Microsystem Technologies 10 (2004) 560–563 © Springer-Verlag 2004
DOI 10.1007/s00542-004-0403-6

Evaluation of optical qualities of a LIGA-spectrometer in SU-8

T. Mappes, S. Achenbach, A. Last, J. Mohr, R. Truckenmüller

Abstract In the past few years, SU-8 negative resist has been used in addition to PMMA positive resist for MEMS applications using deep X-ray lithography [1]. The advantage of SU-8 compared to PMMA is a higher sensitivity and a higher chemical stability. However, it is not yet as well analyzed in terms of microstructure quality. In this work SU-8 was examined with regards to its suitability to be used for high-resolution MOEMS. This is done exemplarily for a LIGA microspectrometer as this device can be thoroughly analyzed evaluating the side wall quality and the optical gratings as single structures, as well as the whole optical system [2]. In order to eliminate the high damping of visible light inside solid SU-8 material, a hollow wave guide design has been chosen. SU-8 was detected to reproduce structures in the nanometer-regime, combined with an averaged peak-to-valley profile better than PMMA. Although the measured roughness of SU-8 is worse than that of PMMA, there is still a comparable damping of the signal in MOEMS for both resists.

1 Introduction

At the Institut für Mikrostrukturtechnik (IMT), microspectrometers made of polymethylmethacrylate (PMMA) are routinely fabricated using deep X-ray lithography. Micro-components made of SU-8 are much faster and cheaper to process because typical x-ray exposure doses are two orders of magnitude less compared to PMMA. While SU-8 has so far been used for micro mechanical applications, it would be favorable if it could be used for micro-optical applications also.

It has not been proven so far, however, that SU-8 resist microstructures have sufficient structure accuracy to be reasonably used for optics. Thus, this study compares microspectrometers components made of SU-8 and PMMA.

While PMMA is a positive resist, SU-8, as a negative resist, requires an inverted mask in order to achieve the same structure. Thus separate x-ray masks have to be used and a direct comparison of two grating structures in the different resist-systems is not possible. The results presented here, therefore refer to spectrometers made of different resist systems with 360 μm thickness each, using the same mask layout and manufacturing technologies but inverted masks.

Received: 8 August 2003 / Accepted: 6 November 2003

T. Mappes (✉), S. Achenbach, A. Last,
J. Mohr, R. Truckenmüller
Forschungszentrum Karlsruhe, Institut für Mikrostrukturtechnik,
P.O. Box 3640, D-76021 Karlsruhe, Germany
e-mail: timo.mappes@imt.fzk.de
Phone: ++49-7247-82-4426
Fax: ++49-7247-82-4331

2 Sample preparation and exposure

2.1 Sample preparation

For sample-preparation a slightly modified process as suggested by MicroChem® [3] was chosen [4] to generate a resist-thickness of 360 μm minimum: 15 g “SU-8 100” were applied on a Si-Wafer and spincoated at 800 rpm for 40 s on Hamatech equipment. The pre-bake at 95 °C on a hotplate was performed for 7 ÷ 11 h to receive a remaining solvent concentration of one to maximum 4%, respectively [4].

2.2 Exposure details

In order to generate the working mask for X-ray-lithography, an intermediate mask was written via e-beam-lithography. This pattern was then transferred with X-ray exposure to a working mask.

For PMMA and SU-8 both working masks consist of 25 μm high gold-absorbers on a mask-membrane of 2.3 μm titanium.

The samples were irradiated at the beamline “Litho 2” of the electron storage ring ANKA in Karlsruhe. This beamline is equipped with a nickel-coated mirror with an incident angle of 8.65 mrad and a length of 800 mm [5] resulting in a cut-off energy of 8 keV. The roughness of this mirror was assumed to be 1 nm.

The microspectrometer is consisting of an entrance-slit, a blazed reflecting grating and a mirror, tilted to 40° in order to launch the spectrometer-signal to a detector.

The exposure is done in two steps. In a first step the entrance slit, fiber guide channel and blazed reflection grating is exposed by keeping the mask and resist perpendicular to the X-ray beam.

A second exposure for generating the mirror was done using the tilting stage of the Jenoptik DEX 02-Scanner. Both exposures for one spectrometer were using one mask and thus an aperture of brass, 1 mm thick, had to be used in order to cover those areas during the exposures, which had to be protected.

