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A Discussion on Resist Development Trend and the Ultimate Limitation

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In order to help the first step selection of an appropriate resist for the specific use, figures of merit for the resist is proposed. The figure of merit explains the past e-beam resist development trend sufficiently and shows it's usefulness.

Resist sensitivity limitations for various energy beams are calculated as a function of resolution.

An approach to strategy-making for resist and lithography development is discussed.

1. INTRODUCTION

In order to make any submicron lithography practical, appropriate selection and optimization of resists are key factors. Recently, standardization of the resist characteristic definitions, such as sensitivity and r-contrast, has been proposed by a resist chemist[1]. It would help in making resist comparison on an indivisual characteristic basis. However,there are various trade-offs between characteristics, and it is still not easy for a lithography engineer to select an appropriate resist for his specific use.

For a resist user, the creation of a figure of merit data would be practical for the first step selection, and for understanding development trends. Other interests would be the ultimate limitation of sensitivity and resolution, since both are very important requirements.

In this paper, a figure of merit for the resist is proposed and trially applied to e-beam resists. Sensitivity and resolution limitations are discussed on e-beam,ion,X-ray and optical resists.

2. FIGURE OF MERIT

Considering resolution/resist thickness trade-off[2] and sensitivity/dry-etching rate trade-off[3], the following figure of merit equation has been derived.

$G = T \cdot R \cdot S \cdot 1/E_R$

where T,R,S and E_R are resist thickness, resolution (reciprocal of minimum linewidth),sensitivity (reciprocal of minimum energy dose) and dry etching rate, respectively. Figure 1 shows the trend in e-beam resist development, evaluated using the figure of merit. An order improvement per decade is clearly found. It shows the usefulness of the figure of merit for general evaluation of resist development achievement.

For specific use consideration, slight modifications to the figure of merit are practical. G·S, G/E and G·R are modification examples for photo-mask making, direct writing research and submicron applications, since sensitivity, dry-etching durability and resolution are more emphasized, respectively. The historical reason for selecting resists is well understood according to this modification.

3. SENSITIVITY LIMITATION

Sensitivity limitation, as a function of resolution, has been proposed regarding electron source noise for a hypothetical e-beam resist[4], in order to guarantee a certain number of events per pixel. It was extended to X-ray and optical resists[6]. This would be more practical when modifying it by signal to noise ratio criteria, assuming that ±W/10 must be controlled and the fluctuation budget is divided evenly to the average linewidth deviation and line-edge variation. Line-edge variation is mostly caused by (1)statistical,(2)electronics,(3)magnetic and electric fields,(4)vibration and (5)temperature noises. Therfore,statistical noise must be less than W/50,considering the worst case of noises. Since signal to noise ratio are given as $\sqrt{n}$, where n is number of events,more than 2500 events must occur in the minimum pattern. What events have meaning here, are least phenomena from energy particle incident to chemical reaction. It differs from a lithography to another.

(a) Electron/Ion Resists

Since electron mean-free-path[5] and Grün range in PMMA is 0.05~0.1 μm and 8~12 μm,respectively for 20 to 30 KV, event uniformity in a pixel and more than one collision in the resist could be expected. Therefore, in order to maintain the statistical noise within ±W/100, 2500 electron injection in the pixel would correspond to sensitivity limitation.

For ion beam, however,achieving event uniformity in the resist is difficult, because of its small mean-free-path and small energy for ejected secondary electrons. Therefore, incident beam positions must be guaranteed in W/100 position basis.

Assuming 100 ions per W/100,the ultimate limitaion is also derived. It is expected that an ion beam resist requires a slightly higher dose than an e-beam resist to obtain smooth fine-lines. Figure 2 shows the relationship.

(b) X-ray Resists

X-ray lithography would be useful for mass-production where longer process optimiztion time for a given mask are allowed. In other words, it must have high throughput for the once set-up process. Therefore, ultimate sensitivity discussion is very important.

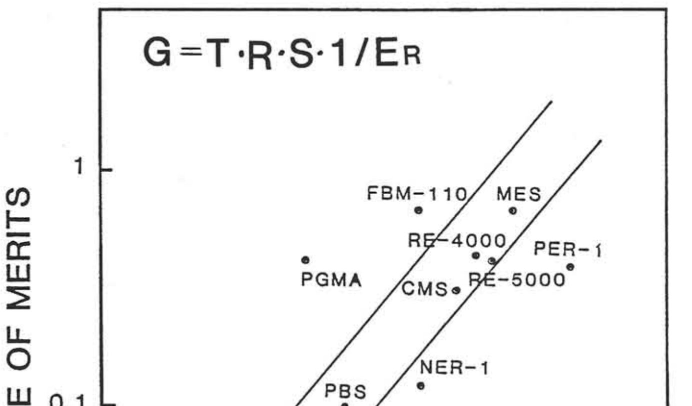

Fig.1
E-beam resist performance improvement trend

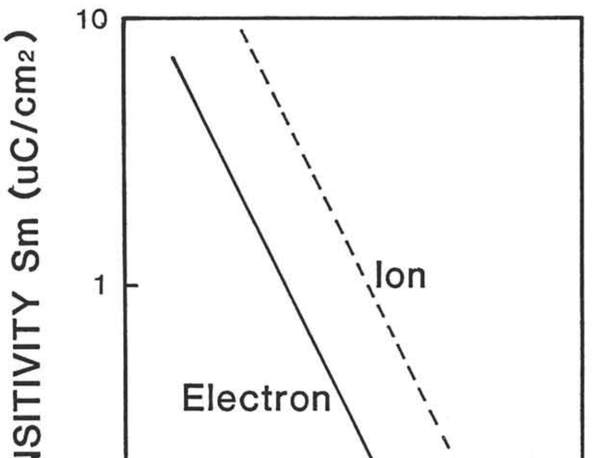

Fig.2
Electron/ion resist sensitivity limitation as a function of linewidth

Basic consideration is the same as in the electron case. Energy sensitivity expression is, however, more common for X-ray and the following equation is derived.

$$D = \frac{4.95 \times 10^{-2}}{\lambda} \cdot \frac{1}{W^2} \ (mJ/cm^2)$$

where λ is wave length and W is the minimum linewidth. This relationship is shown in Fig. 3 for various common X-ray wave lengths as dashed lines.

