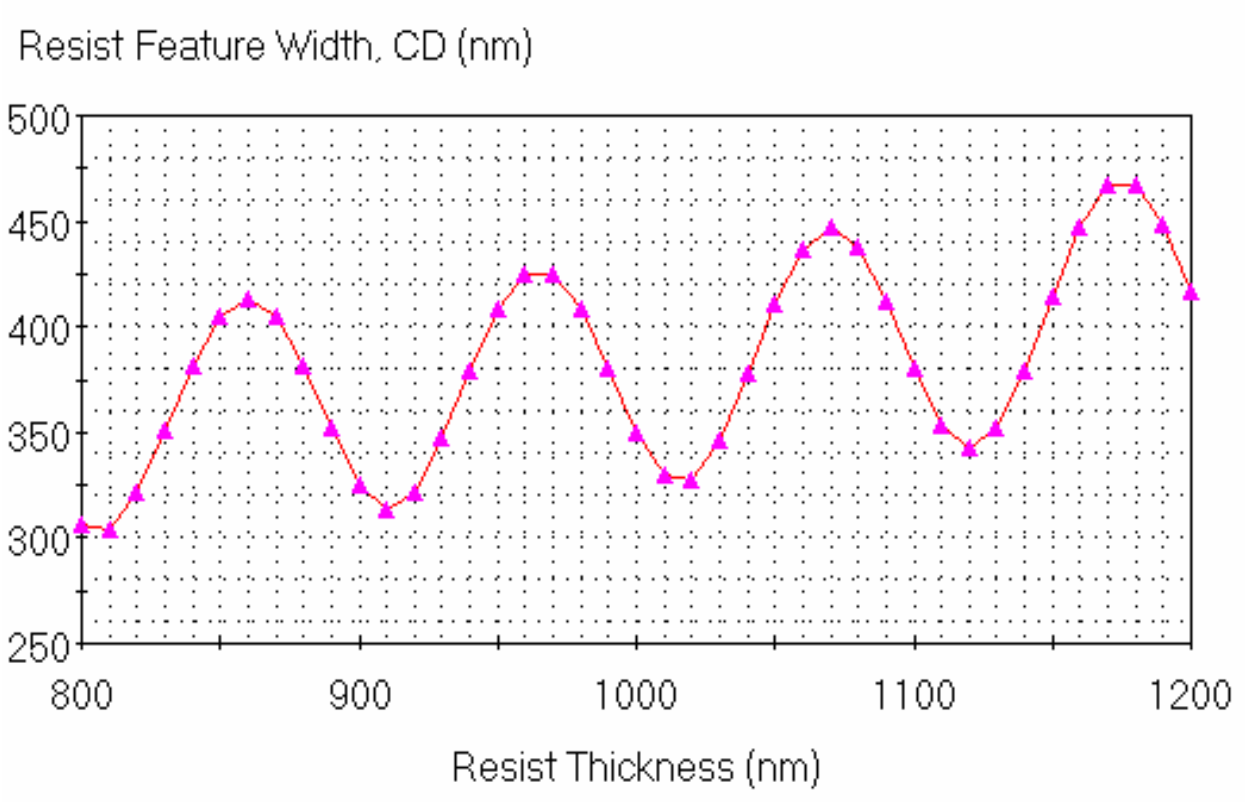
Swing Curve Effect

- 1. Light interaction
- 2. Description
- 3. Impact
- 4. Elimination

Swing Curve Effect

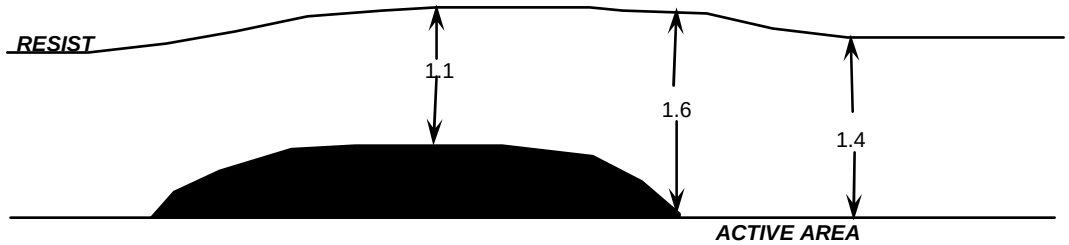
- **Swing curve Example : Prolith : IX700 at 100mj/cm2 dose on SiO_2**



