Sub-millisecond Post-Exposure and Hard Bake of Chemically Amplified Photoresists

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Chemically amplified resists (CARs) continue to be developed to achieve sub-22 nm lithography in both 193i and EUV platforms, with key challenges in resolution, sensitivity and line width roughness (LWR). In this work, we explore the use of transient laser heating to address these challenges by shifting the time/temperature regime for the post-exposure bake (PEB) process from tens of seconds at 90-130^{o}C to sub-millisecond times at temperatures of 250-450^{o}C. For resists with high activation energy for deprotection compared to acid diffusion, a shift to high temperatures should enhance the sensitivity with no loss of resolution, and potentially improve LWR due to polymer flow.

Sub-millisecond laser PEB (*l*-PEB) is achieved using a scanned CW laser source focused to a narrow line and scanned across the wafer. The effective time at temperature is controlled by the beam width and the scan velocity to times ranging from 50 μs to 10 ms, with peak temperature set by the laser power. Preliminary imaging under EUV showed a nearly three times enhancement in resist sensitivity over hot-plate PEB (for comparable resolution) with an ~20% reduction in LWR.

To understand this behavior, kinetic rates of deprotection and acid diffusion were quantitatively determined as a function of hot-plate and *l*-PEB temperature and duration. Deprotection rate is increased by three orders of magnitude under laser heating with changes in activation enthalpies, while acid diffusivity is retarded by almost three orders of magnitude under laser heating with similar activation enthalpies (Figure 1). Results suggest a change in deprotection mechanism between two time/temperature regimes. Possible mechanisms and further investigation using various resist/PAG combinations will be discussed.

In an alternate approach to control LWR, we have examined the use of the scanned laser source to anneal fully developed resist patterns at peak temperatures of 200-400^{o}C – a sub-millisecond laser hard-bake. We hypothesize that patterned resists above their glass transition temperature will flow to minimize the surface energy resulting in reduced LWR. Figure 2 shows SEM images of 30 nm half-pitch lines before and after laser annealing at 22W (~325^{o}C) for 500 μs. Dramatic smoothing (reduced LWR) of the lines is immediately evident – a direct consequence of resist flow at temperatures above T_g. Characterization of LWR reduction to explain the behavior will be presented.

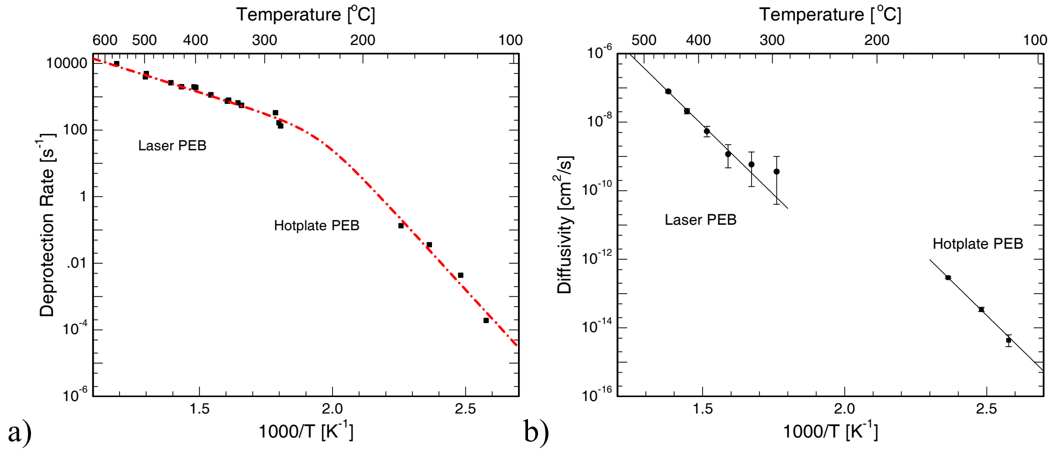

Figure 1: Comparison of deprotection rate and diffusivity between hot-plate and laser PEB: a) Arrhenius plot of deprotection rate for dose to clear, E_0 = 3 mJ/cm^2 and b) Arrhenius plot of estimated acid diffusivity obtained from bilayer studies. Although similar activation enthalpies are observed, the diffusivity ($\Delta x^2/4t$) is retarded by almost three orders of magnitude under *l*-PEB.

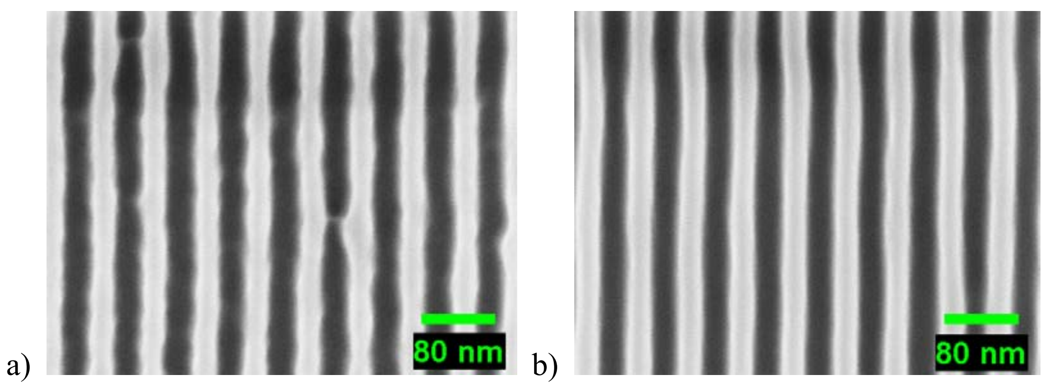

Figure 2: SEM images of 30 nm line/spacing: a) Under conventional EUVL and b) Under conventional EUV lithography followed by laser heating at 22W (~325°C) for 500 µs.