X-ray photons are very poorly absorbed in the resist, only few incident X-ray photons can contribute for chemical reactions. The bottle-neck process in X-ray lithography would be the absorbance. Therefore, the above equation must be corrected by this factor in practice. Assuuming 1 µm resist thickness and carbon-base polymer usage, expected ultimate limitations are indicated as solid lines in Fig.3.

(c) Photoresists

The same equation derived for X-ray could be used for photoresist. The relationships are shown in Fig.4. In this case, G value would be more important. G value is the number of reactions per 100 eV. The following shows numbers of photons per 100 eV for various wave lengths.

G-line: 35.2

I-line: 29.4

KrF : 20

A typical photoresist, Az, has an about 0.3 G value. Therefore, the relationship in Fig.4 would be shifted two-order of magnitude lower. It is close to the currently available highest sensitivity, i.e. 1 mJ/cm^2. However, photography using silver-halide expects 1 nJ/cm^2 sensitivity for extremely high G value. Therefore, it should be possible to develop 10 $\mu J/cm^2$ photoresist by 30 G value, without resolution deterioration.

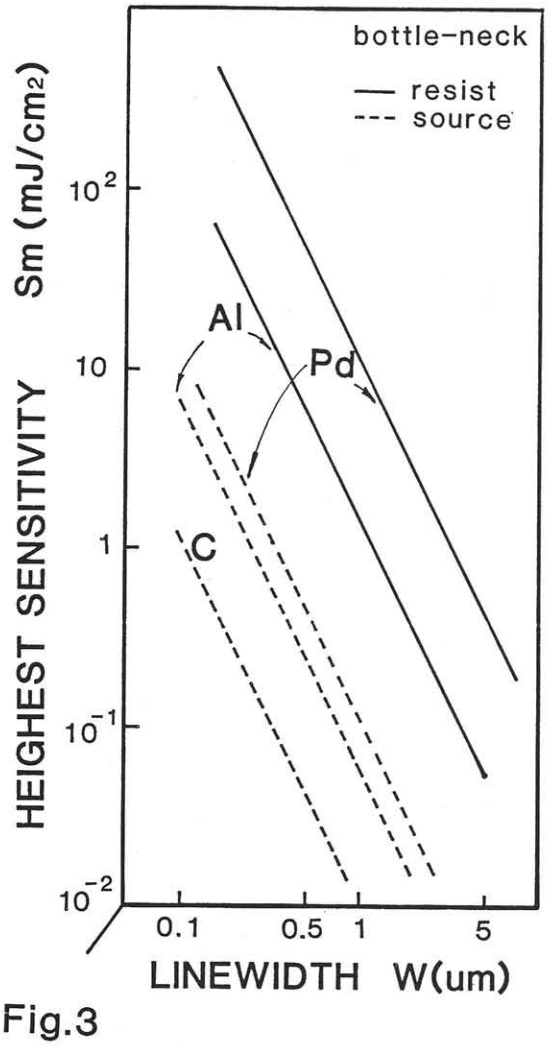

Fig.3
X-ray resist sensitivity limitation as a function of linewidth

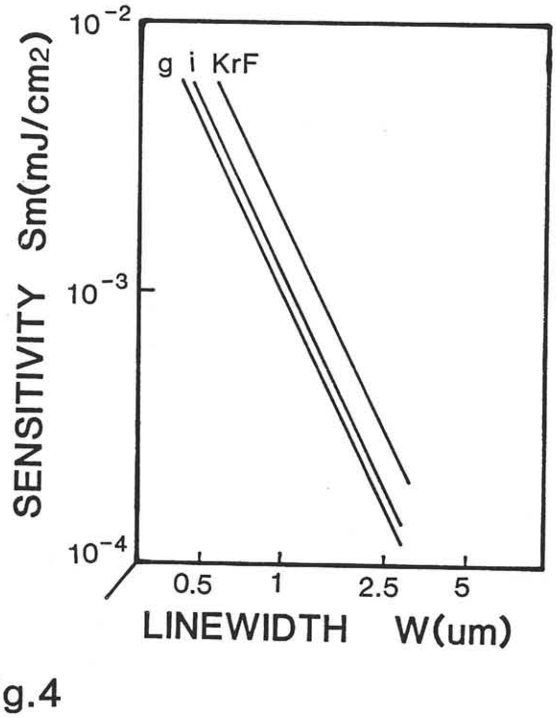

Fig.4
Photoresist sensitivity limitation as a function of linewidth

4. CONCLUSION

Using a figure of merit for resist, the past e-beam resist development trend has been clearly explaind. It's usefulness for future resist targeting is expected.

The ultimate resist sensitivity limitations have been discussed for electron,ion,X-ray and photo resists on the statistical noise basis. It should provide an approach to resist and lithography development strategy making.

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