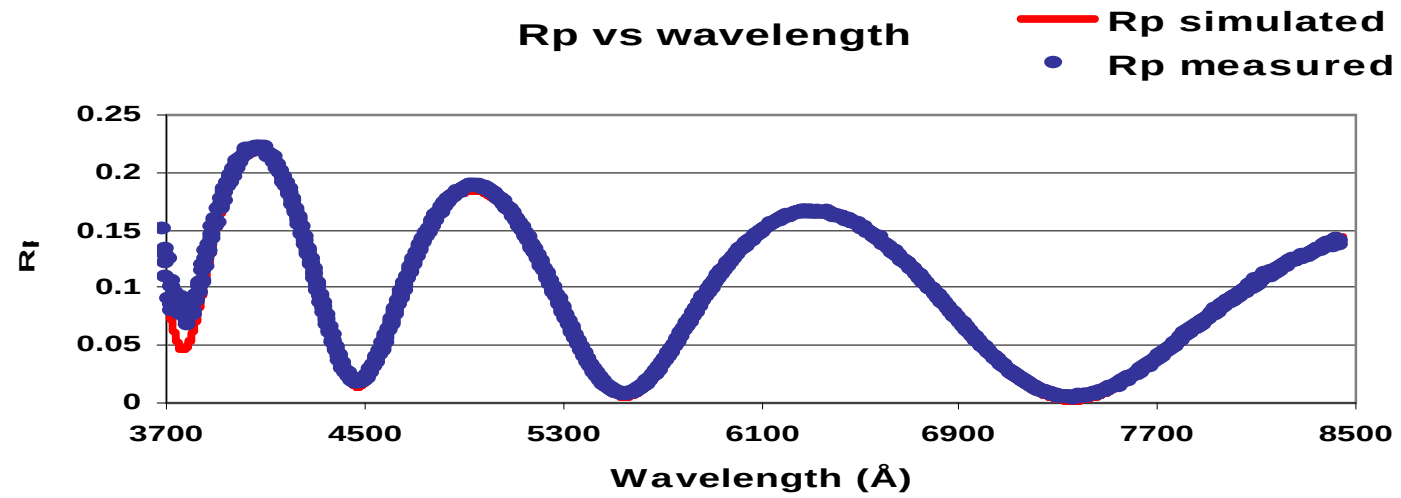
Calibration

$$R = \left(\frac{I_{meas} - I_{bkg}}{I_{ref} - I_{bkg}} \right) R_{th,ref}(l)$$

I_{meas} = measured intensity from sample
I_{bkg} = measured background intensity
I_{ref} = measured intensity from reference material
$R_{th,ref}(l)$ = theoretical reflectance from reference material

