Characterization of resists and antireflective coatings

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Outline

Determination of Dill exposure parameters from reflectivity (or ellipsometric) measurements

Antireflective coatings (with focus on SiON)

Determination of photoresist Dill parameters

Lithography simulation:

Aerial image → resist exposure → resist development

resist models include resist and process dependent parameters

Goal:

Find a simple method, easy to use, to adjust the parameters of the resist exposure model using common equipment of a clean room (only a reflectometer)

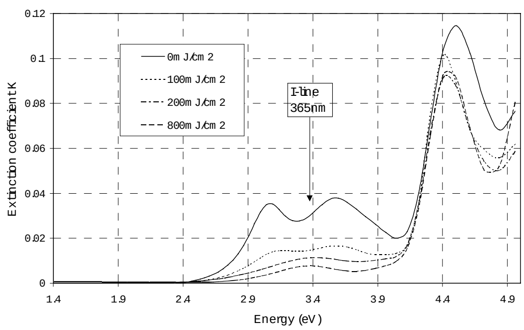
More elaborate solution uses ellipsometry

Resist exposure

I line (365nm) resist bleaches under exposure

Resist simulation models need to acccount for this bleaching in order to accurately represent light propagation and photo-chemical reactions within the resist film

First modeled by Dill et al.



Dill exposure parameters

Beer-Lambert law

$$-\frac{dI(z,t)}{dz} = I(z,t)\,\alpha(z,t)$$

I: intensity within the resist

α: absorption of the resist (μm^{-1})

m: concentration of the photoactive compound (PAC)

$$\frac{dI(z,t)}{dz} = -I(z,t)\left(Am(z,t)+B\right)$$

PAC decomposition rate

$$\frac{dm(z,t)}{dt} = -C\,I(z,t)\,m(z,t)$$

$$\alpha = A.\exp(-I.C.t)+B \quad => \quad \alpha = A.\exp(-C.dose)+B$$

Hypothesis: α constant within the film

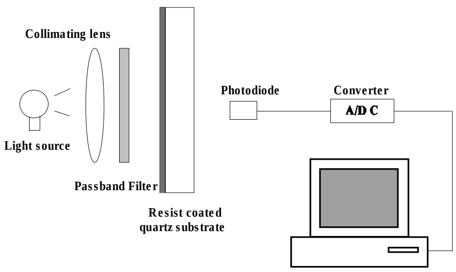
B: absorption of fully bleached resist

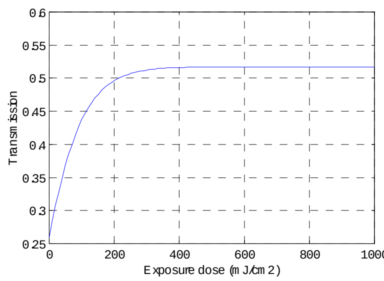
A+B: absorption of unexposed resist

Transmission measurement

Spectrophotometer (here Varian Cary 5E)

Quartz substrate
Transmittance is measured during exposure



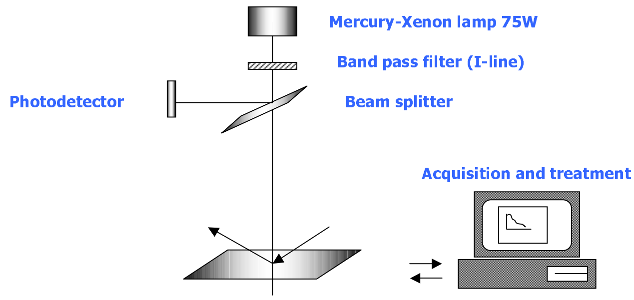


Need a calibration of the source

Reflectivity measurements

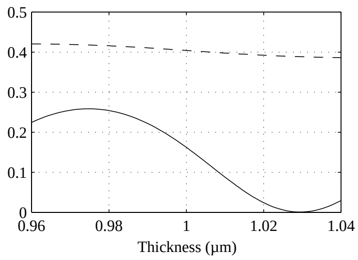
Standard wafers are used

Exposure can take place before (or during) the measurement



Sensitivity to resist thickness

Thin film effects are much more pronounced when using reflectivity measurements



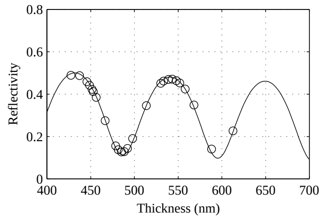
Accurate determination of the resist thickness is necessary at each measurement site

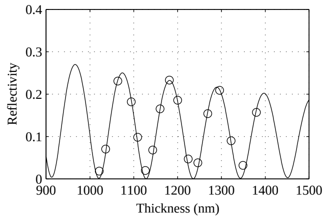
(large wavelength + Cauchy)

Index from reflectivity fit

Real part n of N is supposed to be constant (useless with ellipsometry).