Swing Curve Effect

from Shipley

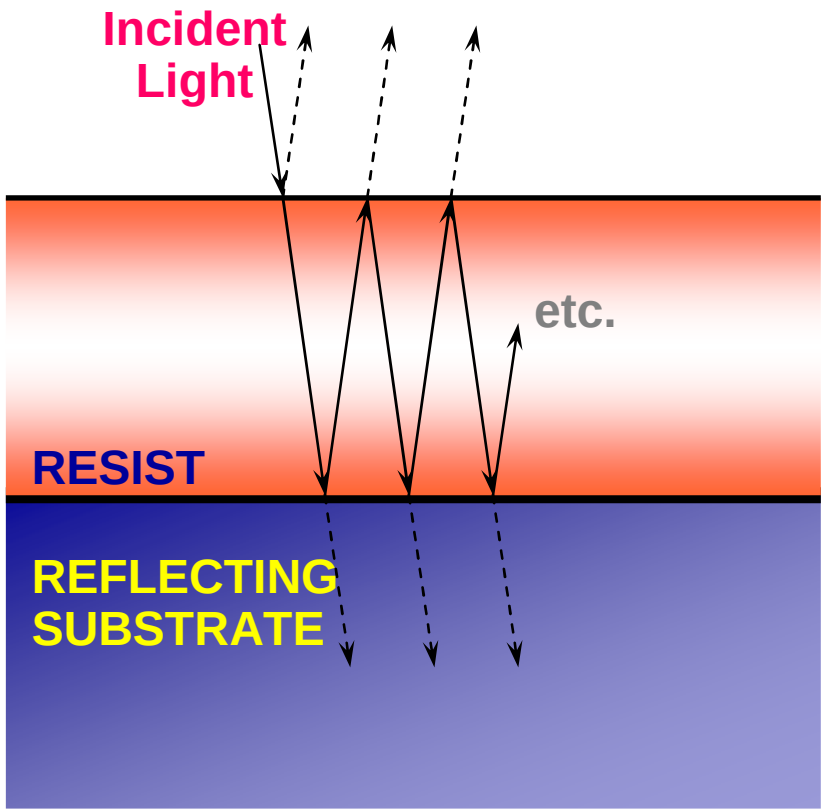
- Another source of CD variation due to changing resist thickness: **interference effect**. This effect is peculiar to optical lithography using monochromatic light (e.g. 5X steppers). Since mono-chromatic light is used and the photoresist is a thin film, optical interference causes changes in reflectivity as a function of film thickness (this is the same problem that pellicles have: as the pellicle thickness changes, so does the transmission).
- Energy coupled into the photoresist is dependent on resist thickness. A periodical function describes the influence of the interference effect on photoresist CD's. In general, CD's go from a maximum to a minimum for every 600 angstrom change in resist thickness. This is significant because topography contibutes much more than 600 angstroms change in resist thickness.