Between the two exposures the apertures had to be changed, thus, the scanner had to be evacuated a second time.

During exposure the substrate was situated in an atmosphere of 100 mbar helium.

Exposure of the samples was done at 2.5 GeV electron energy with doses of 30 J/cm^3 to 60 J/cm^3 and 40 J/cm^3 to 80 J/cm^3 for bottom to top ratio. Basis for these doses was a maximum of 1 J/cm^3 below the gold-absorbers in order to avoid any cross-linking of the resist in this area, a minimum of 30 J/cm^3 in the exposed area in order to have enough adhesion as well as no cracks in the resist. As upper limit 60 to 80 J/cm^3 was chosen to achieve a minimum of sidewall-roughness.

The first samples processed had a thin, unwanted SU-8 film ("T-topping") on top of the regular structures that also span across groves protected by gold absorbers. This effect was attributed to isotropic doses deposit tirade to fluorescence radiation from the titanium mask membrane [6].

A filter-system between the membrane of the mask and the resist-layer was therefore added to absorb the fluorescence radiation. It consisted of a sandwich of a 55.5 μm to 74 μm thick aluminum foil between two layers of 125 μm Kapton [4]. The polyamide could be used in this setup as a filter for fluorescence radiation from the aluminum on one side and on the other side it protected the thin mask-membrane of the possible wrinkling of the aluminum foil.

2.3 Development

For post exposure bake the substrate was placed on the hotplate at 95 °C for 30 min.

The development took place in several steps: The sample was put upside-down in PGMEA with a magnetic stirrer at 150 rpm for 20 min. In a second step the sample was treated under the same circumstances in fresh PGMEA in order to have the fine details of the structure developed. For rinsing the sample was put into isopropanol and was finally rinsed a second time in deionized water.

3 Structure quality

3.1 Photographic images

Using photographic techniques [Fig. 1] and laser diffracting illumination [Fig. 2] [2] the so called "periodic corrugations" found on the straight side walls due to stepping-errors of the mask-writing process could be visualized and analyzed.

