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Characterization of SAL605 Negative Resist at λ=13 nm

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Abstract

We have characterized the response of the negative resist SAL605 in the extreme ultraviolet (λ=13nm). The sensitivity was found to be ~1mJ/cm^2 for all conditions studied. We have identified processing conditions leading to high (γ>4) contrast. The resist response was modeled using Prolith/2 and the development parameters were obtained from the exposure curves.

Keywords: Microlithography, Polymers, Nonlinear optical materials, Photochemistry

Introduction

The purpose of this work is to optimize the processing conditions of SAL605 photoresist for Extreme Ultraviolet (EUV) lithography. Since this resist is very sensitive, it is particularly well suited for an experimental EUV lithography system having a modest illumination intensity.

This work is also aimed at understanding the processing effects on the image quality in SAL605. This is achieved by modeling the exposure/development process using Prolith/2.

Experiment

The chemically amplified Shipley resist, SAL 605 was spun-coated onto 3" diameter, 0.015" thick, n-type silicon wafers with a (111) orientation. Prior to the resist coating, the wafers were put through the standard semiconductor cleaning steps and then primed with Hexamethyldisilazane (HMDS) for resist adhesion.

To achieve the proper resist thickness, the resist was thinned with Propylene Glycol Monomethyl Ether Acetate (PGMEA). The following conditions were used to obtain the resist thicknesses used for this experiment.

60-70nm resist thickness: 10ml SAL605, 30ml PGMEA, 500rpm spread for 5 seconds and then 3500rpm spin for 25 seconds.

110-130nm resist thickness: 10ml SAL605, 20ml PGMEA, 500rpm spread for 5 seconds and 3500rpm spin for 25 seconds

In both cases, the resist was dispensed onto the wafer through a 0.5μm filter and then was softbaked on a vacuum hotplate at 105 °C for one minute after coating. Following the softbake, the 3-inch wafers were cleaved into 6 separate 2cm by 2.6cm samples for use in the exposure tool.

The exposures were made at the Lawrence Livermore National Laboratory, using the AMP EUV lithography station. The EUV source consists of a laser-produced tungsten plasma emitting ~1.5mJ of EUV light per laser pulse in a 3% bandwidth at λ=13 nm. A condenser system collects a solid angle of 0.12 steradians and uniformly illuminates a 0.104cm^2 half-moon area where the resist coated silicon wafers are positioned for exposure. This condenser system is composed of three mirrors that are coated with molybdenum-silicon multilayers for high reflectivity at λ=13nm. The measured dose per laser pulse on the sample is 4μJ/cm^2.

A range of exposures was obtained using different EUV doses varying from 0.1 to about 8mJ/cm^2. This was accomplished by exposing the sample at its initial position with a few EUV pulses, corresponding to the lowest dose, moving the sample laterally by approximately 300μm, exposing it to more EUV pulses and repeating these steps until the highest dose required had been accumulated in the central portion of the exposed area

Following the EUV exposure, the samples were baked on a vacuum hotplate, at 105°C for 50 seconds. The post-exposure bake conditions were held constant. They were set according to the results of a previous study using deep ultraviolet (DUV) light at λ=200nm [1] and to the findings of Fedynyshyn *et al.* [2] obtained with an electron beam exposure.

The samples were developed by immersion with mild agitation, in Shipley developer MF-312 CD-27. This developer is Tetramethyl Ammonium Hydroxide (TMAH) with a Normality of 0.27N. Some experiments were also performed with a developer Normality of 0.22N and 0.18N. The development time was varied between 15 seconds and 8 minutes. After development, the samples were rinsed in deionized water for 30 seconds and blown dry with clean nitrogen.

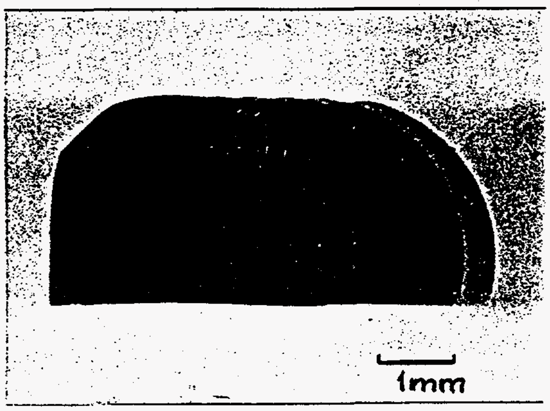

Figure 1. Sample after exposure and development. One can observe the bands of various shades, corresponding to different resist thickness.

Figure 1 shows one of the samples. One can observe different resist step heights, appearing in different shades, that correspond to different doses.

The resist thickness in the exposed areas was measured using a Nanospec/AFT 4000 reflectometer, with a spot size of about 25μm. Independent measurements of the resist thickness were also made with a Tencor P-10 stylus profilometer and yielded similar results.