Swing Curve Effect

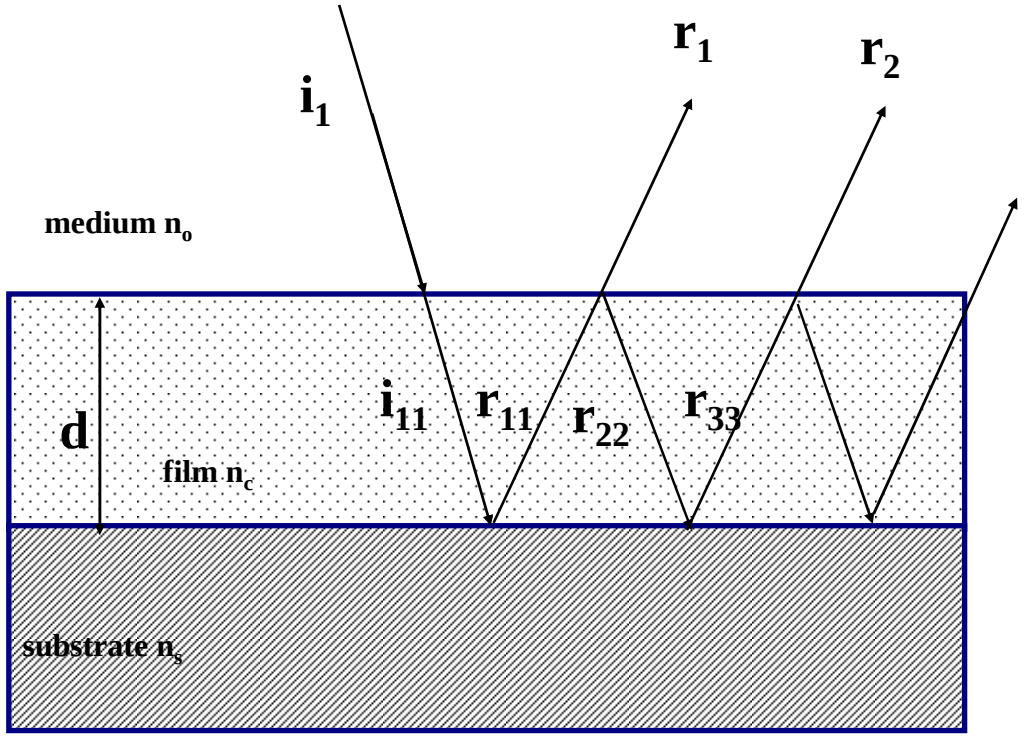
from Shipley

- Interference of incident and reflected light from substrate and photoresist causes standing waves and swing curve effect.



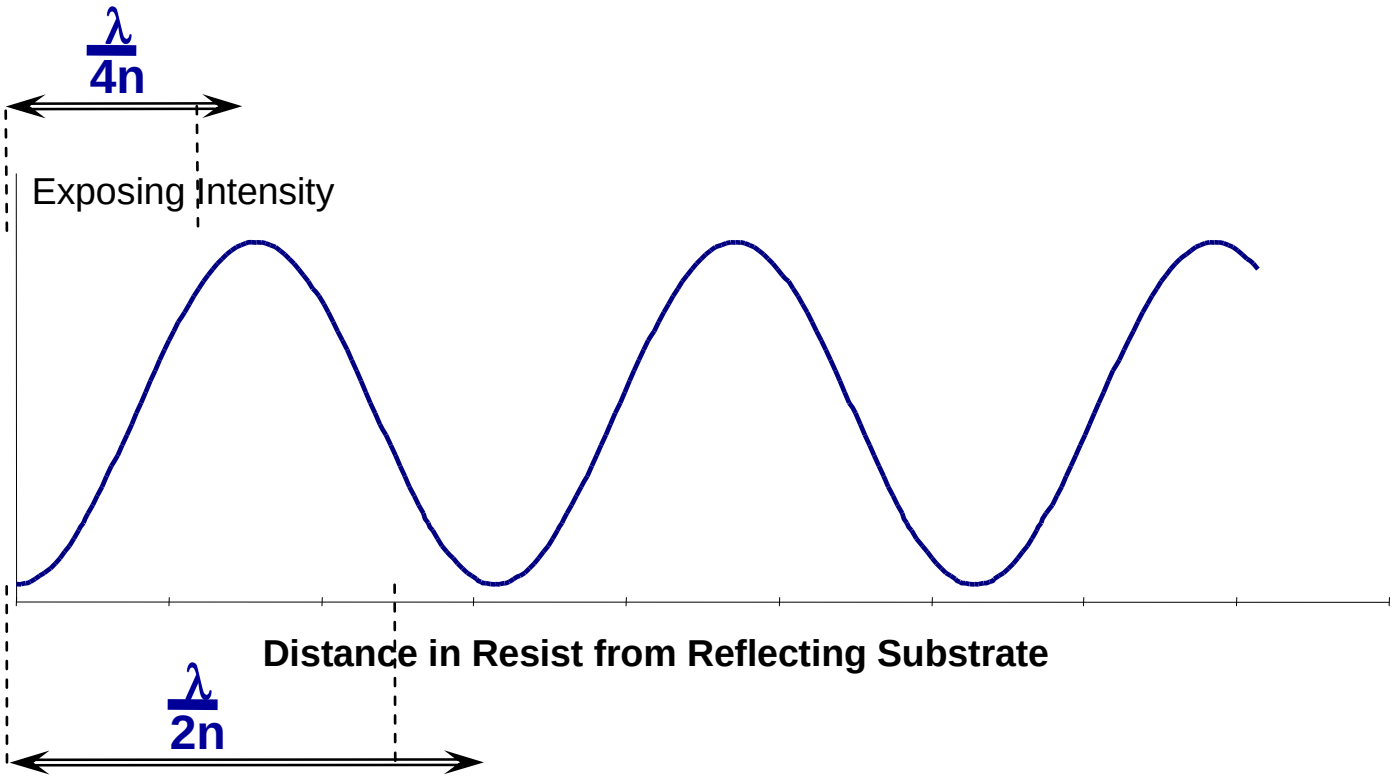
Swing Curve Effect

- Basic Concept:
- **Cause and effect!!!!!!!!!!!**
- **Standing Waves: Interference of i_{11} and r_{11}**
- **Swing Curve: Interference of r_{11} and r_{22}**



