Contact and proximity lithography using 193nm Excimer Laser in Mask Aligner

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Abstract

In this paper we describe the use of an Excimer laser for full-field lithography in a Mask Aligner. The DUV light from the Excimer laser is homogenized by using micro lens based optical integrators instead of a macro lens-array. A simulation of the intensity distribution for 5 µm squares was performed to visualize the diffraction effects and to show the potential of 193 nm illumination. It is demonstrated that compared to the conventional homogenization optics the MO Exposure Optics further improves the illumination uniformity, calculated as 1.8% for MO Exposure Optics and 2.9% for the A-Optics. Moreover the improved optical setup allows a modification of the angular spectrum by using exchangeable illumination filter plates (IFP). Compared to the A-Optics the main improvement effect of MO Exposure Optics is detectable in the patterning of layouts containing critical dimension from 8 µm down to 2 µm.

Keywords:Excimer laser; Mask Aligner; Proximity Lithography; Micro Optics; Vias; TSV

1. Introduction

Since the very beginning in the early 60s, Mask Aligners have been the workhorse of Semiconductor Industry. As the Semiconductor industry as a whole, Mask Aligners have changed much over the years: Evolution from manual lithographic tools for the exposure of 2’’ silicon wafers to the fully automatic 300mm lithography clusters with more than 100 wafers throughput per hour today. However, innovation and constant improvement have always opened new prospering niche markets for Mask Aligners, like e.g. the full-wafer exposure of small holes or vias as required for 3D Interconnects and Through Silica Via (TSV) technology.

Mask Aligners are usually equipped with high power mercury-vapor lamps providing light with peaks of the emission line spectrum at 254 nm, 365 nm (i-line), 405 nm (h-line) and 436 nm (g-line). We now report on the use of an ArF-Excimer laser at 193 nm wavelength for full-field lithography within a SUSS MicroTec MA6 Mask Aligner. Excimer lasers are widely used for lithography in wafer-steppers and scanners. Here a highly complex optical illumination and imaging system is used to achieve uniform mask (reticle) illumination, to minimize aberrations by pupil shaping and to suppress undesired interference effects and Speckles [1]. For contact and proximity lithography, where the mask structures are transmitted by shadow printing, the use of laser light sources was not beneficial in the past. Mask Aligner illumination systems did not allow a precise control of the angular spectrum of the illumination light. Diffraction at the mask, interference effects and Speckles limited the critical dimensions (CD) and registration. The new MO Exposure Optics now allows a modification of the angular spectrum by using exchangeable illumination filter plates (IFP) and additionally improves the illumination uniformity.

2. Principle of MO Exposure Optics

MO Exposure Optics is based on two subsequent Koehler integrators. A Koehler integrator, also referred as fly’s-eye condenser [2], micro lens homogenizer or optical integrator, consists of two micro lens arrays located at a focal length distance of each other and a subsequent large lens which is often referred as Fourier lens. The first micro lens array splits the incident light beam into beamlets. These beamlets are redirected by the second micro lens array and superimposed in the focal plane of the Fourier lens. A uniform illumination is achieved in the superposition plane, referred as Fourier plane. In the MO Exposure Optics illumination system for Mask Aligners the second Koehler integrator is placed in the Fourier plane of the first integrator. This combination is shown schematically in Figure 1 (top) and provides both, a uniform light intensity and a uniform angular spectrum of the illumination light.

MO Exposure Optics significantly improves the uniformity of the exposure light (typically ±2%), decouples the light for lamp position errors, improves telecentricity and allows customized illumination by placing an illumination filter plate (IFP), e.g. a metal plate with a set of holes, in front of the second Koehler integrator. Each position (x,y) on the IFP plate corresponds to a planar light wave with different angles (α_x, α_y) illuminating the photomask. Thus the planar wave spectrum of the mask illumination is defined by the structure of the IFP, e.g. a annular or ring (for annular illumination), a quadrupole or Maltese-cross as shown schematically in Figure 1 (bottom).