10058Å SiO_2 on Si



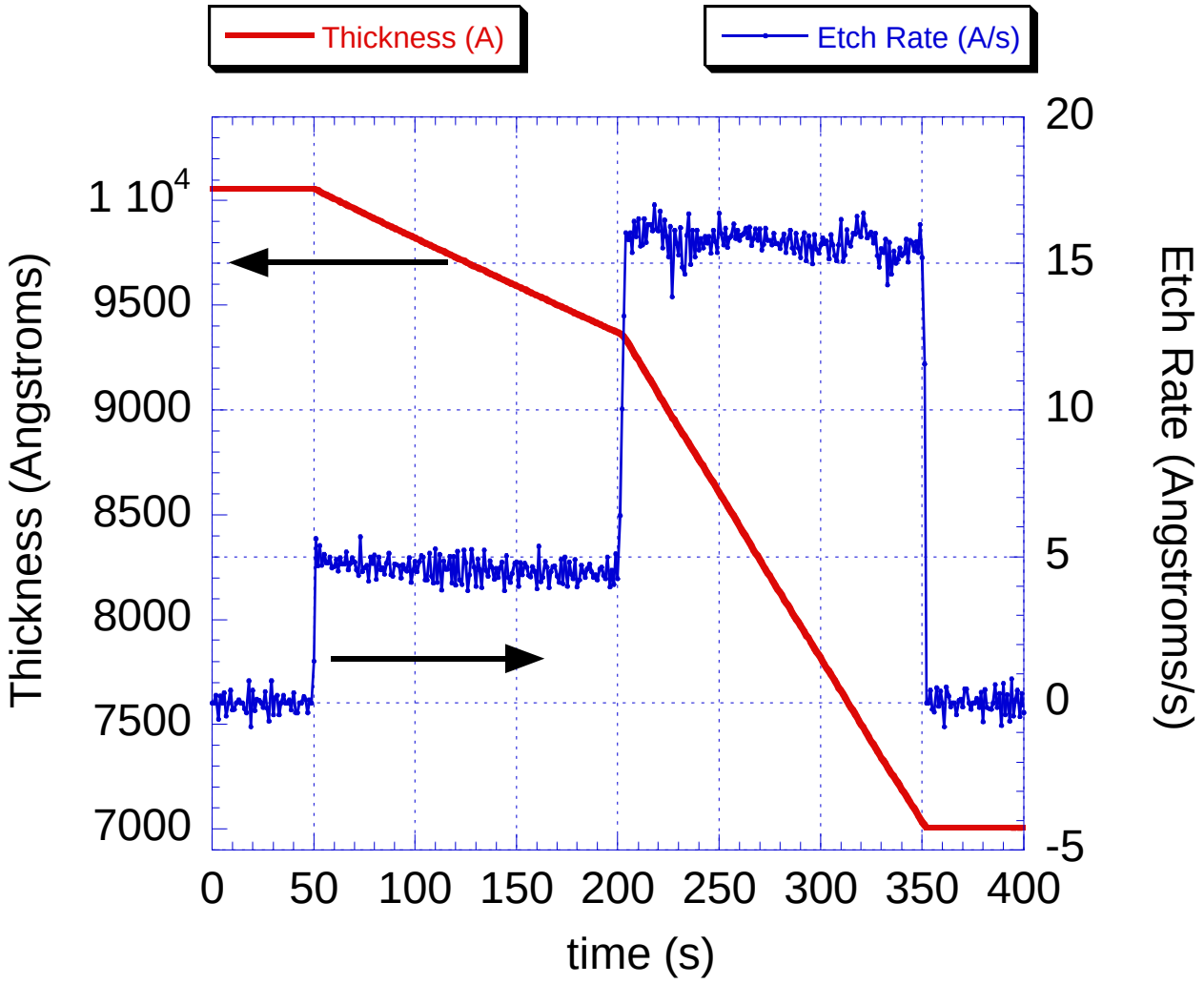


Fit comparison

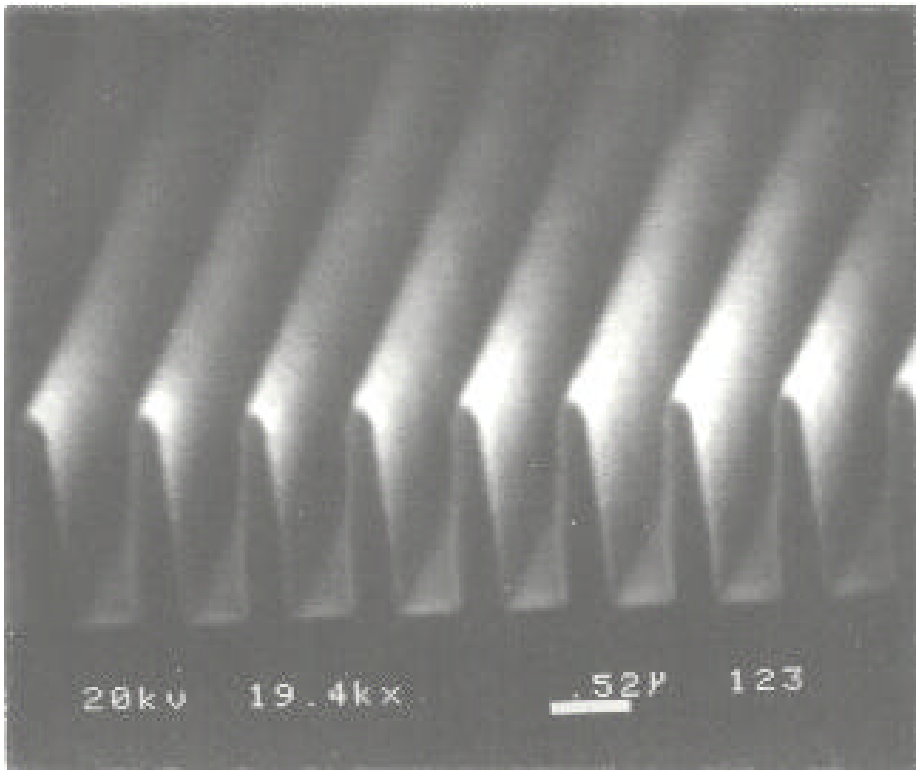
ONSR Tan(ψ) Fit	SE α–β Fit	Difference
17883 Å	17931 Å	48 Å
10050 Å	10052 Å	2 Å
3932 Å	3939 Å	7 Å
494 Å	509 Å	15 Å