When n is known (and thickness measured), absorption can be computed from reflectivity measurement.





Fit of reflectivity vs thickness curve is a simple and accurate way of getting n

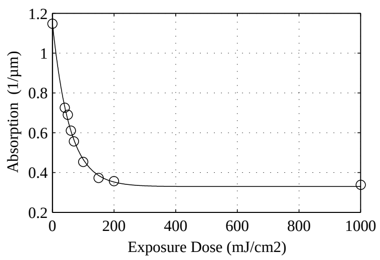
Experimental procedure

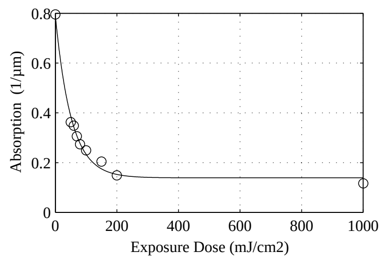
Step by step Reflectivity	Step by step Ellipsometry	Real time Ellipsometry
Measure n		Calibrate light source
Coat silicon wafer	Coat silicon wafer	Coat silicon wafer
Expose (stepper)	Expose (stepper)	
Reflectivity	Ellipsometry	Expose + ellipsometry
- thickness - absorption α	- thickness - n, k (-> α)	- thickness - n, k (-> α)
Fit α vs dose curve -> A, B, C	Fit α vs dose curve -> A, B, C	Fit α vs dose curve -> A, B, C

NB: more sophisticated ABC extraction procedure is possible

Results (reflectivity method)

Good exponential behavior allowing A,B,C fit





Olin OiR 32md

A=0.81µm^{-1}, B=0.33µm^{-1}, C=0.018 cm^2/mJ

Shipley SPRT510

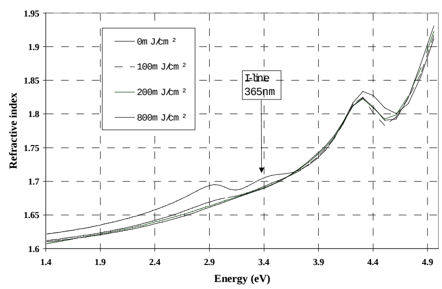
A=0.65µm^{-1}, B=0.14µm^{-1}, C=0.019 cm^2/mJ

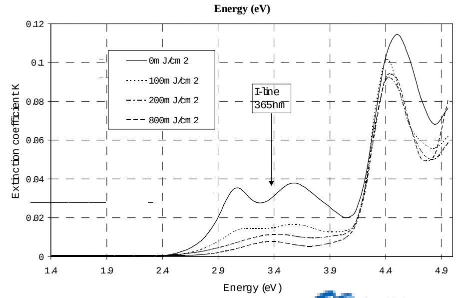
Spectroscopic ellipsometry

The same kind of approach can be performed more efficiently using spectroscopic ellipsometry.

Thickness and complex refractive index can be determined simultaneously.

Real time measurement is possible.

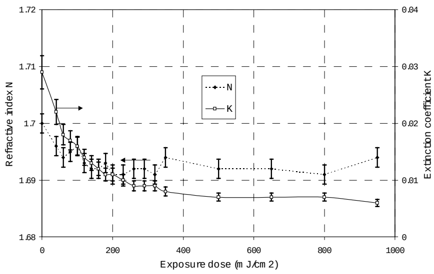




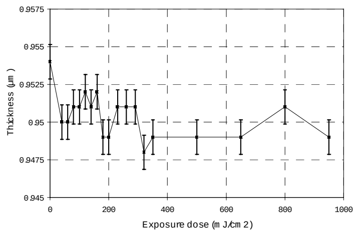
Refractive index from ellipsometry

Strong (exponential) variation of the extinction coefficient

Real part changes slightly

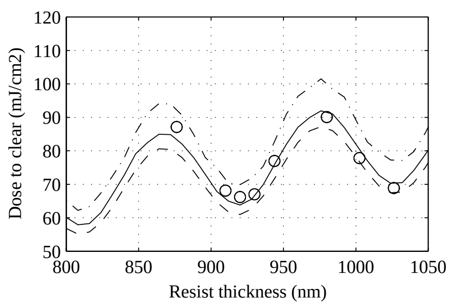


Thickness variations are due to exposure and dispersion on the plate
=> needed for each measurement



Simulated vs experimental results

As extracted parameters fit well experimental data.