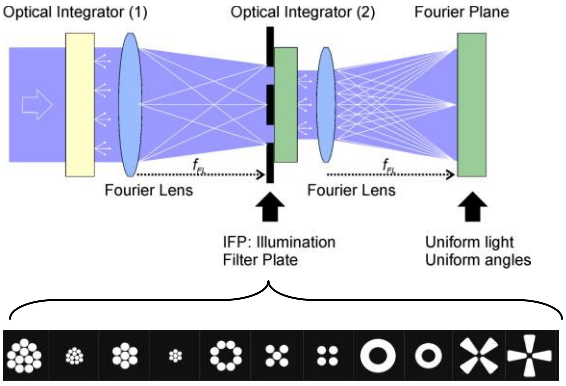


Figure 1. New illumination system (top) for SUSS Mask Aligner using two consequent optical integrators and an exchangeable illumination filter plate (IFP). Different examples of IFPs for multipole, quadrupole, annular and Maltese-cross illumination are shown below.

The micro lens arrays for the Koehler integrators are manufactured in Fused Silica by the use of wafer-based processes like photolithography and reactive-ion-etching [3]. The challenge of these processes is the optimization of the lens profile, which is essential for the quality of the homogenization. For high power and applications in the DUV or UV wavelength range, the micro-optical components are manufactured in Fused Silica [3]. Usually square-lens or crossed cylindrical-lens arrays are used to ensure a high filling factor.

3. Experimental

3.1. Experimental Setup

The MO Exposure Optics was implemented in a standard SUSS MicroTec Mask Aligner MA6 and tested using an ArF-Excimer laser. As a light source a Lambda Physics LPF 220 excimer laser working at 193 nm was used. The laser generates an actual beam size of 24 mm x 7.5 mm at the laser outlet. The laser beam was propagating through nitrogen purged tubing to the rear inlet of the Mask Aligner to minimize intensity losses. For comparative studies the Mask Aligner was equipped with a conventional DUV A-Optics of SUSS and the new MO Exposure Optics based on micro lens arrays, respectively. The A-Optics illumination system for SUSS Mask Aligner MA6 provides an angular spectrum similar to IFP shown at the very left in Figure 1 (bottom). For the conventional illumination system the Köhler integrator was built by two lens plates, each consisting of macro lenses of some 13mm diameter.

To illuminate an entire 6” wafer the laser beam has to be expanded in the lamp house of the Mask Aligner. For DUV exposure at 193 nm the positive-tone (GAR8105G1; 193nm Dense Line Resist) [4] chemically amplified resist (CAR) was applied on bare silicon substrates. For high resolution experiments, the photoresist should be well protected from airborne molecular contamination during exposure and post exposure processes [5]. The CAR was spin coated to a final thickness of 260 nm and soft baked for 90 seconds on a hotplate at 115 °C. Depending on the optical setup the exposure time was optimized, whereas pulse repetition rate and pulse energy of the excimer laser were maintained constant. The exposure time for the MO Exposure Optics without illumination filter plate was 91 seconds at a pulse repetition rate of 50 Hz and pulse energy of 150 mJ at the laser exit. After exposure a post exposure bake (PEB) followed on a hotplate at 115°C for 90 seconds. The development process, performed in tetramethyl ammonium hydroxide (TMAH) for a total time of 60 seconds at a temperature of 21°C, led to optimum results. The obtained resist patterns were evaluated using optical and scanning electron microscopy (SEM).

4. Results

4.1. Simulation:

A theoretical analysis of the exposure distribution using LayoutLAB– Software (GenISys) is shown in figure 2a. The simulated 5 µm resist squares, exposed with a proximity distance of 10µm, show a shape resembling a star (or like a Maltese-cross), whereas the dark blue area indicates low and the green and yellow areas high intensities. The solid black lines around the squares indicate the original contours of the mask layout. The simulation is in a good agreement with the results shown in figure 2b. By changing the corner of the simulated squares to a more rounded corner, as it will appear in the real fabrication process, the simulation converges even more to the real resist pattern.

