Large-scale lithography for sub-500nm features

R. L. Pelzer, T. Steininger
Technology group, EV Group, DI Erich Thallner Str. 1, A-4780 Schaerding, Austria
p.kettner@evgroup.com http://www.evgroup.com

Benoit Belier, Gwenaelle Julie
CNRS, Institut d'Electronique Fondamentale, Universite Paris-Sud Bat 220, F- 91405 Orsay Cedex, France
benoit.belier@ief.u-psud.fr & gwenaelle.julie@ief.u-psud.fr

Abstract. The interest in micro- and nanotechnologies has grown rapidly in the last years. The applications are versatile and different techniques found its way into several research domains as optics, electronics, magnetism, fluidics, etc. In all of these fields integration of more and more functions on steadily decreasing device dimensions lead to an increase in structural density and feature size. Expensive and slow processes utilizing projection steppers or e-beam direct writer equipment are used to fabricate nm features today. A high throughput and cost effective method adapted on a standard mask aligner will be demonstrated, making features of below 300nm available on wafer-level. We will demonstrate results of 4 different resists exposed on a DUV proximity aligner and plasma etched for optical and biological applications in the sub-300nm range.

Keywords: DUV lithography, proximity mask aligner, MOEMS, gratings

1. Experiments

The deep-UV (DUV 200-290nm) exposure step in this lithographic structuring process utilizes an advanced proximity mask aligner. The equipment establishes a 500W deep-UV light source for a 150mm exposure area and a wavelength range between 220-260nm. A lot of effort was placed into the design and manufacturing of a specialized wafer chuck in terms of chuck flatness (<1µm) and vacuum groove design (with a minimum of deflection of the Si wafer), in order to secure a best possible wafer flatness. Features above 800nm are produced in hard contact (HC) exposure mode, where the wafer is pressed against the mask without correcting the unevenness of the mask. The process of replicating sub-800nm gratings requires a vacuum contact (VC) exposure mode. This method evacuates the space between the mask and the wafer and impinges the wafer softly from the bottom side with CDA or nitrogen of several hundred mbar. The wafer is sucked against the mask, eliminating distance variations due to mask unevenness.

The advantages of a proximity mask aligner for producing sub-1µm features are a faithful reproduction of the mask patterns, structuring occurs on large area and the COO are much less compared to a stepper. Several DUV photoresists are also structurable with e-beam, which opens a wide field of
applications by mix-and-match techniques – structuring “bigger” features by UV lithography on a mask aligner and the smaller features by e-beam. Researchers have reported that resolution of sub-50nm relaxed pitch lines were obtained with UVIII (UV-3) at an electron beam dose of 60µC/cm² at 100kV². The following polymers were used for the exposure: AR-P679, AR-P639 and UVIII.

1.1. AR-P679.02 & AR-P639.04 PMMA from Allresist GmbH

Table 1. Processing parameters for 120nm AR-P639.04 and a 100mm thick AR-P679.02 on 100mmSi/SiO2

| Process step | Parameter |
|--------------|-----------|
| Pre-treatment | Primer none |
| Coating | Spin-up Manual static dispense |
| | Spin-off 2000rpm ; 5000rpm/s ; 45sec |
| | Soft bake 150°C ; 180sec ; on hot plate |
| Exposure | Machine setup EVG620DUV ; 220-260nm ; 14,3mW/cm² @ 240nm ; non-U = 0,95% |
| | Exposure parameter 3440mJ/cm² ; VC 700mbar |
| Rehydration | Parameter Immediately ; RT = 20,5°C ; H = 31% |
| Developer | Material Stopper: AR600-60 ; IPA ; Dev.: AR600-56 |
| | Developer parameter Dev.time = 5min ; Stopper time = 30sec |

The e-beam/DUV resists AR-P639-679 from Allresist GmbH3 are positive working resists. These resists are filtered to a particle size of 0,2µm. The PMMA-polymer layers show an excellent adhesion on glass, silicon and metals. In both resists the PMMA is solved in ethyl lactate. The two types differ in their polymer weight.

AR-P639 has a PMMA chain length of 50k and the AR-P679 has a length of 950k monomers. The polymer 50K has a ~20% higher sensitivity as the polymer 950K. The developed patterns have a thermal stability up to 120 °C.

The polymers are available in different solids contents between 1-10%, indicated by the extension. Thus “.02” denotes 2% solids content and specifies, due to different viscosity, the final resist thickness after spin-off. The spin curves are imaged in figure 1. Additionally to the 100nm thick layer (see

Fig. 1. Layer thickness of AR-P639 and AR-P679 at different spin speeds
process values in Table 1), a 60nm AR-P679.02 layer was coated at 6000rpm. Exposure results are shown below.

1.2. UVIII (UV-3) from Rohm&Haas (former Shipley Europe Ltd.)

UVIII is a chemically amplified positive resists (CAR) for e-beam, DUV and X-ray applications. These kind of resists are focused more often recently, due to their high resolution, high sensitivity, high contrast, and good etch resistance. In positive-tone CA resists an acid is generated in the exposed regions of the resist by radiation-sensitive photoacid generators (PAGs) (widely used in KrF and ArF lithography).