Swing Curve Effect

Interference of incident and reflected waves cause periodic intensity variations in the photoresist.



Swing Curve Effect

Quarter wavelength Expression

Extrema separation is given by the quarter wavelength expression $(\lambda/4n)$ which is dependent on:

Exposing wavelength (λ)
Resist refractive index (n) at λ

G-line: $\lambda = 436nm$, $n \approx 1.69$
$\Rightarrow$ Extrema Separation ≈ 645 Å

I-line: $\lambda = 365nm$, $n \approx 1.74$
$\Rightarrow$ Extrema Separation ≈ 524 Å

KrF: $\lambda = 248nm$, $n \approx 1.77$
$\Rightarrow$ Extrema Separation ≈ 350 Å

Swing Curve Effect

Brunner equation from AZ

Swing ratio S

$$S = 4\sqrt{R_b R_t}\, e^{-\alpha \cdot d}$$

where

R_b: reflectivity at the resist/substrate interface - reduced by antireflective bottom coats;

R_t: reflectivity at the resist/air interface - reduced by antireflective top coatings;

α: resist absorbance - increased by dye addition.

Swing Curve Effect

The theory of Fabry-Perot etalons allows us to write the intensity at the bottom of the resist as

$$I_{bottom} = I_1\left(1 - 2|F|\cos(\phi + \delta)\right),$$

where δ is the phase change at the substrate surface, and where we have used

$$I_1 = \frac{4 n_r}{(n_r + 1)^2} e^{-\alpha_r \cdot d}$$

$$\phi = \frac{4\pi n_r d}{\lambda}$$

$$|F| = \sqrt{R_t R_b} \cdot e^{-\alpha_r \cdot d}$$

In turn, R_t is the reflection coefficient at the resist-air interface, and R_b the one at the resist/substrate interface.

The region at the bottom of a photoresist is the one that generally sees the least light, and will therefore be critical to the development process. We can therefore defend the definition of the swing ratio S as the peak to valley change in I_{bottom} divided by the average intensity:

