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Microlens Lithography: A new approach for large display fabrication

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Microlens lithography is a new lithographic method, that uses microlens arrays to image a lithographic mask onto a substrate layer. Microlens lithography provides photolithography at a moderate resolution for an almost unlimited area. The imaging system consists of stacked microlens arrays forming an array of micro-objectives. Each micro-objective images a small part of the mask pattern, the images overlap in the image plane. Potential applications for microlens lithography are the fabrication of large area flat panel displays (FPD), color filters, and micromechanics.

1. INTRODUCTION

The future requirement for the production of flat panel displays (FPD) and color filters is a fast and cheap fabrication method for very large areas (>20''x 20'') which provides a resolution in the order of 2-5 µm and a high dimensional accuracy.

In principle all standard lithographic methods are suitable for large area lithography, but they have severe limitations and drawbacks:

- Wafer Steppers provide a very high resolution, but stitching errors and the very small printing area are severe drawbacks.
- Contact Copying requires careful alignment and high flatness of the substrate; the mask or the substrate is easily damaged by the direct contact.
- Proximity Printing provides a moderate resolution, but the depth of focus is rather small; very flat substrates are required.

Microlens lithography[1,2] is a non-contact method (>500 µm distance mask to substrate) and permits photolithography for an almost unlimited area (>20''x 20'') at a moderate resolution (typically 2 to 5 µm) without distortion or stitching errors. The large depth of focus (typically 50 µm) provides reduced requirements to the flatness and the alignment precision of the substrate. The almost negligible influence of chromatic aberrations for microlenses allows multiple wavelength exposure.

2. IMAGING SYSTEMS FOR PHOTOLITHOGRAPHY

Imaging systems for photolithography are characterized by the diffraction limited resolution W and the depth of focus Z, which are in general ruled by the two equations

$$W = K_1 \times {}^{\lambda}\!/_{NA} \quad (1)$$

$$Z = K_2 \times {}^{\lambda}\!/_{NA^2} \quad (2)$$

where λ is the wavelength and NA is the numerical aperture. K_1 and K_2 are scaling factors that are determined by the lithography process.[3] The factor K_1 has been reduced from about 1.0 to below 0.7 now, mainly by resist and processing improvements. Using multiple wavelength illumination, K_2 is in the order of 0.5. The factor K_2 is 1.0 for classical imaging systems.

Aberrations of the optical system may significantly reduce the image quality. For a given numerical aperture the influence of the aberrations scales with the lens diameter. The smaller a lens, the less severe is the influence of the aberrations on the image quality.[4] The basic idea behind microlens lithography is to distribute the imaging task to an array of microlenses or micro-objectives. Each micro-objective images only a small part of the mask pattern, the images overlap in the image plane.

3. MICROLENS ARRAYS

Optical imaging systems using microlens arrays are well established since many years.[5,6,7] In the past, the fabrication methods for lens arrays were complicated and the optical performance of microlenses was often poor. Nowadays, high quality microlens arrays are available, e.g. ion exchange lenses, photo-thermal lenses, melting photoresist lenses and diffractive lenses.

The most promising fabrication method for very large microlens arrays is the melting resist technology.[8,9,10] Photoresist cylinders are formed by lithography and melted at a temperature of $T \approx 150°C$. Surface tension forms an almost perfect sphere.

Melting resist microlenses are well suited for high resolution imaging tasks. An almost diffraction limited optical performance is observed. Figure 1 shows the image of a test pattern imaged with a melted resist lens ($Ø=250\mu m$, $NA=0.36$). A resolution of 1.2 µm (≈ 400 lines per mm) is observed in a microscope with white light illumination.