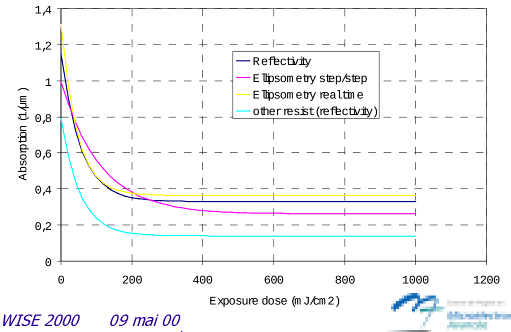
Dose to clear for different diffusion lengths (remaining resist model parameter)

Comparison of the different methods

Resist: Olin OiR32md

All methods give consistant results

	A (1/µm)	B (1/µm)	C (cm^2/mJ)
Transmission	0.82	0.33	
Reflection (step by step)	0.81	0.33	0.018
Ellipsometry (step by step)	0.73	0.26	0.009
Ellipsometry (real time)	0.95	0.36	0.022



Application to Chemically Amplified resists?

Absorption coefficient does not vary significantly or does not reflect PAC decomposition during exposure.

Post exposure bake plays the major role in the catalytic chemical reactions.

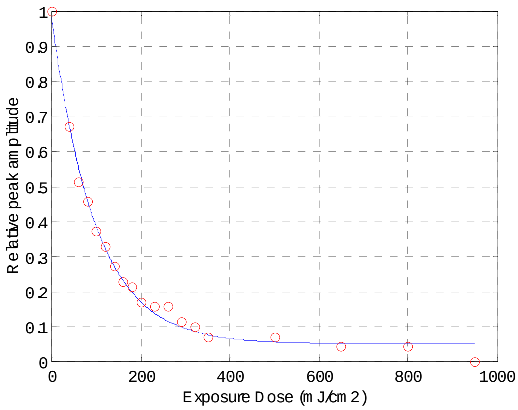
C parameter describing the PAG decomposition rate under exposure cannot be determined by absorption measurement .

One possibility: FTIR spectroscopy

Validity of C.A. resist simulation is questionable (cf C. Mack et al., D. Kang et al. SPIE 99)

FTIR spectroscopy measurement

Example: I line resist
amplitude of the diazide of the photoactive compound is significant of PAC decomposition kinetics



C=0.011

Conclusion (1st part)

A simple method has been presented to extract Dill exposure parameters using reflectivity (ellipsometry) measurements.

The use of standard silicon wafers can be prepared using the exact process to be simulated.

Step by step exposure using the stepper avoids dose calibration problem

Real time exposure and rigourous parameters extraction is also possible using reflectivity method

Antireflective coatings

Why ARC?

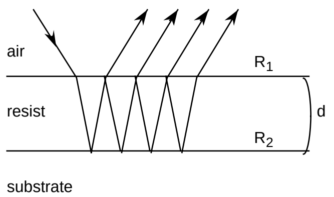
Optimization procedure

SiON properties

Lithographic results

Why antireflective coatings ?

Thin film interference effects within the resist :



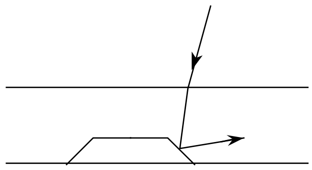
swing : sinusoidal variation of reflection coefficient, dose to clear, CD, ... with resist thickness

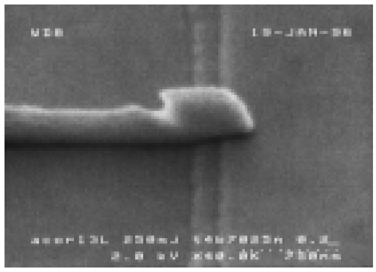
CD dispersion

standing waves

Why antireflective coatings ?(ctd)

Reflection from the substrate:





- reflective notching
- sensitivity to the substrate reflectivity

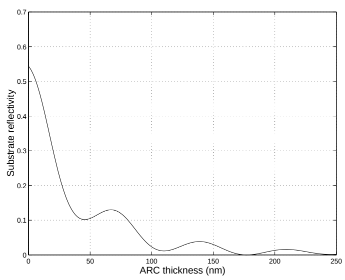
Antireflective strategies:

died resist, top ARC, bottom ARC

Two strategies for bottom ARC

low absorption BARC

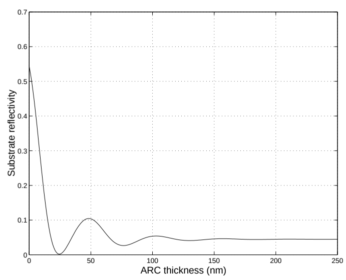
(the resist does not "see" the substrate anymore)



