# EECS 243 – Advanced IC Processing and Layout

**Fall 2000 Office Hours Prof. A. R. Neureuther,**
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# Solution Assignment # 4,

**4.1 Thin-film effects in resist**

a) $\rho_{sub\text{-}air}$ = {1-(1.68-j3.58)}/{1+(1.68-j3.58} = {-0.68+j3.58}/{2.68-j3.58}
= {3.64 < 100.8$^o$}/{4.47 < -53.2$^o$}= 0.82< 154.0$^o$ => R = $(0.82)^2$ = 0.67

b) $\rho_{sub\text{-}resist}$ = {(1.8-j0.03) –(1.68-j3.58)}/{(1.8-j0.03)+(1.68-j3.58)}
= {3.55<88.1$^o$}/{5.0 <46.1$^o$} = 0.71<134.1$^o$

c) $E_{max}$ = 1+0.71 = 1.71 => $I_{max}$ = 2.92; $E_{min}$ = 1 – 0.71 = 0.29 => $I_{min}$ = 0.084
C = (2.92 – 0.084)/(2.92+0.084) = 0.94

d) |ρ| = 0.71; Now look for an equivalent material that will produce the same magnitude reflection coefficient in the resist (and with a negative sign). Since ρ = { $n_{resist}$ -$n_{eq}$}/( $n_{resist}$ + $n_{eq}$) solving for $n_{eq}$ gives $n_{eq}$ = $n_{resist}${1- ρ }/{1+ ρ } = 1.8{1-(-0.71)}/{1+(-0.71)} = 10.6. When the resist acts like a quarter wave coating the effective refractive index seen from the air is $n_{eff}$ = {$n_{eq}$}/{$n_{resist}^2$} = 10.6/{$1.8^2$} = 3.28. This produces a reflection coefficient in air of $\rho_{air}$ = {1- $n_{eff}$ }/{1+ $n_{eff}$ } = {1-3.28}/{1+3.28} = 0.53 => R = 0.28

e) $\rho_{baked}$ = {1-1.8}/{1+1.8} = 0.8/2.8 0.294 => R = 0.086

**4.2 Non-linearity of resist dissolution rate with exposure**

(Actually the I-line stepper in the Microlab has NA = 0.315.) A 1.0 μm equal line and space pattern imaged with a 365 nm wavelength, σ = 0.5 and NA = 0.30 has a peak intensity of 1.17 compared to a clear field. This makes the exposure dose in the middle of the feature 117 mJ/cm$^2$. (We assume that the etch rate was measured for this exposure dose in air and thus already includes the fact that 100% is not transmitted into the resist. It will affect all values in the resist by the same fraction and thus is not an important issue in this problem.) The exposure dose at the line edge is 30 mJ/ cm$^2$. The exposure at the bottom of the resist is smaller by a factor $e^{-(0.67x1.0)}$ = 0.51 or 59.7 and 15.3 mJ/ cm$^2$ at the center an line edge position. The etch rates for these four locations are 237, 4.16, 4 and 0.018 nm/s. For the vertical path under the maximum intensity, the average dose is (117+59.7)/2 = 88.4 mJ/cm$^2$. This gives an etch rate of 102 nm/s and a $t_{ver\text{-}center}$ of 9.8 seconds. For the path along the bottom, we assume that only ¼ of the feature width needs to be developed. The average dose is (59.7+0.018)/2 = 29.9 mJ/ cm$^2$ . This gives an etch rate of 3.94 nm/s and a delay of $t_{across}$ = 250/3.94 = 63 seconds. Alternatively going from top to bottom at the feature edge has an average dose of (30+0.018)/2 = 15 mJ/ cm$^2$. The rate is 0.5 nm/s and the delay is 1000/0.5 = 2000 s.

**4.3 Models for Chemically amplified resists**

a) Since A = 1-P use dP/dt = -0.126$s^{-1}$P => e-folding time is $t_{1/e}$ = 1/(0.126) = 7.9 sec; dV/dt = -10V => $t_{1/e}$ = 1/(10) = 0.1 sec; dF/dt = 2F => $t_{1/e}$ = 1/(2) = 0.5 sec. The volatile products leave 80 times quicker than they form. The free volume decays 16 times quicker than it forms.

b) Dp = 0, v = 1; 5F/(1+F) = 1.2 => D = 1.3 x $10^{-4}$ μm$^{-2}$/s; $\sqrt{2Dt}$ = 11.4 nm. This diffusion rate for the acid is quite high compared to the line width growth with time of about 0.5 nm/s.

c) & d) In the constant diffusion constant (Fickean) case, diffusion always reduces the slope of the acid. The deprotection tends to amplify the acid profile once acid reaches 0.1. The type-II case shows an increase in the acid slope and a sharp front with little acid in advance.

An exact solution can be found for $t_{ver}$ for a film of thickness d as follows.
$dz/dt = Re^{-\gamma\alpha z}$
$dt = \{1/R(z)\}dz$

$$t = \int_0^d \left( \frac{e^{\gamma\alpha z}}{R_o} \right) dz = \left(e^{\gamma\alpha z} - 1\right) \Big/ \gamma\alpha Ro = \frac{\left(e^{d\alpha z} - 1\right)}{d\alpha R_o}$$

For $\gamma = 3$, $\alpha = 0.67$, $R_o = 237$ nm/s and d = 1 μm this gives

$t_{ver} = (e^{2.01} - 1)/\{(2.01\text{x } 10^{-3})(237) = 13.6$ s

A similar derivation can be made for $t_{across}$ if a spatial variation is assumed in the x direction that can be integrated.