PHS8310E - Microfabrication

Devoir 1

Work presented to Marc-Antoine Bianki

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0.95/2

Problem 1 (2 points)

(a) Describe the photolithography technique and specify the main process control parameters.

(b) Describe two problems commonly encountered in photolithography that can affect performance.

Suggest solutions to the problems mentioned in (b).

Solution 1

Very short description of the technique.. -0.25

(a) The main steps are : spin-coat resist (+softbake) → exposition through a mask → develop → rinse/dry. The main process control parameters are :

0.45/1

- positive vs negative resist.
- thickness of resist from spin speed and viscosity.
- softbake and hardbake
- exposure dose
- exposure optics : space to the mask, wavelength
- development time
- DOF
- ~~and others~~

Good! But you're missing a bit of parameters. The goal was to cover the main control parameters in the technique as a whole (each step seen in class), such as bake times and temps, photoresist type and viscosity, spin coating rotation speed and spread time, exposure time and lamp intensity, types of mask contacts, development time... -0.3

(b) problems and solutions :

Please provide a bit more details when the question asks a description -0.5

0.5/1

- Problem : dust lands on the photomask or wafer. Solution : use a cleanroom for clean masks and clean the wafer before use.
- Problem : The feature size is wrong. Solution : a probable cause would be exposure time. For a positive resist for example, if the lines are too wide, a litle more exposure could solve the problem. We have equations to help us we could use too.

?

why?

Problem 2 (1 point)

A photoresist deposited at 3000 rpm reaches a thickness of 310 nm, and 390 nm at 1900 rpm.

(a) At what rotation speed should the same resist be deposited to obtain a 290 nm thick layer?

(b) Considering that the maximum rotation speed of 200mm wafer is 4000 rpm, from what thickness should a lower viscosity composition of this resist be used?

Solution 2 1

(a) The equation for the thickness can be simplified to two constants for one photoresist as :

$$d = K\frac{C^{\beta}\eta^{\gamma}}{\omega^{\alpha}} = \frac{K}{\omega^{\alpha}}$$

We then find α with the data we have :

$$310 = \frac{K}{3000^{\alpha}} \longleftrightarrow K = 310 \times 3000^{\alpha}$$

$$390 = \frac{K}{1900^{\alpha}} \longleftrightarrow K = 390 \times 1900^{\alpha}$$

$$310 \times 3000^{\alpha} = 390 \times 1900^{\alpha}$$

$$\longrightarrow \alpha = \log_{\frac{3000}{1900}}(\frac{390}{310}) \approx 0,5026$$

We find K with data again :

$$K = d \times \omega^{\alpha} = 310 \times 3000^{0,5026} \approx 17338,89$$

Finally :

$$\omega = \sqrt[\alpha]{\frac{K}{d}} = 3426,61\text{rpm}$$

(b)

$$d_{min} = \frac{K}{\omega_{max}^{\alpha}} = 268,3\text{nm}$$

Target thickness lower than this should use a lower viscosity formulation.

0.75/1

Problem 3 (1 point)

Discuss the advantages and disadvantages of using thicker photoresists than usual (>1μm).

Solution 3

Advantages :

1. We have more options for etching since we have more stopping power. (RIE)
2. It is a requirement to have thicker photoresist with tall features.
3. Also a ~~requirement~~ for lift-offs.

depends on the thickness of the film you want to pattern but ok

Disadvantages

1. For aligner optics, the resolution is worse as the thickness gets bigger as we can see with the approximation equation : $R = 1,5\sqrt{\lambda(s + \frac{t}{2})}$.
2. There is more chance that the photoresist cracks of lifts. ?

not clear what you mean but the resist won't necessarily lift more easily if it's thicker? -0.25
please explain your answers a bit more

0.75/1 ## Problem 4 (1 point)

You are the engineer in charge of building a new clean room and you wonder what HVAC system you should buy for temperature control. The process you will be using requires a tolerance of 3nm in the accuracy of the structures. To this day, you consider using either 200mm or 300mm diameter silicon wafers for your microfabrication process. Considering silicon has a linear expansion coefficient of $3x10^{-6}K^{-1}$, what should be the temperature stability of the HVAC system for each diameter of wafer?

Solution 4

Let the expansion coefficient be $\alpha = 3 \times 10^{-6} K^{-1}$, then :

$$\Delta L = \alpha L \Delta T \leq 3 \text{ nm}$$

For 200mm=0,2m wafer :

use the radius -0.25

$$\Delta T \leq \frac{3 \times 10^{-9}}{(3 \times 10^{-6})(0,\cancel{2}00)} = 0,005K$$

For 300mm=0,3m wafer :

$$\Delta T \leq \frac{3 \times 10^{-9}}{(3 \times 10^{-6})(0,\cancel{3}00)} = 0,00\bar{3}K$$

Problem 5 (1 point)

What will be the impact on the design of the masks of a process if we must change from a positive resist to a negative resist?