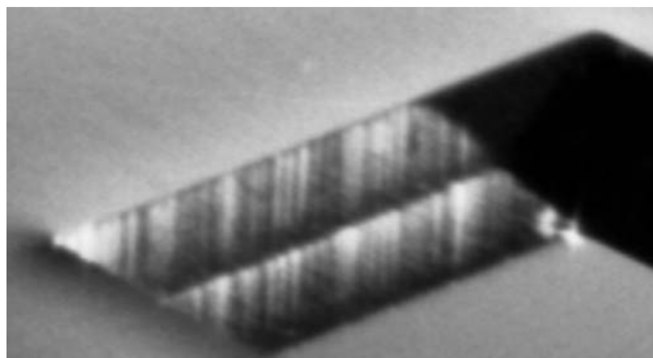

Fig. 1. Corrugations on arbitrary the straight side-walls of SU-8

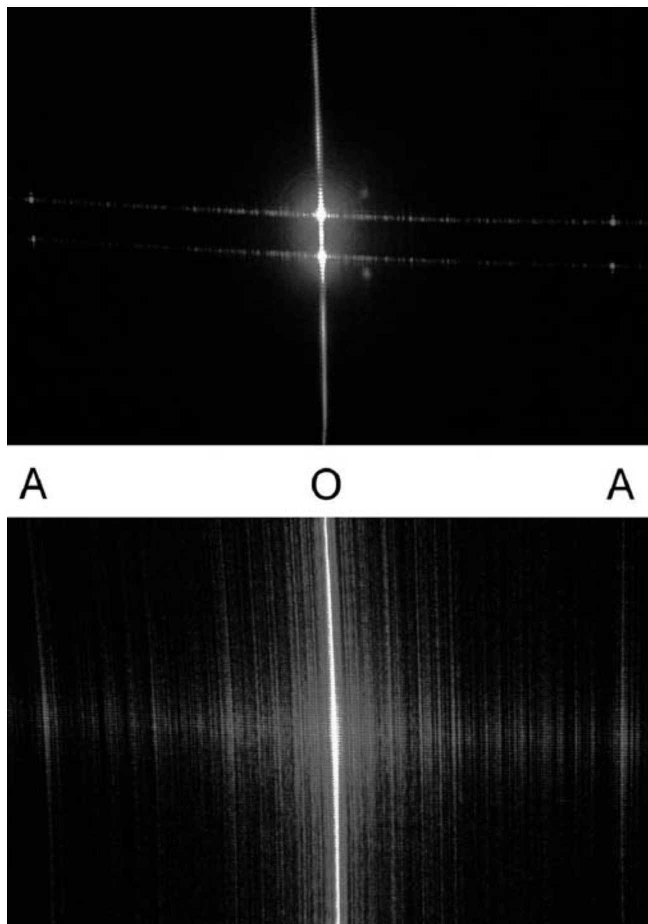

Fig. 2. Laser diffracting image of a straight sidewall in PMMA (upper image) and SU-8 (lower image). A central reflex (O) and two maxima of first order (A) stem from periodic corrugations due to stepping-errors (nanometer-regime) of the e-beam during primary mask-writing

As seen on Fig. 2 there was a central reflex at O as well as equidistant on both sides a maximum of first order at A. The geometric setup for this laser illumination and the maxima visible on the screen as seen in Fig. 2 indicated that a periodic structure with a constant of 4.03 μm had led to this pattern. This value fits with the maximum trapezoid field size of the writing process of the E-beam [2].

As seen in Fig. 2 there is a difference in those images generated with the PMMA-sample (upper part) and those attained with the SU-8-sample. The reason for those are discussed in 3.3.

This means that even structural details with amplitudes of some few nanometers could be transferred into SU–8. The intensity of the signal is even higher compared to the signal received from straight PMMA sidewalls [2] which indicates that the pattern is even sharper in SU-8 compared to PMMA.

3.2 Super-elevations

"Super-elevations" occur at the resist top edges of larger SU-8 structures. They are typically 2 μm high (0.5% of the

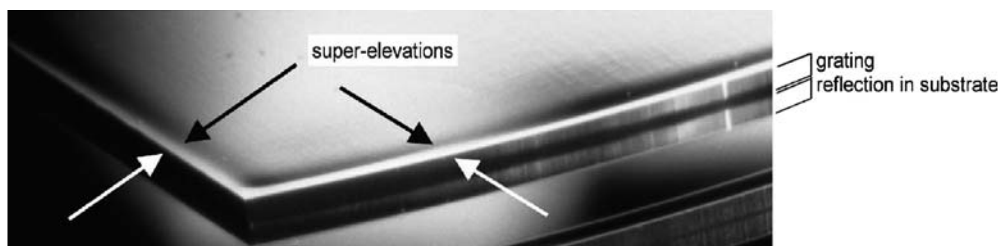

Fig. 3. Super-elevations on the edges of large SU-8 structures

SU-8 resist thickness) and cover a lateral distance similar to the SU-8 resist thickness, e.g. 360 μm. They are caused by secondary radiation [1] which leads to a higher dose and thus a different inner structure and shrinkage behavior of the material [Fig. 3].

3.3 AFM measurements and signal quality

Further on, the structure accuracy of SU-8 spectrometer gratings and sidewalls was measured using atomic force microscopy (AFM). AFM measurements of these sidewalls require a vertical access of the microscope tip. Therefore, the microstructures have to be separated from the substrate. However SU-8 has a very good adhesion to any metal-plated Si-substrate and therefore can not easily be removed from the substrate. To facilitate the removal and minimize any stress introduced, the resist was processed on a detachable additional release layer. 125 μm thick self-adhesive Kapton® tape [Fig. 4] was chosen.

AFM-measurements of the structure accuracy were done in several areas of the grating. These measurements were done both close to the resist bottom and in the middle of the height of the sidewall. However, the vertical position of the measurement spot did not influence the result.

The mean roughness was determined to be $R_a^{Su-8} = 13 \pm 2$ nm [Fig. 5]. This is 63% higher compared to PMMA samples ($R_a^{PMMA} = 8 \pm 3$ nm).

In order to better access the quality of the grating, the peak-to-valley profile was averaged over several AFM scan lines to eliminate the effects of local roughness. This averaged peak-to-valley profile is given in Fig. 6, it amounts to 133 nm.