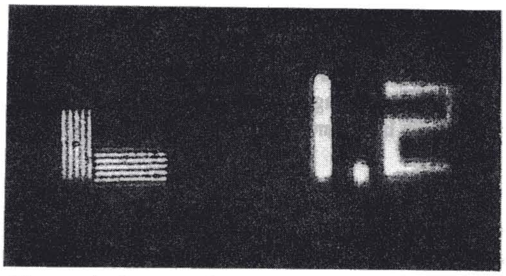
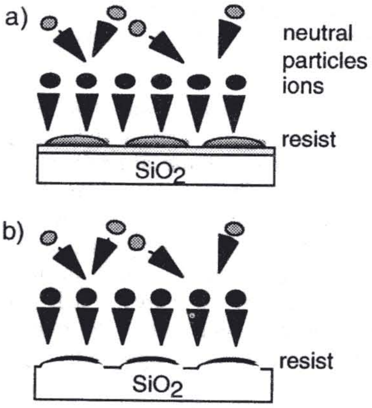


Figure 1. Image of a test pattern imaged with a single microlens (1.2 µm resolution).

To obtain high transmission in the UV, the shape of the melted resist lens is transferred into fused silica by reactive ion etching (RIE) as shown in Fig. 2 (a)-(c). Melting resist lenses are fabricated on top of a fused silica substrate. Atoms from the resist surface and the silica are simultaneously removed by energetic ions until the lens shape is completely etched into the silica.



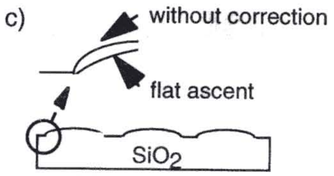


Fig. 2. (a)-(c) Scheme of the etching process. A correction of the lens at the rim is obtained by increasing the O_2 content during the etching process.

The reacting gas in a RIE machine is normally a mixture of CHF_3 and O_2 gases. Depending on the O_2 content of the reacting gases, the etch rates of photoresist and silica may differ up to factor 3. The higher the O_2 content, the higher is the etch rate of the resist. Spherical aberrations can be corrected during the etching by changing the oxygen content of the reacting gas to vary the slope in the rim region of the microlenses.[11,12] Figure 3 shows the modulation transfer function (MTF) of a resist microlens ($Ø=190\mu m$, $NA=0.13$) transferred in fused silica by RIE.

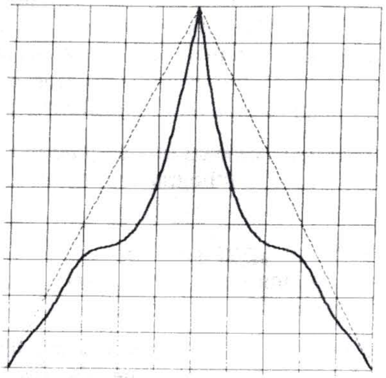


Figure 3. Modulation transfer function (MTF) of a microlens in fused silica.

Standard semiconductor equipment is only required for the fabrication of large microlens arrays. Microlens lithography is therefore available for all manufacturable display sizes.

4. MICROLENS IMAGING SYSTEMS

Figure 4 shows the basic principle of a microlens imaging system. A stack of microlens arrays form an array of micro-objectives. Two lens arrays (L1 and L2) are used for imaging, a third array (FL) acts as a field lens. Each micro-objective independently transports a part of the mask pattern. The images from different channels overlap. The overlapping areas coincide in the final image to provide a single, complete image of the mask.

The field lens images the exit pupils of L1 onto the entrance pupils of L2 to improve the radiometric efficiency of the system. A demagnification of the intermediate image avoids crosstalk between adjacent imaging channels.

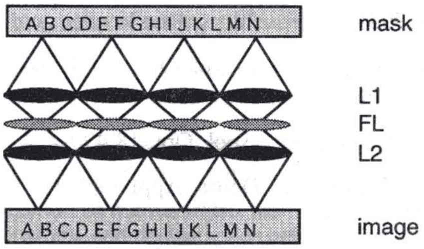


Figure 4. Imaging system with field lens (FL).

The imaging system described in Fig. 4 transports the light simultaneously through separate, independent micro-objectives. To ensure a proper channel separation, all rays passing lens L1 have to pass the field lens FL1 of the same objective and reach the entrance pupil of lens L2. To fulfill this condition, only a limited angular spectrum of rays is allowed.