1/1

Solution 5

1. With a positive resist, the obtained image of the resist is the same as the mask. If we had to change to a negative resist, we would need to invert the mask meening that opaque "features" of the mask become transparent and vice-versa.
2. The resolution is usually better with positive resist.
3. If we have a lift-off to do, it will work better with negative resist.

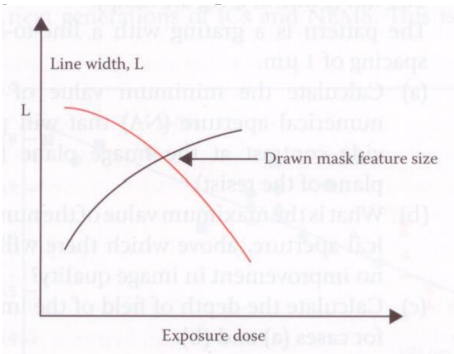
Problem 6 (1 point)

Indicate in the figure below which curve corresponds to solid lines and which curve corresponds to empty spaces in a) a negative resist and b) a positive resist.

0.5/1

Solution 6

(a) negative resist
With negative resist, the remaining resist gets bigger with exposure time. It is then represented by the black line.



you have to assign both curves (red/black) for both cases (opening/solid) for each resist -0.5

(b) positive resist
With positive resist, the remaining resist shrinks with exposure time. It is then represented by the red line.

Problem 7 (3 points)

An optical lithography system comprises an excimer laser (ArF) emitting at a wavelength of 193 nm, has a numerical aperture NA = 0.63 and $k_1 = 0.68$, and $k_2 = 0.45$.

1. What are the theoretical resolution and depth of field for this equipment?
2. What can be done in practice to adjust NA, k_1 and k_2 to improve the resolution?
3. Which parameter is changed by the phase shift mask technique to improve the resolution (NA, k_1 and k_2)?

Solution 7

2/3

1. • theoretical resolution

$$R = k_1 \frac{\lambda}{NA} = 0,68 \times \frac{193}{0.63} \approx 208 \text{ nm}$$

   • DOF

$$DOF = k_2 \frac{\lambda}{(NA)^2} = 0.45 \times \frac{193}{0.63^2} \approx 219 \text{ nm}$$

2. • NA : $NA = n \sin\theta$. We can increase the refractive index (We can even achieve n > 1 with immersion lithography). Or we can play with the aperture (θ).

   • k_1 : In the wavefront Engineering slide slide (of lithography ppt), it is told that to reduce k_1, it is possible to use Phase-Shifting Masks that "cause destructive interference effects" to maximize the resolution. Off-axis illumination is also mentioned to reduce k_1. Using both these tools together can greatly increase resolution.

   • k_2 While we could say PSM and OAI are mainly to increase resolution, they also help to improve DOF. This is great because with NA, improving resolution decreases DOF.

3. Again, as we said, it mainly improves k_1, ~~but also k_2.~~ It does not improve NA.

Problem 8 (3 points) 2.75

Effect of the variability of the parameters on the profile.

(a) Show that when the thickness of photoresist varies by ΔT_0, Δx is given by :

$$\Delta x = -\frac{\Delta T_0}{\gamma T_0}\left(\frac{1}{E_0}\frac{dE}{dx}\right)^{-1}$$

(b) Show that when the dose baries from ΔE, Δx is given by:

$$\Delta x = \frac{\Delta E}{E}\left(\frac{1}{E}\frac{dE}{dx}\right)^{-1}$$

(c) Discuss the influence of contrast on Δx

Solution 8 2.5

We already have some relations given in the slides around the edge :

$$T(E) = T_0\gamma \ln\left(\frac{E_0}{E}\right)$$

$$\frac{dT}{dx} = \frac{dT}{dE}\frac{dE}{dx} = -T_0\gamma\frac{1}{E(x)}\frac{dE(x)}{dx}$$

(a) At the edge, we have $T = 0$ at x_0 :

$$\longrightarrow T = 0 \approx \frac{dT}{dx}\Big|_{x_0}\Delta x + \Delta T_0$$

0.75

$$\longleftrightarrow \Delta x = -\frac{\Delta T_0}{-T_0\gamma(\frac{1}{E_0})\frac{dE}{dx}\big|_{x_0}} = -\frac{\Delta T_0}{\gamma T_0}\left(\frac{1}{E_0}\frac{dE}{dx}\right)^{-1} \quad \blacksquare$$