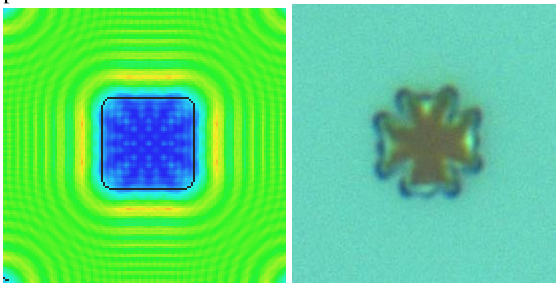


Figure 2: (a) Simulation of the intensity distribution for 5 µm square using 193 nm monochromatic light and 10 µm proximity gap. (b) Optical micrograph of 5 µm resist square after development.

4.2. Experimental results:

To specify the experimental conditions the intensity distribution by using the MO Exposure Optics as well as the A-Optics was measured. For this purpose a suitable photo diode (GaP Photodiode; spectral sensitivity: 150-550 nm) was used. Seventeen measurement points up to a diameter of 100 mm were taken to evaluate the illumination uniformity at the wafer surface. Figure 3a shows the measured intensity distribution of the conventional A-Optics with a calculated 2.9% uniformity and the maximum intensity in the upper right region. The MO Exposure Optics (Figure 3b) shows a nearly circular symmetrical illumination over the measured surface with a 1.8% uniformity. The resulting measurements indicate a significant uniformity enhancement for the new optical setup.

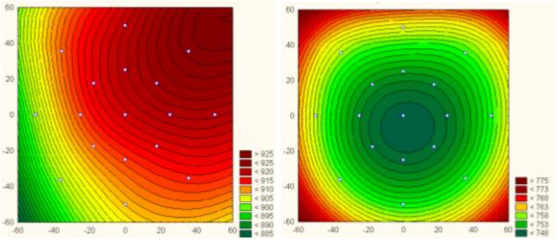
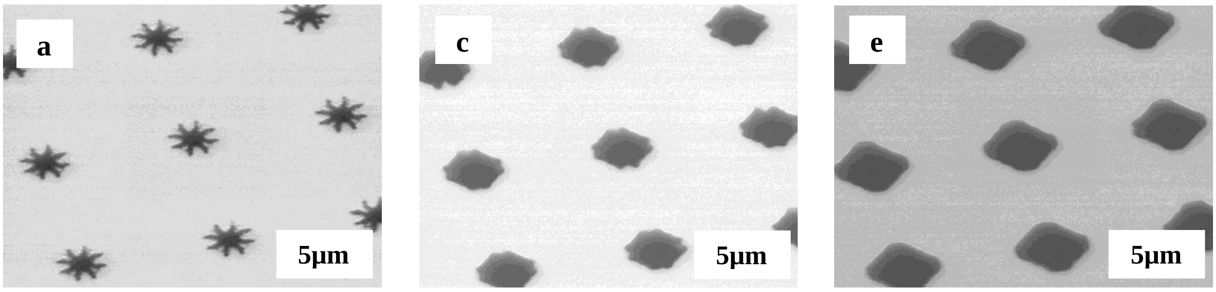


Figure 3: (a) Intensity distribution of A-Optics with a uniformity of 2.9%. (b) Intensity distribution of MO- Exposure Optics with a uniformity of 1.8%

4.3. Overview of the exposure results:

To investigate the performance of the MO Exposure Optics, mask layouts with squares in the range of 2µm up to 8µm were chosen. Thereby the conventional DUV Optics (A-Optics) acts as an illumination reference which is shown in figure 4a, respectively 4b. The SEM pictures are showing the 5 µm and 8µm squares with a proximity gap of 10µm. At a square size of 8 µm interference effects can be identified just at the corners of the structure (Figure 4b), whereas the interference effects are dominating at a square size of 5 µm (Figure 4a). These effects are not evident for the 8 µm patterns when applying MO Exposure Optics without filter (Figure 4 c,d). At lower feature sizes the interference effects are marginal distinguishable at 5 µm and are forming crosses at 3 µm structures which are not resolvable with the conventional optics (see figure 4a). By inserting a filter plate, in this case a Maltese opening (This opening looks similar to figure 2b), the interference effects are barley visible at the 5 µm and 3 µm structures (Figure 4e, 5c). Astonishingly, the 2 µm features are visible at a proximity gap of 10µm (Figure 5a). Compared to the A-Optics the main improvement effect of MO Exposure Optics is detectable in the patterning of layouts containing critical dimension from 8 µm down to 2 µm.