The actual dose accumulated on the resist was obtained by measuring the EUV signal per laser pulse at the wafer location with a calibrated silicon photodiode coated with a 1 μm Be film. The total dose was obtained by multiplying that number times the number of pulses used to expose a particular area on the resist. Since the laser energy varied by ±8% (1σ) from pulse to pulse, an error is introduced in the total accumulated dose. An additional source of error comes from the fact that the thin Si membranes used to protect the condenser optics from the laser plasma debris are coated during an exposure. The transmission drops exponentially as a function of the number of laser pulses. This effect is taken into account in the calculation of the dose, but we estimate that the error associated with this process amounts to ±10% of the calculated dose. The total uncertainty on the dose is therefore ~ ±13%.

Results and discussion

Figure 2 illustrates a typical resist exposure curve, where the normalized thickness remaining after exposure and development as a function of the logarithm of the dose is plotted. In this case the initial resist thickness was 65nm and it was developed for 15s.

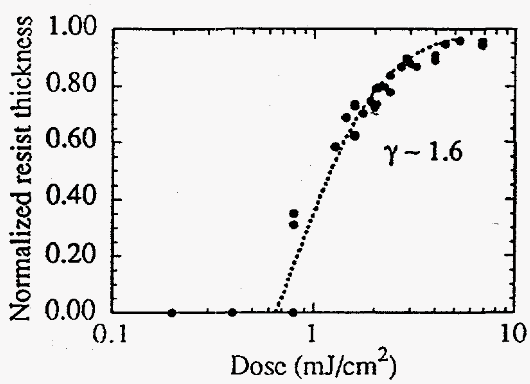

Figure 2. Typical exposure curve for SAL605. Plotted here are the results for an initial film thickness of 65nm developed in TMAH, N=0.27 for 15s (solid circles). Also plotted is the corresponding best fit to this curve, as calculated with Prolith/2.

Let us define two parameters that are extracted from these curves. The sensitivity (D_o) is defined as the dose at the elbow of the exposure curve, where the slope changes from a fast growing function to a saturation plateau. The contrast, γ, is the slope of the steep part of the exposure curve. For the different processing conditions that were studied, the resist sensitivity was around 1mJ/cm^2. A slightly higher sensitivity (lower D_o) is obtained with thicker films and lower developer normality, as indicated in table 1.

	65nm	110nm
N=0.22	1.3±0.3	1.0±0.3
N=0.27	1.6±0.4	1.1±0.3

Table 1. Sensitivity of SAL605 in mJ/cm^2 for different developer normality and different resist thickness.

These data also indicate that the resist contrast (γ) increases with the duration of the development (see figure 3). In addition, an increase in the normality of the developer tends to yield higher γ values even for short development times. This behaviour is consistent with the results obtained by Gat *et al.* [3] with x-rays (λ=1nm) and with those of Fedynyshyn *et al.* [2] using an electron beam.

Comparison of lithography prints of 0.35µm features for different conditions indicates that a developer normality of 0.27 yields better results than a normality of 0.22. Also, the longer development time (t_{dev}), corresponding to higher contrasts result in steeper sidewall angles for these 0.35µm lines and spaces. Sidewalls of ~ 37° were obtained for t_{dev}=15s and N=0.27, whereas a longer development time, t_{dev}=90s with the same normality improved this value to ~ 53°. Increasing the development time to 120s resulted in sidewall angles of ~70°. These conditions correspond to increasing contrast values from γ=1.6 to γ=4.

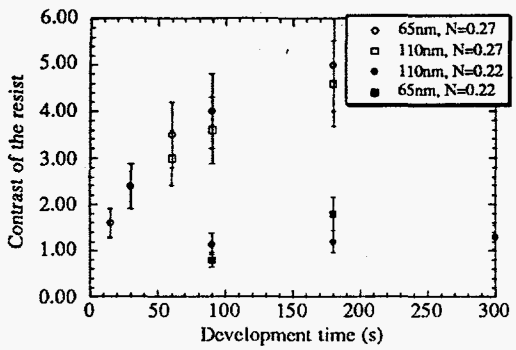

Figure 3. Dependence of the contrast of SAL605 with development time and developer normality.

Finally, we were able to simulate the exposure curves obtained for different processing conditions, using Prolith/2 [4], in order to infer the development rate parameters for SAL605 used with TMAH, N=0.27. Several parameters are used by this lithography simulator. The Dill resist parameters [5] were: A=0µm^{-1}, B=4.4µm^{-1} and C~1cm^2/mJ, and the development rate parameters used in the Mack model [6] were : R_{max}=11nm/s, R_{min}=0nm/s, mth=-1 and n=3.0. Only two of these parameters were varied to fit the data, n and C, which are related repectively to the contrast and the sensitivity of the resist. All the other parameters were either known or were measured experimentally. The agreement of the simulation with the experimental results is good, as can be seen in Fig.1.

The knowledge of these resist/development parameters is essential to be able to model correctly the printing of fine features in SAL605.

Conclusions

We have completed a characterization of SAL605 at λ=13nm. The sensitivity was found to be ~1mJ/cm^2 and was insensitive to the processing conditions studied. The contrast varied from γ~1, for short development times and low developer normality, to γ~5 for longer development times, thin resist and higher normality. We have identified the best processing conditions for EUV lithography, namely a developer normality of 0.27 and development times longer than ~100s for 110nm thick films and longer than 30s for 65nm films. These conditions allow for steeper sidewalls.

Acknowledgments

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