Table 2. Processing parameters for 400-500nm UVIII on 100mmSi/SiO2

| Process step | Parameter |
|--------------|-----------|
| Pre-treatment| Primer    |
| Coating      | Spin-up   |
|              | Spin-off  |
|              | Soft bake |
| Exposure     | Machine setup |
|              | Exposure parameter |
|              | PEB       |
| Rehydration  | Parameter |
| Developer    | Material  |
|              | Developer parameter |

Table 2 summarizes the process parameters for the UV-3 resist from Rohm&Haas.

1.3. Equipment Configuration

We used an EVG620 proximity mask aligner, which was reconfigured to allow deep-UV exposures. The used Hg/Xe short arc lamp has a quite high intensity emission in the range of 200-290nm. In this wavelength range UV mercury lamps (used for mid- and near-UV exposures from 290-350nm and 350-450nm, respectively) emit scarcely anything. The intensities of the 500W DUV lamp measured with narrow band UV radiometer were: 5mW/cm² @ 220nm, 40mW/cm² @ 248nm, 15mW/cm² @ 260nm and 0.5mW/cm² @ 350-450nm. The achieved non-uniformity across a 150mm wafer chuck area is <1%.

Fig. 2. Spectral distribution of a deep-UV Hg short arc lamp in the range from 200-270nm [Advanced Radiation Corporation, USA]
Figure 2 shows the spectral distribution of the used 500W DUV lamp. The UV radiation is produced by a Hg/Xe plasma. The wavelength region between 350-450nm is not shown. As some of the resists are also sensitive in this UV range, the lamp house has to guarantee a complete cut-off above 260nm. The VIS and IR radiation is also reduced significantly in order to have no warming of the substrate/mask during the long exposure times.

2. Results

Figure 3 a. shows the impact of the proximity (distance between mask and resist) on the intensity profile of the aerial image. These simulated Fresnel diffraction (function of distance and slit width) images can be found in real resist images too. The second effect (see Figure 3 b.) is also significantly influencing the results.

![Aerial image as a function of the proximity & Standing waves](image)

Due to reflection on the two interfaces resist /Si and Si/Si-oxide standing waves appear which will be discussed later. It’s also described\(^5\) how destructive light reflection can prevent remove of a thin layer of positive resist close to the Si wafer.

2.1. Feature reproducibility on large area

Figure 4 a. shows 1cm² 500nm lines/spaces area structured by DUV-Lithography in the e-beam resist AR-P679. Figure 4 b. presents a SEM image of 500nm large lines/spaces on 4000Å thick SiO\(_2\) layer deposited on Si(100) 100mm wafer after RIE and removing of the resist mask. A depression on top of the feature was observed in this grid. This groove has to be investigated in more detail in the future.

![SEM image of 3µm L/S with vertical sidewalls in PMMA 950K resist](image)

Due to reflection on the two interfaces resist /Si and Si/Si-oxide standing waves appear which will be discussed later. It’s also described\(^5\) how destructive light reflection can prevent remove of a thin layer of positive resist close to the Si wafer.

2.1. Feature reproducibility on large area

Figure 4 a. shows 1cm² 500nm lines/spaces area structured by DUV-Lithography in the e-beam resist AR-P679. Figure 4 b. presents a SEM image of 500nm large lines/spaces on 4000Å thick SiO\(_2\) layer deposited on Si(100) 100mm wafer after RIE and removing of the resist mask. A depression on top of the feature was observed in this grid. This groove has to be investigated in more detail in the future.

![SEM image of 3µm L/S with vertical sidewalls in PMMA 950K resist](image)

3. SEM image of 3µm L/S with vertical sidewalls in 3.2µm thick PMMA 950K resist structured by UV mask alignment process @ 220nm; a.) VC & b.) HC exposure mode [Courtesy of IMT/FZK; produced on an EVG620]
Figure 5 a. and b. illustrate the difference between VC and HC. The same resolution and sidewall angles were achieved, but a diffraction effect was detected at the corners of the lines.

2.2. SiO₂ as Antireflective coating

The defined thickness of SiO₂ layer was used as an anti-reflective layer to control interference in the photoresist during exposure. The resist pattern was transferred into silicon dioxide using plasma reactive ion etching with CF₄/CHF₃. Figure 6 a. and b. show sub-300nm UV-3 resist structures with a profile control correlated to the SiO₂ layer underneath.

Fig. 6. SEM images of high aspect ratios of sub-300nm cavities etched in a.) 400nm and b.) 600nm thick SiO₂

It’s interesting, that the effect of the standing waves can be seen on the 400nm SiO₂ (Figure 6 a). Changing the oxide layer thickness to 600nm influences positively the results, as this effect can be reduced completely (Figure 6 b).

2.3. High Aspect Ratios in Si

Aspect ratios of 1:10 utilizing RIE of the UV-3 mask are imaged in the figures 7 a. & b.

Fig. 7. a.) & b.) SEM images high aspect ratio sub-300nm cavities etched in SiO₂

References

[1] Chestech Ltd. (distributor of Rohm & Haas Electronic Materials) http://www.chestech.co.uk
[2] Z. Cui and P. Prewett, Microelectron. Eng. 46, 255 (1999)
[3] Allresist GmbH, Germany, http://www.allresist.de/
[4] D. R. Medeiros, et al., Recent progress in electron-beam resists for advanced mask-making, Volume 45, Number 5, Advanced Semiconductor Lithography (2001)
[5] Hovinen, A. Malinin and A. Lipsanen, Lithography in Experimental Environment, (Reports in Electron Physics, 2000/01)