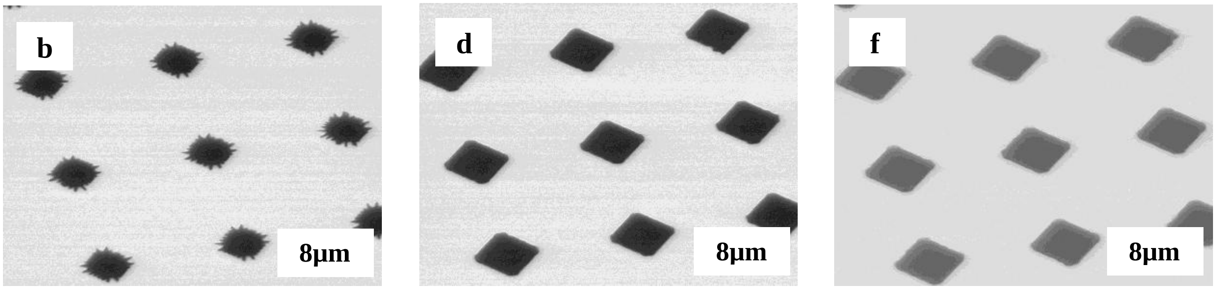


Figure 4: Scanning electron micrographs of resist patterns for the A- Optics (a,b) at a proximity distance of 10 µm. (a) shows the 5 µm square structure with strong interference effects. At 8 µm size (b) the effects are visible at the corners of the structures. Compared to the MO Exposure Optics, without using a IFP (c,d) the interference effects are insignificant. With the use of a Maltese filter plate (e,f) the effects are not visible anymore.

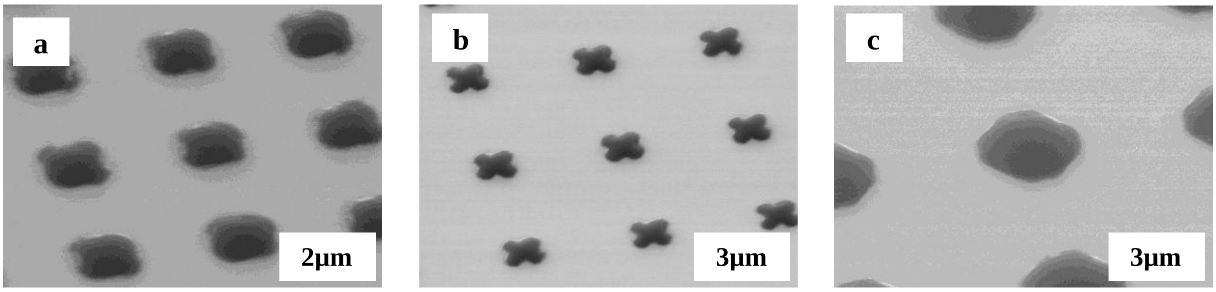


Figure 5: SEM pictures of the 2 µm and 3 µm structure at a proximity distance of 10 µm. Without a filter plate the 3 µm can be fabricated, but showing strong interference effects (b). At the corners of the structure the influence is very strong and therefore forms a cross like structure. With mounting a Maltese-cross IFP the 3 µm structures don't show this effect anymore (c). Even the 2 µm (a) squares are visible.

5. Conclusion

We have shown that the MO Exposure Optics improves uniformity of intensity distribution and enlarge the resolution for the proximity printing. The MO Exposure Optics further improved the illumination uniformity, which was calculated as 1.8%. The exposure results show a significant improvement of reducing interference effects. An additional enhancement can be achieved by inserting a Maltese IFP. With this setup 2 µm structures at 10 µm proximity distance has been realized. In this paper we showed the results for a Maltese-cross illumination filter plate, but also other aperture forms, like ring openings, rotated Malterse-cross, pinholes, etc. are possible.

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