N = 1.79 - i 0.235

"strong" absorption BARC

(use interference + absorption to cancel the reflected light)

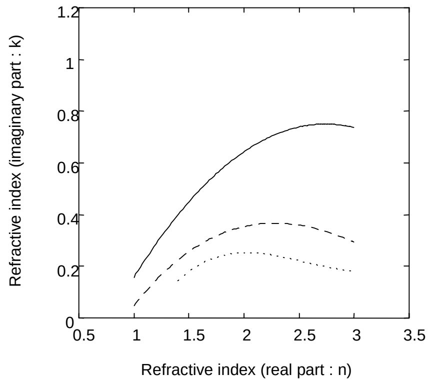


N = 2.3 - i 0.6

Refractive indices of optimum BARCs

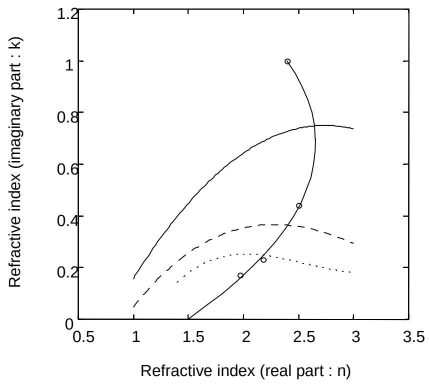
3 parameters space : n, k, thickness (not shown)

3 first lobes (R < 2%)



BARC Optimization

Directly from the optimum BARC abacus, we choose the suitable materials



everything relies on a proper determination of the complex refractive index of the materials

Thickness is deduced from simulations

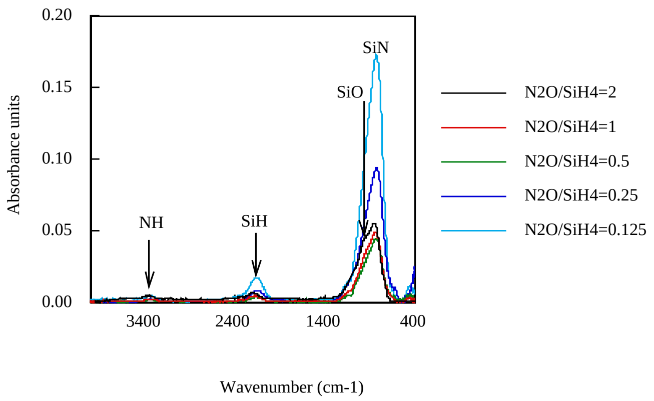
SiON based ARC

PECVD , precursor gases : silane (SiH_4) and nitrous oxide(N_2O); carrier gas : nitrogen

Trikon Planar 200

deposition temperature : 300°

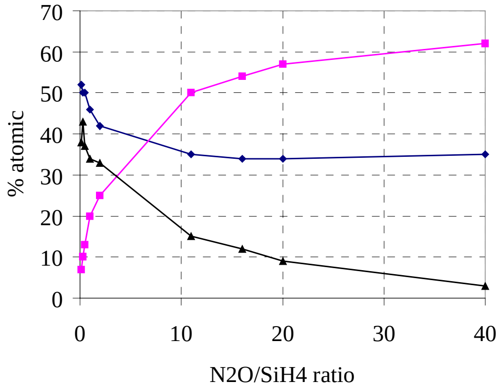
SiON film physical properties



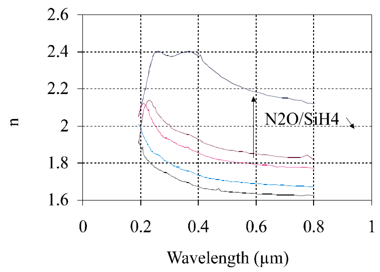
Two phase structure => Si is promoted, the gap is pushed toward larger wavelength

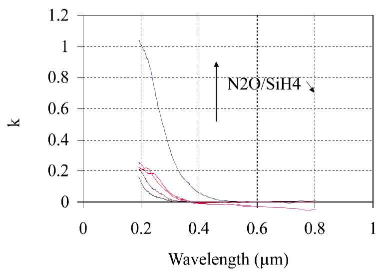
Atomic composition vs. N_2O / SiH_4 ratio