$$S = \frac{I_1(1 + 2|F|) - I_1(1 - 2|F|)}{I_1} = 4|F|,$$

yielding Brunner's formula

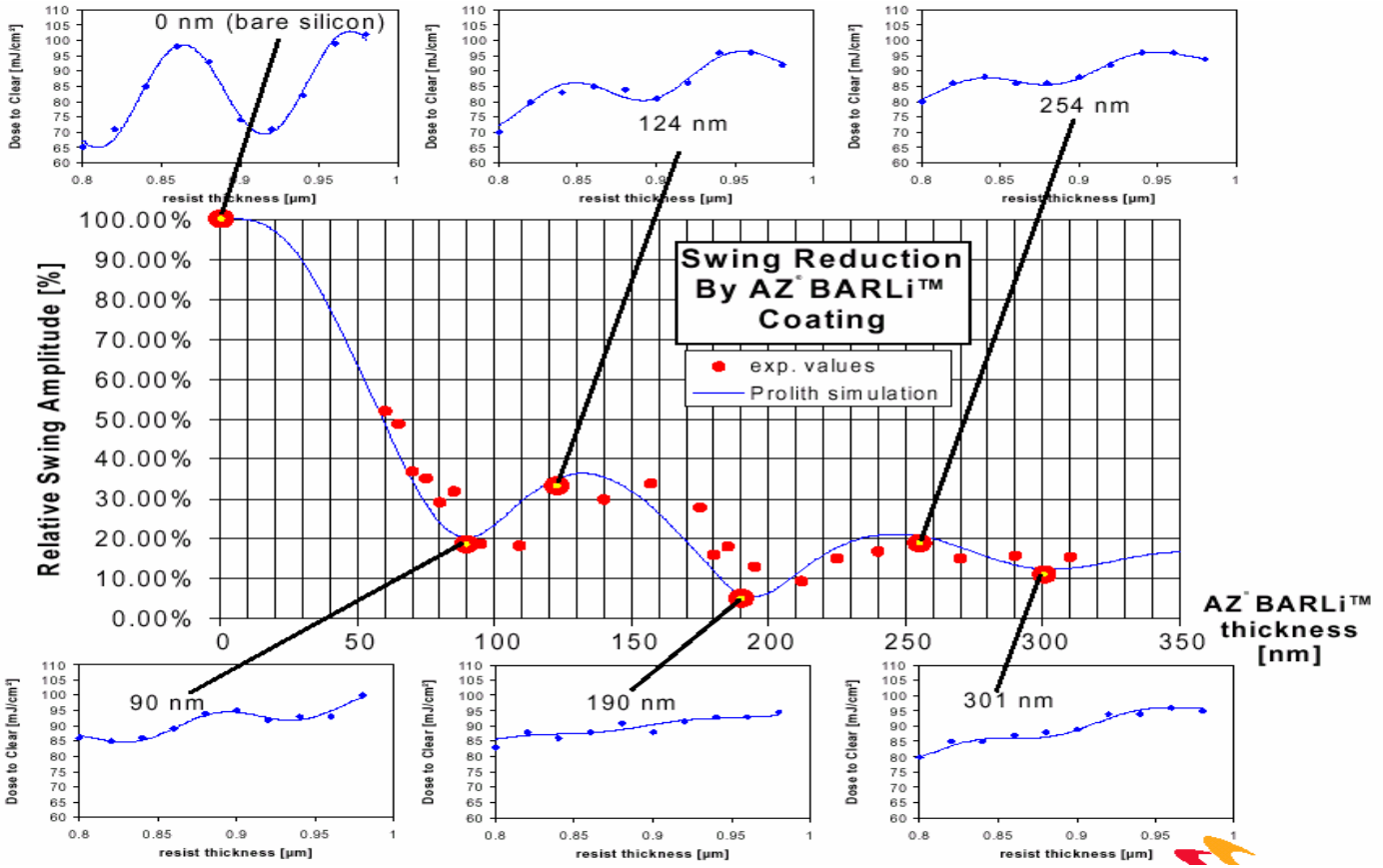
Swing Curve Effect

Brunner Equation

$$S = 4\sqrt{R_t R_b} \cdot e^{-\alpha_r \cdot d}$$

Swing Curve Effect

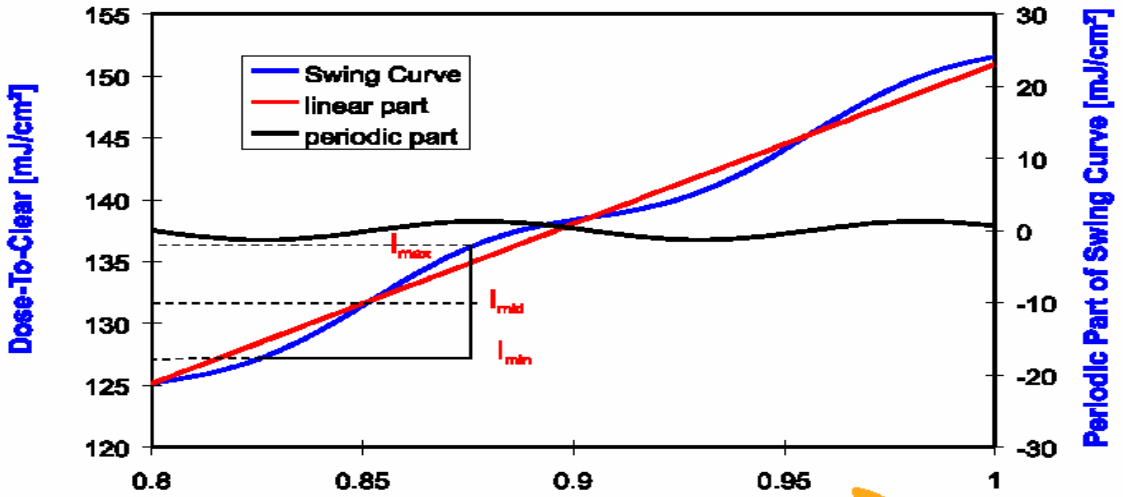
Swing curve ratio from AZ



Swing Curve Effect
Brunner Equation from AZ

On anti-reflective coatings, the swing curves can be so shallow that the conventional definition of "swing curve ratio" as $S = \frac{I_{max} - I_{min}}{I_{mid}}$ can be misleading. In the example below, one would still find a swing ratio of nearly 9% in the limit of the periodic part going to zero. For shallow swing curves, this definition is best replaced with that of the amplitude of the periodic part.

