Digest of Tech. Papers The 14th Conf. (1982 International) on Solid State Devices, Tokyo

A—5—6 Process Parameter Control in Optical Lithography

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Today, in projection lithography the loss in useful resolution stems primarily from the problem of process control. In this paper simulation is used to perform quantitative studies on the sensitivity of critical dimensions of positive resist profiles with respect to variations in resist thickness T, illumination dose and development time t_{dev}. A modified version of SAMPLE was used.

LINEWIDTH SENSITIVITY ON FLAT SUBSTRATES. Here critical dimension CD_{min} is defined as the minimum reproduced linewidth in resist for a mask pattern of either isolated lines or equal line and space. The total linewidth loss from the original mask dimension is labeled ΔCD. The objective of this study is to evaluate the sensitivity of CD_{min} to dose and t_{dev}. We explore the combination of these two variables which produces the minimum sensitivity of CD_{min}. The simulated positive resist is AZ1350J; both conventional development and development with a post-exposure bake (PEB) are investigated. The simulated optics uses a projection printing system with NA=0.28, a partial coherence factor of 0.7, and a defocus of 1.4μm (corresponding to ½ Rayleigh unit). The single wavelength used is 436nm. The geometrical parameters are: T=0.91μm spun on a 75nm oxide film on a Si substrate. With such thicknesses we obtain an intensity maximum at the resist-oxide and air-resist interfaces. The results are reported in Fig. 1 for a 1.5μm line. Here we plot the sensitivity S of normalized linewidth change to dose variations versus t_{dev}, for different values of ΔCD. Linewidth loss can be traded for decreased linewidth sensitivity. The usefulness of PEB is obvious from this plot. Not only is the sensitivity reduced to less than 0.5, but no linewidth loss is necessary. Fig. 1 also illustrates the general result that over a reasonable range, dose may be traded for t_{dev} with virtually no change in process sensitivity. Thus t_{dev} may be safely determined by other considerations, such as resist thickness loss and adhesion.

LINEWIDTH CONTROL OVER STEPS. Here simulation is used to quantitatively explore linewidth control in the vicinity of steps; the goal is to determine the minimum obtainable value of the linewidth discontinuity at the step as a function of dose and t_{dev}, for a given step thickness. The linewidth undergoes a major jump at the step and is modulated periodically on both sides of the step. In the simulation we have used a 1.1μm step in Si and a maximum resist thickness of 1.42μm (11 half waves). For this thickness we have determined a suitable dose to safely develop the resist within the chosen time; such procedure has been repeated for three different times, 90, 120, 150 sec. For each time and corresponding dose we have obtained the resist profiles for the critical resist thicknesses in proximity of the step. We have used a 1.5μm line-space mask and an Al substrate. The result are summarized in Fig. 2 with and without PEB; the most interesting parameter is d, the linewidth discontinuity at the step, while m_1 and m_2 are the modulation parameters. The high reflectivity of Al results in a deterioration of linewidth control under normal operating conditions, a fact that is well known experimentally. The standing waves are very pronounced and the intensity minima, combined with resist nonlinearities, result in very long develop times and/or large doses. Consequently considerable lateral development occurs. In this case the improvement due to PEB is quite dramatic, especially for CD_{min} and d. Without PEB the 1.5μm line is reduced to a 0.2μm at the neck, whereas PEB increases this value to about 0.8μm.

MODIFICATIONS IN RESIST TECHNOLOGY. A planarization technique can be used in order to virtually eliminate the steps in the substrate; this planarization is obtained by spinning a passive under-layer. The goal of this study is to estimate the potential improvements in linewidth control for such multi-level resist systems. The optics and resist parameters are equal to those reported in the previous examples. In the single level resist system we have used a quarter wave of oxide on Si, covered by 1um of resist. We have chosen the value of exposure at a dose D_0 such that large areas of resist clear in a 30 sec development time, ½ the actual nominal t_{dev} of 60 sec. We have then found the value of CD_{min} for nominal conditions with patterns of equal lines and spaces. We have then considered a +25% variation of the value of dose and found the values of CD_{min} for the same masks. Moreover we have simulated a thickness change added to dose variation and again we have found the values of CD_{min}. From these sets of values of CD_{min} we have obtained the percentage variations of linewidth control for the changes in dose and resist thickness. THe results for the single level case are reported in Fig. 3 as a function of the different masks linewidths. Fig. 3 also shows the results for a multi-level resist system; in this case we have a Si substrate which is covered by a planarization layer of 2um in which there is an absorbing medium. On top of this layer there is a 0.5um film of resist. The only variable in multi-level resist was an assumed ±5% dose variation. Finally we have considered a fixed mask pattern of 1.5um line-space and we have repeated the whole previous procedure for both single and multi-level systems; in this case we have changed the values of defocus to get different values of image contrast; the results are shown in Fig. 4.

ACKNOWLEDGEMENT. This work was supported by a NATO Grant,by CNR(Italy) and by NSF (USA).

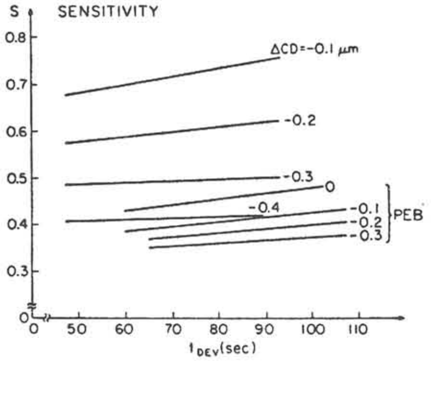

Fig. 1

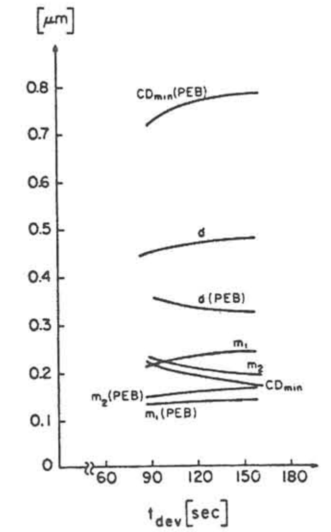

Fig. 2

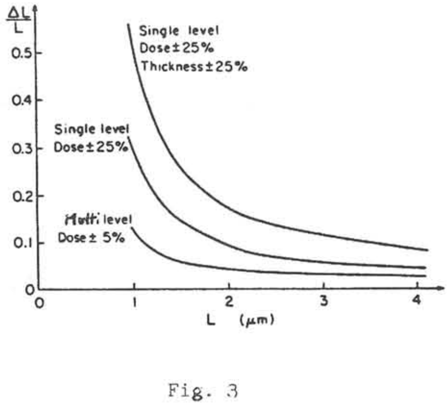

Fig. 3

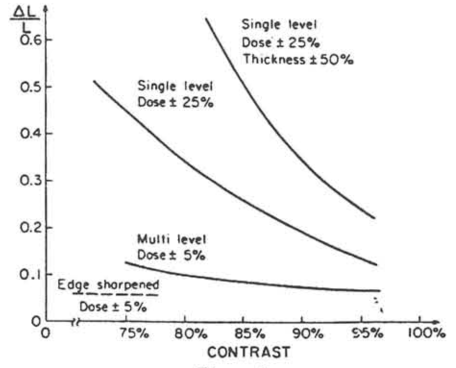

Fig. 4