■ oxygen, ◆ silicon , ▲ nitrogen



SiON refractive indices



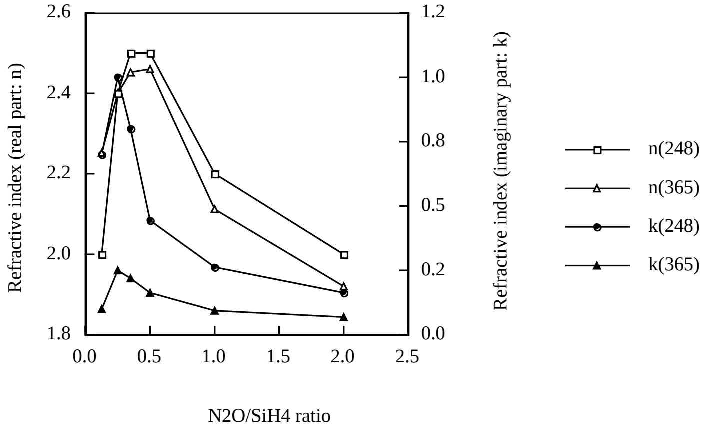


real part **imaginary part**

from bottom to top: α=5, 4, 3, 1, 0.35

Refractive index vs. N_2O / SiH_4 ratio

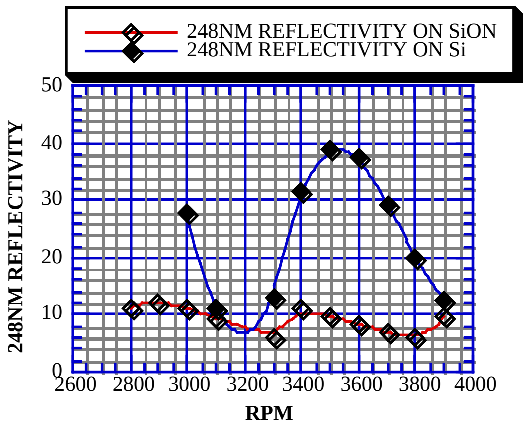
index is easily adjustable depending on the application



Swing amplitude reduction

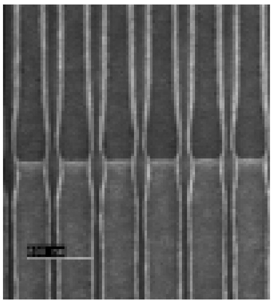
SiON (N= 2.35 - i 0.61) on Si

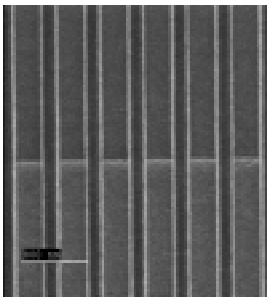
thickness 25nm



Lithographic results

Positive 248nm resist



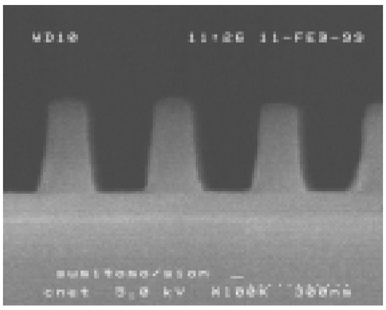


step height 200nm

Lithographic results

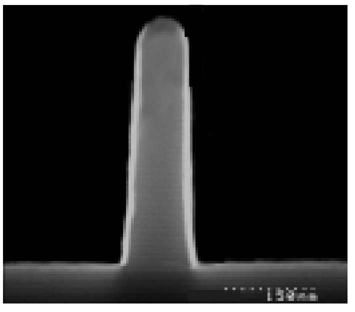
193nm

Sumitomo PAR-101A4 resist

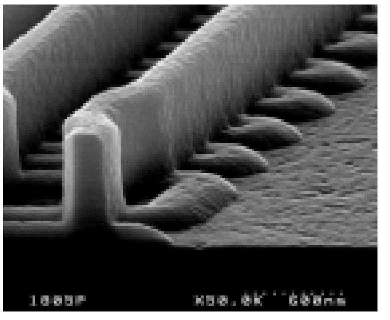


Lithographic results

positive 248nm resist



0.12µm line on poly



0.25 µm line poly2 NVM

Conclusion (2nd part)

- Efficient BARC optimization can be achieved
- SiON due to its silicon rich and easily adjustable composition is a good candidate for 248nm and 193nm lithography.
- Accurate refractive index measurement is a key point.

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