The predictions made by Brunner's formula do not include the linear part of the swing curve, and can therefore only be compared to swing amplitudes.



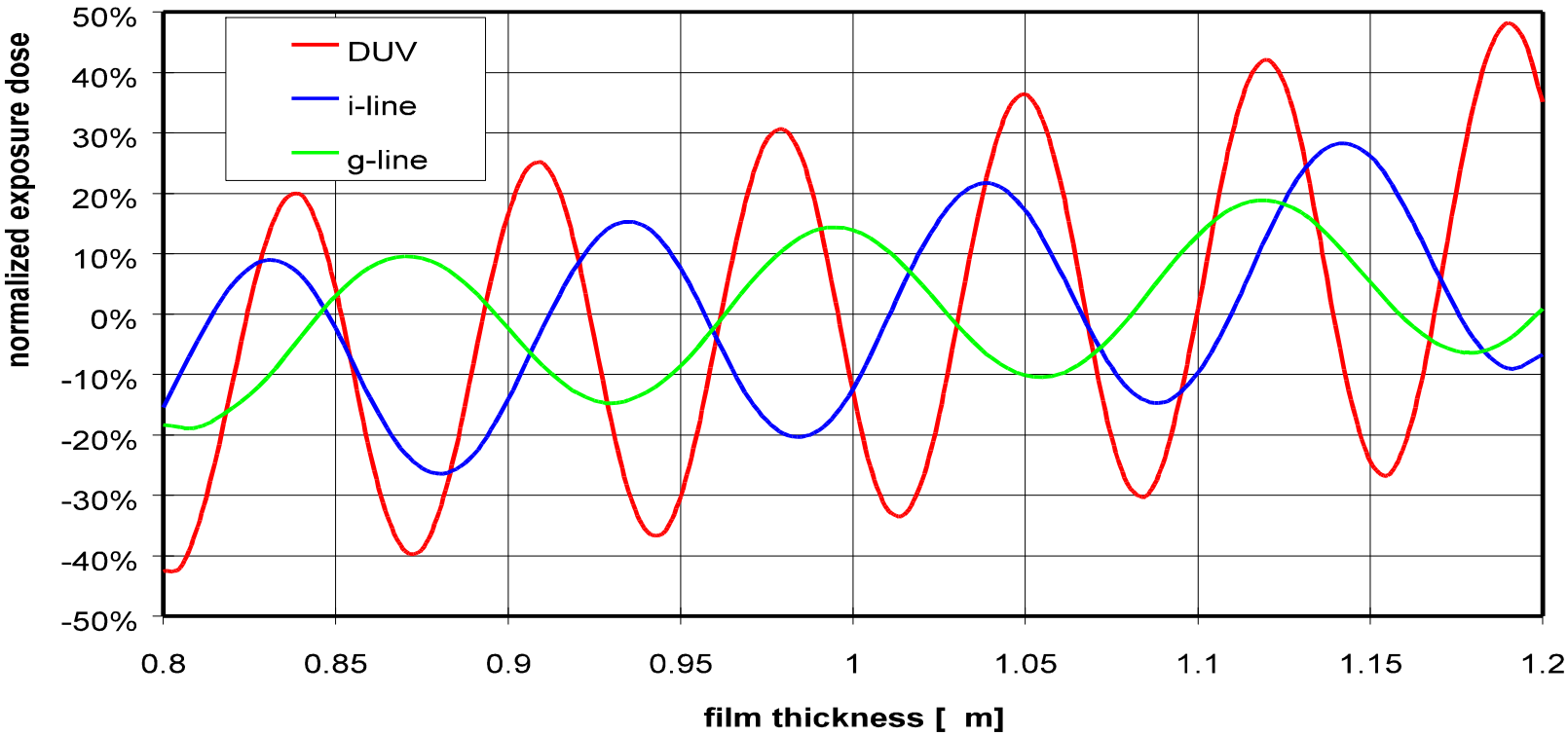
Swing Curve Effect

Brunner Equation from AZ

$$S = \frac{E_{0\,max} - E_{0\,min}}{E_{0\,mid}} = 2\,\frac{E_{0\,max} - E_{0\,min}}{E_{0\,max} + E_{0\,min}}$$