(b) Same, $T = 0$, but $E \longrightarrow E + \Delta E$

$$\frac{dT}{dx} = \frac{dT}{dE}\frac{dE}{dx} \longleftrightarrow \Delta x = \frac{\frac{dT}{dE}}{\frac{dT}{dx}}\Delta E = -\frac{-T_0\gamma\frac{1}{E}}{-T_0\gamma\frac{1}{E}\frac{dE}{dx}}\Delta E = \frac{\Delta E}{E}\left(\frac{1}{E}\frac{dE}{dx}\right)^{-1} \quad \blacksquare$$

0.75

(c)

$$\Delta x \propto \frac{\frac{1}{\gamma}}{\frac{1}{E}\frac{dE}{dx}}$$

We see that with higher contrast, we get smaller Δx which means that you get sharper edges.

1

Problem 9 (4 points)

In electron beam lithography, there is an optimum aperture angle to obtain a minimum beam size:

(a) Determine this angle considering only the influence of the source and spherical aberrations.

(b) What is the minimum size of the beam?

(c) How much should the focal plane be moved to obtain an increase of 0.1 um in the spot diameter? ($d_{min} = 0.2\mu m$ and $\alpha = 0.005$ rad)

Solution 9 2/4

2/2

(a) Only considering source and spherical aberrations :

$$d^2(\alpha) = d_{SO}^2(\alpha) + d_s^2(\alpha) = \frac{I}{3.08\alpha^2 B} + \frac{1}{4}C_s^2\alpha^6 \quad \checkmark$$

$$\frac{d}{d\alpha}\left(\frac{I}{3.08\alpha^2 B} + \frac{1}{4}C_s^2\alpha^6\right) = 0 \quad \checkmark$$

$$\longleftrightarrow -2\frac{I}{3.08B}\alpha^{-3} + \frac{6}{4}C_s^2\alpha^5 = 0$$

$$\longrightarrow \alpha = \sqrt[8]{\frac{4}{3\times 3.08}\frac{I}{BC_s^2}} \quad \checkmark$$

(b) From the ~~derivation~~ :

From d_t!! you have to insert alpha_min from a) in d_t

0/1

$$\frac{3}{2}C_s^2\alpha^8 = 2\frac{I}{3.08B} \longleftrightarrow 3\left(\frac{1}{4}C_s^2\alpha^6\right)\alpha^2 = \frac{I}{3.08B}$$

$$3d_s^2 = \frac{I}{3.08B}\alpha^{-2} = d_{SO}^2$$

$$\longrightarrow d_{min}^2 = d_{SO}^2 + d_s^2 \longleftrightarrow d_{min} = \sqrt{4d_s^2} = 2d_s$$

$$\longrightarrow d_{min} = C_s\alpha^3$$

0/1

(c) ???

Problem 10 (3 points)

For an X-ray mask, what should the thickness of the silicon membrane and absorbers (gold or tungsten) be if 80% through Si and a 5 times weaker transmission through the absorbers is required considering emission of the Al line (0.834 nm).

2.75/3

Solution 10

Were are going to use the table at page 168 in Chapter II Lithography.

First, let's find the energy of our 0.834 nm wave.

$$E = \frac{hc}{\lambda} \approx 1.5keV$$

-0.25

For silicon, we find $\frac{\mu}{\rho} = \overset{5}{\cancel{7}}33 \frac{cm^2}{g}$
For gold, we find $\frac{\mu}{\rho} = 2223 \frac{cm^2}{g}$
For tungsten, we find $\frac{\mu}{\rho} = 1825 \frac{cm^2}{g}$ (interpolation)

We find the attenuation coefficient :

For silicon, we find $\underline{\overset{5}{\cancel{7}}33} \times 2.33 = 1707.89 cm^{-1} = 0.1708 \mu m^{-1}$
For gold, we find $2223 \times 19.3 = 42903 cm^{-1} = 4.29 \mu m^{-1}$
For tungsten, we find $1825 \times 17.6 = 31120 cm^{-1} = 3.11 \mu m^{-1}$

We use the Beer-Lambert absorption law $T = e^{-\mu t}$ or $t = -\frac{\ln(t)}{\mu}$

For silicon, we find $t = -\frac{\ln(0.8)}{0.1708} \approx 1.31 \mu m$
For gold, we find $t = -\frac{\ln(0.16)}{4.29} \approx 0.42 \mu m$
For tungsten, we find $t = -\frac{\ln(0.16)}{3.11} \approx 0.59 \mu m$