The angular spectrum of the rays behind the mask plane depends on the illumination and on the type of the mask objects. The incoming light is diffracted at the edges of the objects as shown in Fig. 5. The number of contributing micro-objectives involved in the imaging of one object point may change for different objects.

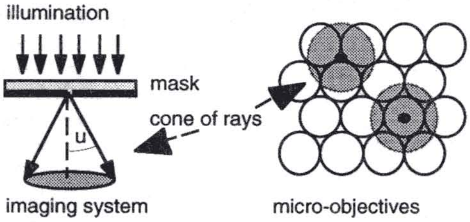


Figure 5 (Left): Rays behind a binary mask. (Right) Distribution of the rays at the entrance pupils of different adjacent micro-objectives.

A large number of contributing micro-objectives guarantees minimum intensity variation in the image plane, even if some channels should not work properly because of defects or pollution.

5. DEMONSTRATION SYSTEM

A microlens lithography demonstration was built. Two microlens arrays (hexagonal closely packed, Ø=190 µm, NA=0.15) were used for imaging. The intermediate image was demagnified to ß=0.6. A third microlens array (Ø=190 µm, NA=0.23) served as a field lens. The image plane was observed in a microscope with white light illumination. Figure 6 shows experimental results.

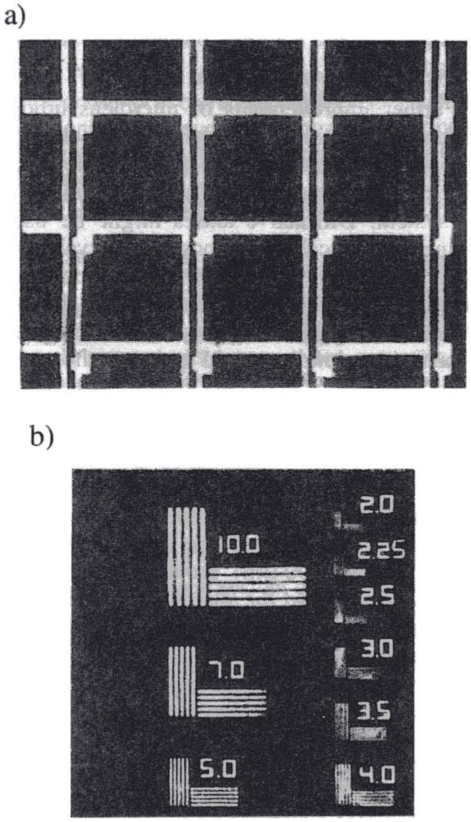


Figure 6. Image plane of a microlens imaging system. (a) Image of a mask used for FPDs. (b) Image of a standard resolution target. 5 µm resolution was observed for white light illumination.

Figure 6 shows (a) the image plane of a standard mask used for the fabrication of FPDs and (b) the image plane of a standard resolution target. Both were imaged using the set-up described above. The resolution in the order of 5 µm (≈ 100 lines per mm) was found for white light illumination.

6. OUTLOOK

The described optical systems are classical imaging systems, using refractive plano-convex microlenses. Their optical performance is mainly limited by the spherical aberrations and Petzval curvature. A reduction of the aberrations could be achieved by reducing the diameter and focal length of the microlenses. However, the smaller the lenses, the more severe are alignment and stability problems of the imaging system.

Further improvements of microlens lithography systems are expected by integrating non-classical micro-optical elements, such as diffractive lenses, phase shift elements or off-axis illumination in the imaging system. Diffractive lenses might be useful to minimize spherical aberrations and Petzval curvature, but they are mainly limited to monochromatic applications. Phase shifting elements could be used to increase the depth of focus beyond the classical limit. Off-axis illumination could improve the resolution (Abbe's law).

7. SUMMARY

Micro-imaging systems permit photolithography for an almost unlimited area at moderate resolutions (typically 2 to 5 µm). The large depth of focus (typically 50 to 100 µm) provides low requirements to the waviness and the alignment precision of the substrate. The almost negligible influence of chromatic aberrations for microlenses allows multiple wavelength exposure. Potential applications for microlens lithography are the fabrication of large area flat panel displays and color filters, and micromechanics.

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