CHE323/384 Chemical Processes for Micro- and Nanofabrication
Chris Mack, University of Texas at Austin

Homework #12 Solutions

1. An i-line resist has the following properties:

$A = 0.85$ µm^{-1}
$B = 0.05$ µm^{-1}
$C = 0.018$ cm^2/mJ
Refractive index = 1.72

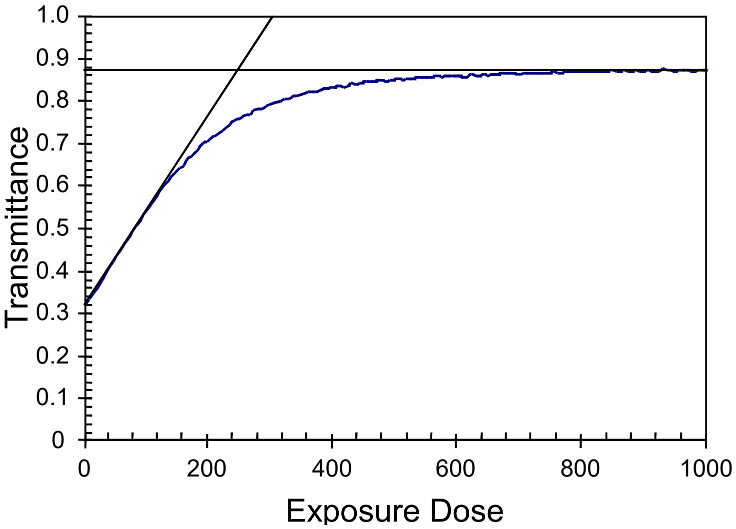
The resist is coated to a thickness of 1.1 µm on a glass substrate optically matched to the photoresist. At the beginning of exposure, what percentage of the incident light makes it to the bottom of the resist?

Note that $T_{12} = 1 - \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$

At the start of exposure, $\alpha = A + B = 0.90$ µm^{-1}. $\frac{I(D)}{I(0)} = e^{-\alpha D} = e^{-(0.90)(1.1)} = 0.3716$. But,

$$T_{12} = 1 - \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 = 1 - \left(\frac{1.72 - 1}{1.72 + 1}\right)^2 = 0.930, \text{ so that } \frac{I(D)}{I_{inc}} = (0.930)(0.3716) = 0.346$$

2. From the transmittance curve below, estimate the values of A, B and C. The resist thickness used was 0.75 µm and the measurement was performed in the standard way. Assume a typical i-line resist with refractive index = 1.69.



From the curve, $T(0) = 0.32$, $T(\infty) = 0.88$, $dT/dE = 0.0022$ cm^2/mJ, and $T_{12} = 1- [(1.69-1)/(1.69+1)]^2 = 0.934$. (Of course, all the graphical measurements have reasonably high uncertainty. If this were a real problem rather than a homework problem, you'd have to estimate the uncertainty.)

$$A = \frac{1}{D}\ln\left[\frac{T(\infty)}{T(0)}\right] = \frac{1}{0.75}\ln\left[\frac{0.88}{0.32}\right] = 1.35\ \mu\text{m}^{-1}$$

$$B = -\frac{1}{D}\ln\left[\frac{T(\infty)}{T_{12}}\right] = -\frac{1}{0.75}\ln\left[\frac{0.88}{0.934}\right] = 0.079\ \mu\text{m}^{-1}$$

$$C = \frac{A+B}{AT(0)\left[1-T(0)\right]T_{12}}\left.\frac{dT}{dE}\right|_{E=0} = \frac{1.35+0.08}{1.35(.32)\left[1-0.32\right](0.934)}(0.0022) = 0.011\ \text{cm}^2/\text{mJ}$$

3. For a chemically amplified resist (and ignoring the effects of diffusion and acid loss on concentration),

$$h = 1 - e^{-CIt}$$
$$m = e^{-K_{amp} t_{PEB} h}$$

From these equations,

(a) Derive an expression for the relative bake time sensitivity of m (i.e., calculate $dm/d\ln t_{PEB}$).

(b) Derive an expression for the relative temperature sensitivity of m (i.e., calculate $dm/d\ln T$). From this, will a low activation energy resist or a high activation energy resist be more sensitive to temperature variations?

(c) Does the presence of base quencher change the bake time or temperature sensitivity of m?

$m = e^{-K_{amp} t_{PEB} h}$

a) $\dfrac{dm}{dt_{PEB}} = \left(-K_{amp} h\right) e^{-K_{amp} t_{PEB} h}$, $t_{PEB}\dfrac{dm}{dt_{PEB}} = \dfrac{dm}{d\ln(t_{PEB})} = \left(-K_{amp} t_{PEB} h\right) e^{-K_{amp} t_{PEB} h}$

$\dfrac{dm}{d\ln(t_{PEB})} = m\ln(m)$

b) $\dfrac{dm}{dT} = \left(-t_{PEB} h\right) e^{-K_{amp} t_{PEB} h} \dfrac{dK_{amp}}{dT}$, $T\dfrac{dm}{dT} = \dfrac{dm}{d\ln(T)} = \left(-t_{PEB} h\right) e^{-K_{amp} t_{PEB} h} \dfrac{dK_{amp}}{d\ln(T)}$

$\dfrac{dm}{d\ln(T)} = \left(-K_{amp} t_{PEB} h\right) e^{-K_{amp} t_{PEB} h} \dfrac{d\ln(K_{amp})}{d\ln(T)} = m\ln(m)\dfrac{d\ln(K_{amp})}{d\ln(T)}$

From the Arrhenius equation, $\ln(K_{amp}) = \ln(A_r) - E_a / RT$, $\dfrac{d\ln(K_{amp})}{dT} = \dfrac{E_a}{RT^2}$, $\dfrac{d\ln(K_{amp})}{d\ln(T)} = \dfrac{E_a}{RT}$. Therefore, $\dfrac{dm}{d\ln(T)} = m\ln(m)\left(\dfrac{E_a}{RT}\right)$. A high activation energy resist will be more sensitive to relative temperature changes, for a given *m* and *T*.

c) With base quencher, $m = e^{-K_{amp} t_{PEB} (h-q_0)}$. Repeating all of the above calculations will give the same results. The time or temperature sensitivity does not change for a given value of *m*.

4. Why does the addition of base quencher reduce the sensitivity of the resist to airborne base contaminants?

The sensitivity to airborne base contaminants is reduced with the use of quencher for the same reason that the resist is less sensitive to acid diffusion: quencher results in a dramatic improvement in the latent image gradient near the resist feature edge (when processed at the dose to size). The error in edge position (*x*) at the top of the resist (that is, the size of the T-top) is given approximately by

$\Delta x = \dfrac{dx}{dh}\Delta h = \dfrac{acid\ loss\ due\ to\ airborne\ base}{dh / dx}$, where *h* = acid concentration. Base quencher does not change the amount of acid loss, it increases the value of *dh*/*dx*.