Real-Time Etch Monitoring: Blanket Film

- SiO_2 Etched in CF_4 at 50 & 100W
- Thickness from Fit to Both $|R_p|^2$&$|R_s|^2$
- 6ms Integration Time, 1s Sampling Time
- Thickness Repeatability σ_d=0.22Å
- Etch Rate Standard Deviation σ_e=0.37Å/s

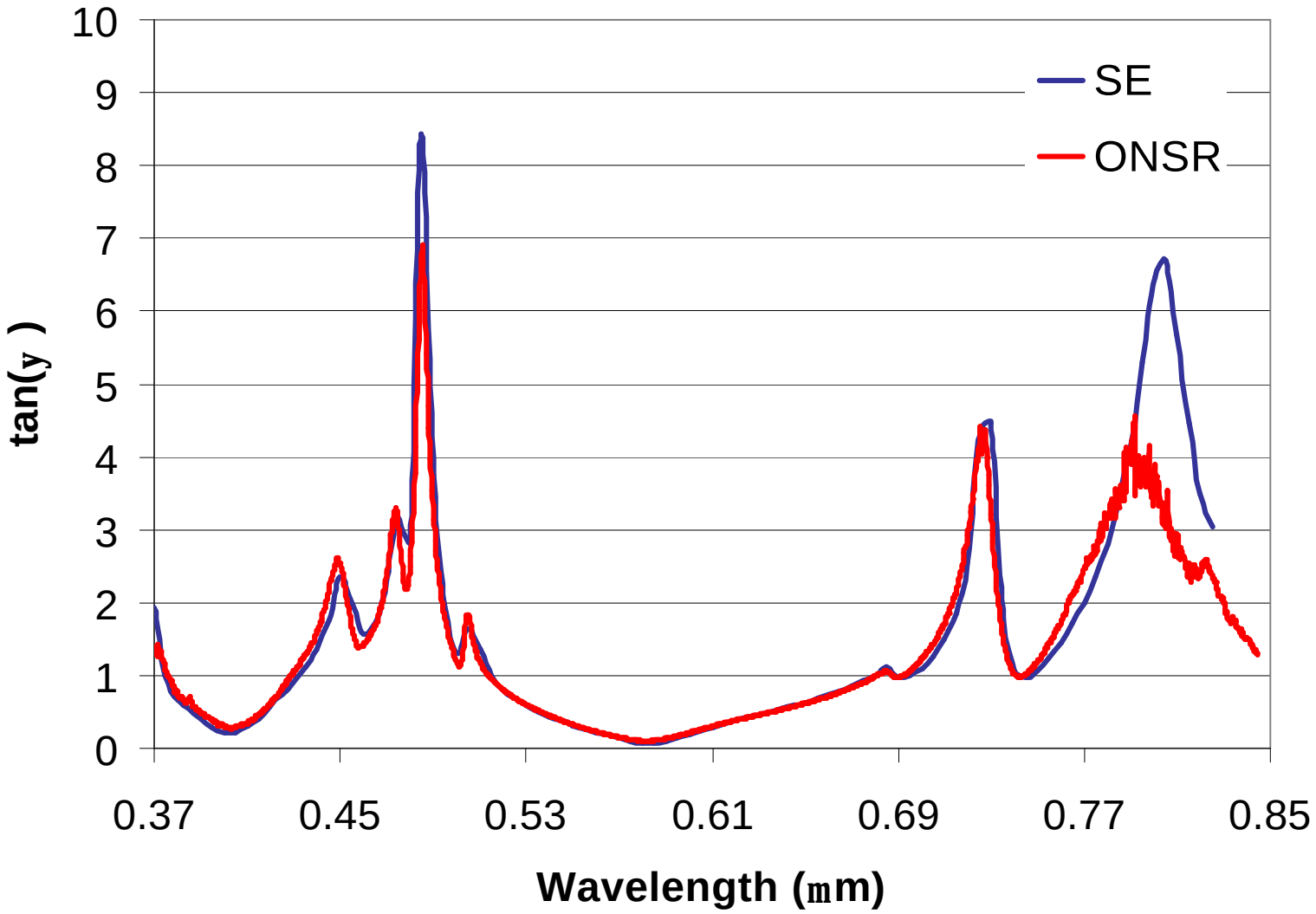