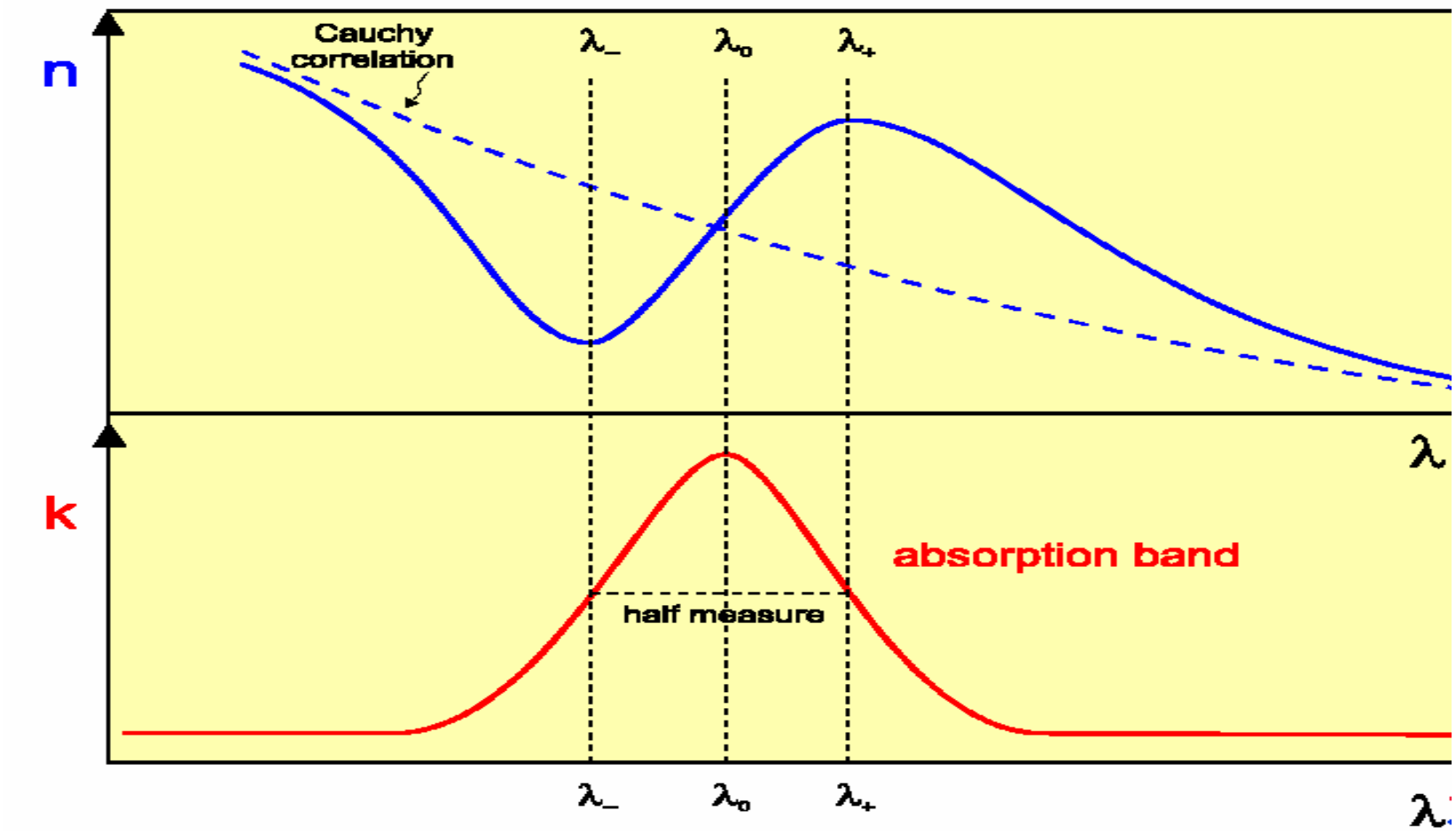
Swing Curve Effect

Wavelength Effect: as wavelength decreases swing amplitude increases due to increased reflectivity at shorter wavelengths (higher n)



