3.155J/6.152J
Microelectronic Processing
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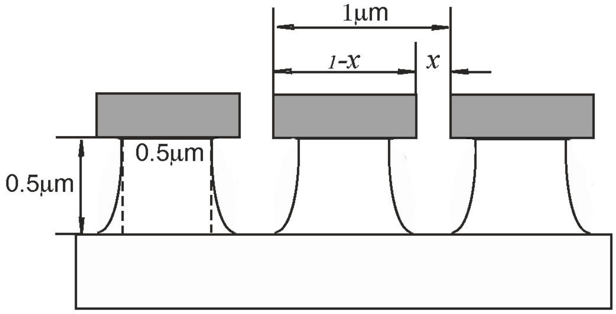
<u>Problem set 5 Solutions Out Oct. 29, 2003 Due Nov. 5, 2002</u>

1. (Plummer 10.3) In a certain process, it is desired that the pitch of metal lines be equal to or less than 1.0mm (the pitch equals one metal linewidth plus one spacing between metal lines, measured at top of features). Assume that the metal linewidth and spacing are equal (that is, 0.5μm each). The height of such structures is also 0.5μm, and the minimum lithographic dimension is 0.25μm.

a. What minimum degree of anisotropy is needed in an etch process in order to produce such a structure?

b. What minimum pitch could be obtained for such a structure with wet etching? (Again with minimum lithograph dimension of 0.25μm, thickness of 0.5μm and equal metal width and spacing.)



Answer (a).

Consider the anisotropic etching effect, to obtain 0.5μm equal linewidth and spacing, suppose the mask width is 1-*x*, the anisotropy of etching would be:

$$A_f = 1 - \frac{w_{mask} - w_{metal}}{2} / x_f$$

$$= 1 - \frac{1 - x - 0.5}{2 \times 0.5} = 0.5 + x$$

$$\min(A_f) = 0.5 + \min(x) = 0.5 + 0.25 = 0.75$$

(b). Metals are usually polycrystalline structure and thus are subjected to isotropical etch in wet etching. Therefore, we can determine the anisotropy of wet etching is $A_f = 0$. Similar to part (a), we will have this following equation between the pitch *p* and the mask spacing *x*:

$$0 = A_f = 1 - \frac{w_{mask} - w_{metal}}{2x_f} = 1 - \frac{(p - x) - \frac{p}{2}}{2 \times 0.5} = 1 - (\frac{p}{2} - x) \Rightarrow p = 2(1 + x)$$

$$\Rightarrow \min(p) = 2(1 + \min(x)) = 2 \times (1 + 0.25) = 2.5 \mu m$$

2. (Plummer 10.4) What are the advantages and disadvantages of reactive ion etching (RIE) versus sputter etching? Cite a hypothetical example of when you might want to use sputter etching rather than RIE?

Answer:

The reactive ion etching technology is a combination of physical and chemical etching. The substrate is sitting on a smaller electrode and the RF energy is applied to the substrate in a low pressure, generally 10 – 100 mtorr environment. At the substrate surface, materials can be removed by both ion bombardment and chemical reaction.

The physical part of RIE is similar to sputter etching, while the chemical part brings some unique properties to this technology. The major advantage of RIE is more etching selectivity. This can be accomplished by replacing the inert gas with other chemical species. By chemical means, RIE can also achieve higher etching rate with lower damage. Lastly, more parameters in RIE can be set independently for rapid process optimization.

Since the chemical etch reaction is isotropic, the combination can form sidewalls that have non-vertical shapes. Less directionality is possible compared to sputter etching. And the control becomes more complex because of more process parameters.

A hypothetical example to use sputter etching rather than RIE is such a material that is very difficult to etch by chemical means, sputter etch remains as the only alternative. Sputter etching is also most often used to preclean the wafer before deposition.

3. (Plummer 10.5) Explain how loading effects can affect endpoint detection.

Answer:

Loading effects can cause etch rate nonuniformity, which means different etch rates across a wafer, from wafer to wafer, and from batch to batch. The loading effects include macroscopic loading and microscopic loading. Wafer to wafer or batch to batch etch rates could differ if more wafers are loaded in a chamber or more surfaces are exposed to etchant species; Within-wafer etch rate difference occurs as a result of local difference in aspect ratios. The overall etch rate nonuniformity can affect endpoint detection. For example, the endpoint can be set as the concentration of certain target species in the chamber exceeds the threshold value. If etch rates decrease due to loading effects, it will take longer time for the etch system to reach endpoint.

4. (Plummer 10.6) It is found that a certain plasma etch chemistry in a certain RIE etch system produces vertical sidewalls with zero etch bias when etching a particular film. Adding chemical A to the etch chemistry results in nonvertical sidewalls, and an etch bias. Adding chemical B to the original etch chemistry results in nonvertical sidewalls, but with zero etch bias. Explain what may be going on.

Answer:

Chemical A may have a higher spontaneous chemical reaction rate with the film and etch the film isotropically.

Chemical B may cause photoresist erosion during the etching. Another possibility is that chemical B itself or the byproduct of its reaction with the film may be deposited on the sidewall as inhibitor that leads to non-vertical slope of sidewall with zero bias.

5. (Plummer 10.8) It is observed that the sidewall slope in an etch process becomes more sloped as the temperature is reduced. Why?

Answer:

This observation of more sloped sidewall at lower temperatures can be explained by the negative net temperature dependence of inhibitor deposition. In a plasma etching, the removal rate of substrate is limited by bond breaking and forming, which is sensitive to the incident ion's energy, while insensitive to temperature. However, the desorption rate of the deposited inhibitor layer is strongly temperature dependent. When the temperature is reduced, the desorption of inhibitor is slower, which will cause relatively faster deposition of inhibitor on the sidewall and eventually lead to more sloped etch profile.