Submicron Grating

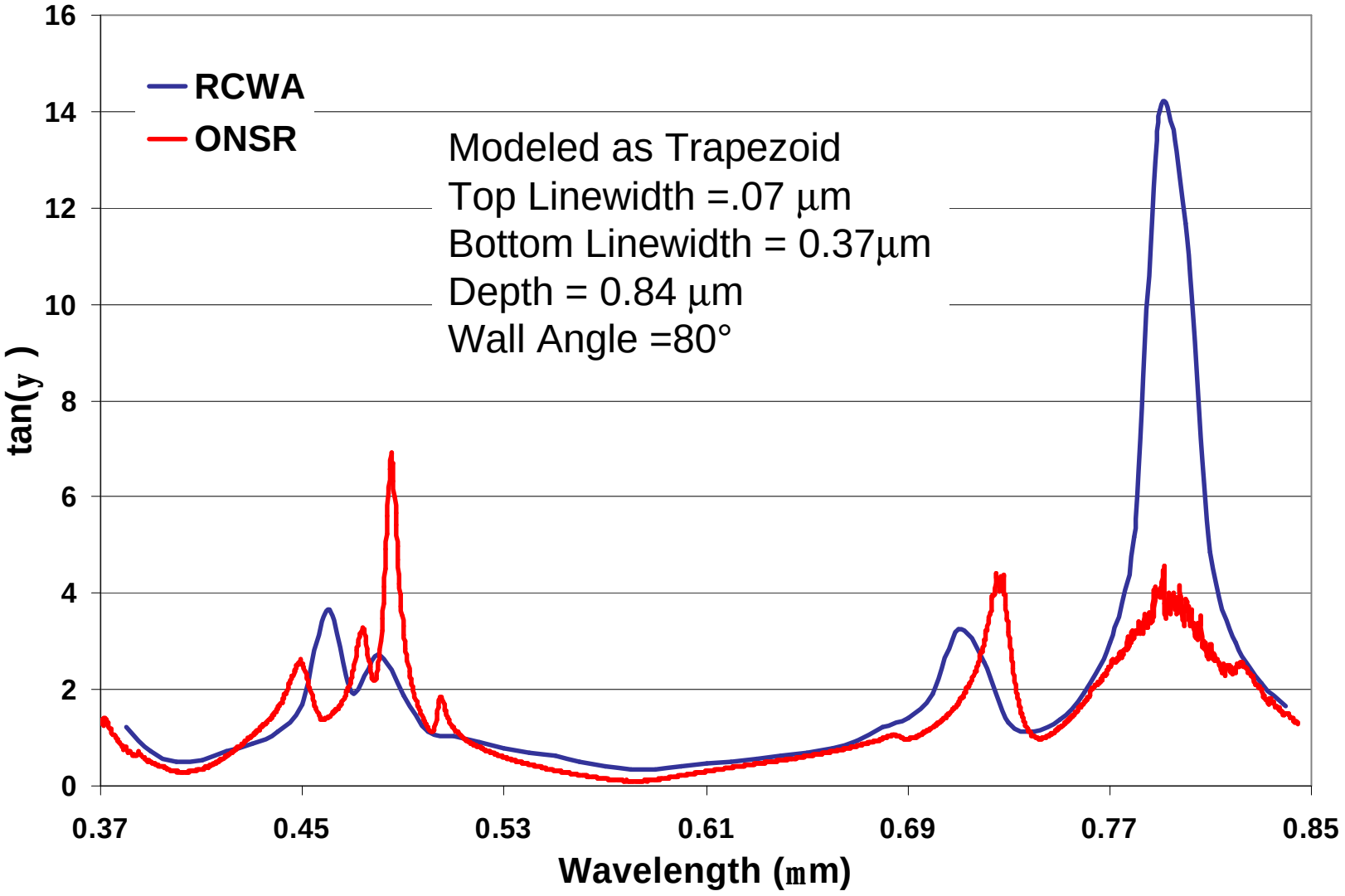


- 0.35µm Line/Space Grating In Photoresist/300Å SiO_2/Si
- Period Measured as 0.700 µm Using 1st Order Diffraction Angle at Multiple λ's
- Diffraction from Grating Yields Strong Structure-Related Features in Both tan(ψ)&cos(Δ)