Swing Curve Effect

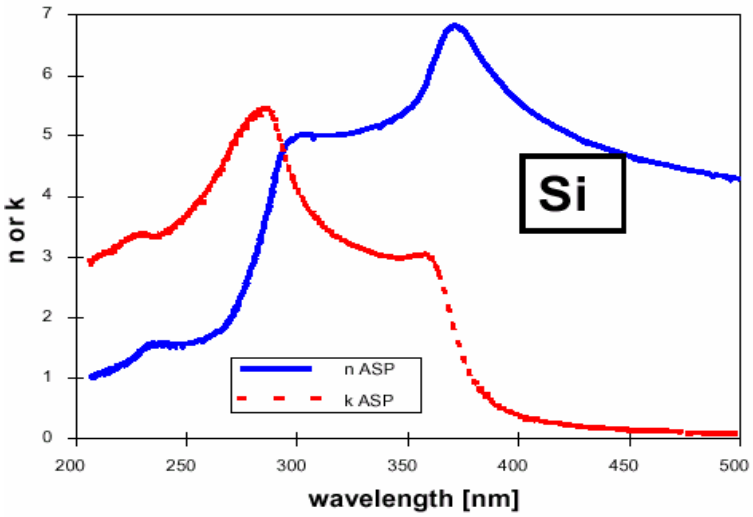
n change in regions of high absorbance

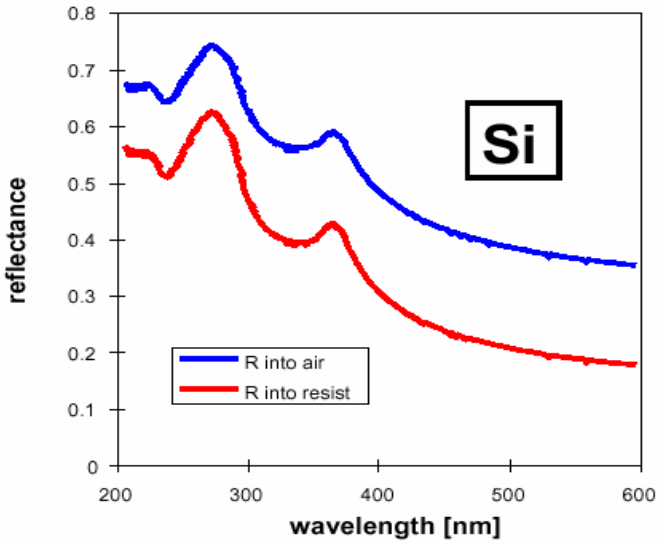


Swing Curve Effect

Wavelength Effect: as wavelength decreases swing amplitude increases due to increased reflectivity at shorter wavelengths (higher n). I.e. Dispersion

$$R_{air} = \frac{(1-n_{Si})^2 + k_{Si}^2}{(1+n_{Si})^2 + k_{Si}^2}; \qquad R_{PR} = \frac{(n_{PR}-n_{Si})^2 + (k_{PR}-k_{Si})^2}{(n_{PR}+n_{Si})^2 + (k_{PR}+k_{Si})^2}$$





Swing Curve Effect

Dispersion Models

- Sellmeier dispersion model

$$n^2(\lambda) = 1 + A_S + \frac{B_S}{1 - \left(\frac{\lambda_0}{\lambda}\right)^2}$$

- Cauchy dispersion model (approximation to Sellmeier)

$$n(\lambda) = A_C + \frac{B_C}{\lambda^2} + \frac{C_C}{\lambda^4}$$

Both models are only valid far from the region of absorbance.

Swing Curve Effect

Dispersion Models

- Sellmeier dispersion model

$$n^2(\lambda) = 1 + A_S + \frac{B_S}{1 - \left(\frac{\lambda_0}{\lambda}\right)^2}$$

- Cauchy dispersion model (approximation to Sellmeier)

$$n(\lambda) = A_C + \frac{B_C}{\lambda^2} + \frac{C_C}{\lambda^4}$$

Both models are only valid far from the region of absorbance.

Swing Curve Effect

Wavelength Effect: as wavelength decreases swing amplitude increases due to increased reflectivity at shorter wavelengths (higher n). I.e. Dispersion

$$R_{\infty} = \frac{(n_1 - n_2)^2 + (k_1 - k_2)^2}{(n_1 + n_2)^2 + (k_1 + k_2)^2}$$