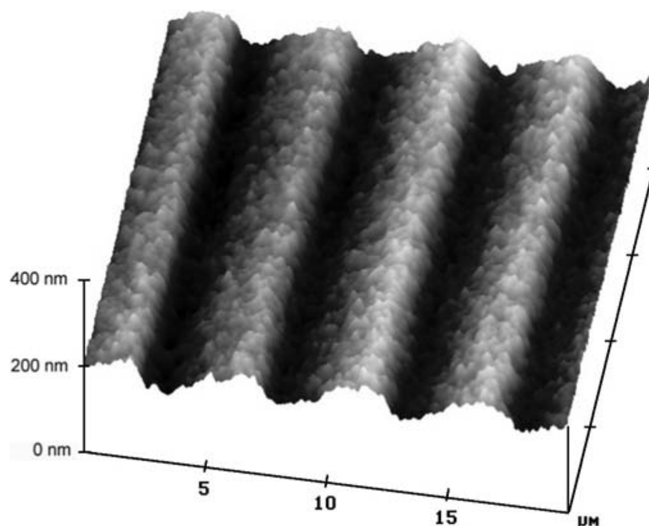

Fig. 5. AFM-measurements: Pattern of a grating in SU–8. The averaged profile of the grating with peek-to-valley of 133 nm is better than those of PMMA [2]

Using a similar processed X-ray mask with inverted tone for PMMA results in a worse peak-to-valley-profile accuracy for PMMA.

The different roughness and peak-to-valley profile combined should be the reason for the slightly differing images of the laser illumination [Fig. 2]. A simple higher roughness would create a none-structured, brighter, halo around the central reflex.

Finally, the overall performance of the SU-8 spectrometer was compared to that of PMMA spectrometers. The damping of the signal in the visible light microspectrometer in SU-8 was detected to be 7.4 dB compared with of direct-lithographic positive-resist PMMA samples with 12.7 dB. Exact spectra still remain to be taken.

Fig. 4. SU-8 structures on 125 μm Kapton® release layer for later examinations with AFM

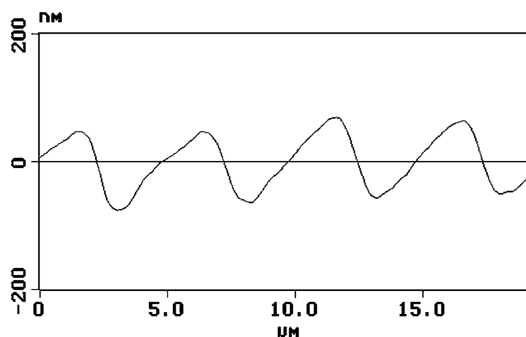

Fig. 6. Averaged accuracy of the grating seen in Fig. 5

4
Conclusions and outlook

SU-8 structures were measured and compared to equivalent structures in PMMA. Structures with sizes in the range of a few ten nanometers can be resolved in SU-8 at least or even better than in PMMA.

A resolution in the nanometer-regime of SU-8 could be detected trough the imaged e-beam steps. The averaged peak-to-valley profile of SU-8 was measured to be better than those of PMMA, although the roughness of SU-8 is worse.

The damping of the signal in the MOEMS in SU-8 itself is significantly lower than the one in PMMA.

Although it would be interesting to further explore this resist-system for certain optical applications as the exposure doses are significantly lower than those required for PMMA.

References

1. **Bogdanov AL; Peredkov SS** (1999) Use of SU-8 photoresist for very high aspect ratio x-ray lithography, Microelectronic Engineering. In: Proceedings 25th International Conference on Micro- and Nano-Engineering '99, Rom, Vol. 53 (2000) S. 493–496
2. **Last A** (2003) Fehllicht in LIGA-Mikrospektrometern, Wissenschaftliche Berichte FZKA 6885
3. http://www.microchem.com/products/su_eight.htm (03/17/2003)
4. **Reznikova EF; Nazmov VP; Mohr J** (2003) Deep X-ray lithography characteristics of SU-8 photo-resist, Fifth International Workshop on High-Aspect-Ratio Micro-Structure Technology Book of Abstracts, June 15–17, Monterey, 2003
5. **Göttlicher J; Hagelstein M [Hrsg.]** (2002) ANKA Synchrotron Radiation Microfabrication and Analytical services Beamline Book, FZK/ANKA, Karlsruhe
6. **Pantenburg F-J; Mohr J** (1995) Influence of secondary effects on the structure quality in deep X-ray lithography NIM B7: pp 551–556