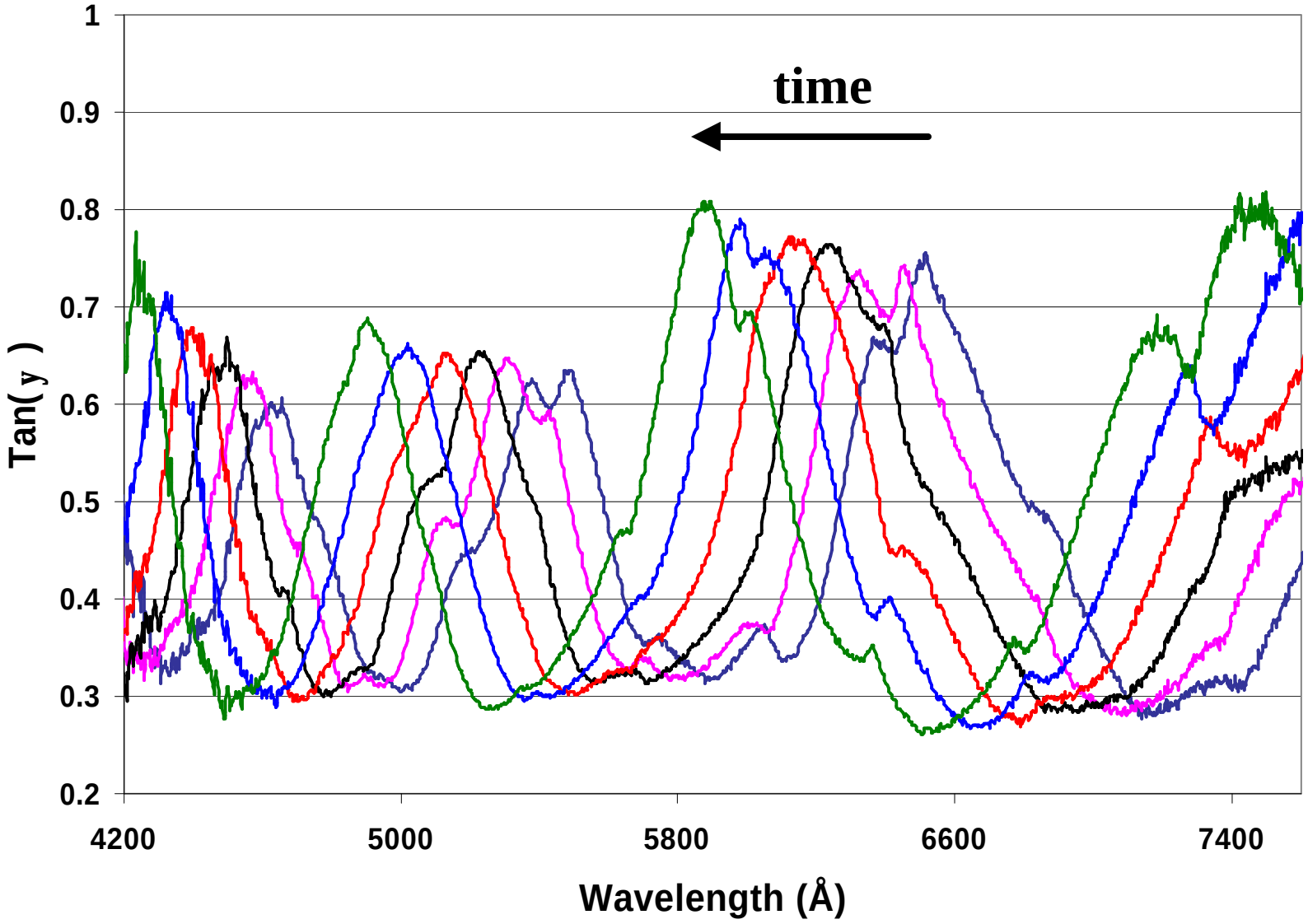
Tan(y) Vs wavelength, SE and ONSR



tan(y) Vs wavelength



2mm PR grating evolution during etch



Conclusions

- More than half SE info
- Affordable
- Small
- Accurate
- High speeds possible
- No moving parts

Future Work

- RCWA method - detailed feature analysis
- Scalar reflection model - high speed analysis
- Correlate pattern evolution with plasma parameters
- Extend Instrument to Spectroscopic Ellipsometry Mode with 1/4 Wave Achromatic Compensator

Acknowledgements

The authors would like to thank T. Li, P. Klimecky, A. Salian, M. Gulari, D.Grimard, C. Galarza, C. Garvin and D. Schweiger for their help on this project.