Micro optical elements fabricated by RIE proportional transfer

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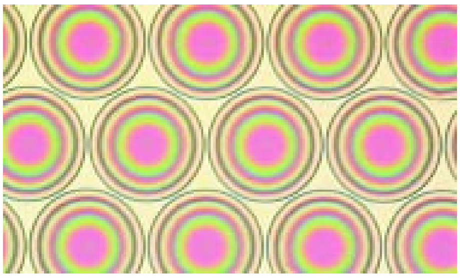

Fig. 1:
Extreme shallow structures (Ø120 µm, sag 1µm).

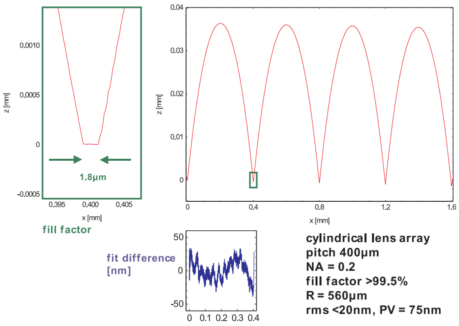

Fig. 2:
Surface profile of refractive cylindrical lens array in photoresist.

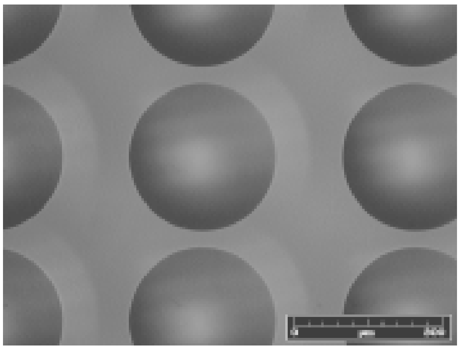

Fig. 3:
Aspheric lenses etched to borosilica glass.

One competence of Fraunhofer IOF is the wafer scale fabrication of micro optical elements. We apply photolithography in combination with reflow techniques or laser grey scale lithography for structure generation and UV micro moulding technique for structure replication. The corresponding thin film equipment is established so far for the preparation of optical elements based on polymers.
Some applications demand for features exceeding that of polymer optics concerning first of all optical power densities, extended wavelength transparency and mechanical and chemical resistance. In those cases, fabrication of optical elements in appropriate inorganic materials is required.
Supplementing our thin film polymer technology we have realized reactive ion etching (RIE) processes with the objective of proportional transfer of polymer optical elements prepared on wafers of fused silica, borosilica glass and silicon to the corresponding substrate material.

Polymer Technology

The IOF resist technologies for generation of micro optical elements and arrays on a wafer scale are based on commercial thin-film equipment and lithographic processes. High accuracy of the generated profiles is the main focus in the generation of optically functional surfaces in photoresist, as well as good homogeneity across the wafer, good repeatability, low surface roughness and a suitable stabilisation of the structures for the subsequent RIE transfer.
Special features are a broad variety of spherical and cylindrical reflow lenslets including those with arbitrarily small contact angle (Fig 1). The surface roughness of reflow patterns is well below 1nm rms. Spacings between lenslets can be as small as 1.5 µm, independent of the lens dimensions (Fig. 2); the homogeneity of the focal length (or sag) across a 4" area can be below ±1%.
Furthermore, the combination of reflow and variable dose writing has been realized resulting in multifunctional optical elements.
Structures on top and back side of a wafer can be aligned with an accuracy of ±2 µm. Lateral precision and good homogeneity are the prerequisite for a potential wafer scale integration of subsystems.

RIE proportional transfer

We have focused our efforts mainly to the proportional transfer of polymer masks prepared in reflow technology. The reactive ion etching (RIE) is done in fluorocarbon or SF_6 based plasma chemistries aiming at a selectivity (etching rate ratio of substrate : polymer mask) near 1:1 which is most favourable for proportional transfer. Typical RIE parameters (pressure 2…6 x 10^{-3} mbar, bias voltage about 250…400 volts) are adapted to yield best results concerning profile accuracy and surface quality necessitated by the use for high performance optical systems.
A continuous process control, particular control of selectivity was proved and successfully applied for the purpose of controlling the lens profile even to form aspheric lenses as well as to counteract some detrimental effects caused by the etching process itself.
The RIE process results in flattening of the etched profile in comparison to the primary polymer profile depending on its dimension and a surface etch removal attributable to an almost isotropic etch effect, even though the RIE plasma process is an anisotropic one. This isotropic effect limits fill factors of arrayed optical elements, or the minimum distance between

neighbouring lenses, respectively.
By modelling the transfer process and assuming 100% isotropic etching effect we found best consistence with experimental data. Referring to this we are able to predict the limits of process control in order to adjust a particular profile, its evolution during etching itself and the expected dimension loss.
The following table estimates the limits for conical constants k of etched borosilica lenses depending on numerical apertures NA taking into account only the potential of selectivity control.

NA	0.11	0.12	0.13	0.15	0.19
k	-6	-5	-4	-3	-2

The calculation was done irrespectively of other effects. Especially the stronger influence of the profile flattening for the higher numerical aperture elements with etch depths larger than about 20 µm may extend deviations from requested profiles.

The achieved accuracy of proportional transfer is best illustrated by the following example.
Fig.3 shows aspherical lenses etched into borosilica glass starting with spherical polymer lenses prepared in reflow technology. The profiles before and after etching are shown in Fig.4 revealing also the inevitable loss of diameter during etching. For this particular geometry (NA = 0.11 and lens diameter= 300 µm) we achieved k = -5.6 characterizing also the limit of selectivity control.
Fig. 5 indicates the deviations from the ideal profiles, i.e. from a sphere before etching and from a conical profile after etching. The process obviously reproduces the deviation from the ideal profiles at nearly the same accuracy. The deviation from the ideal profile is 26nm rms inside 97% of the entire diameter of the etched lens.

The surfaces of etched elements were characterized by AFM measurements. We have demonstrated a surface roughness of less than 5 nm for fused silica, borosilica glass and silicon, see for example Fig.6.

Conclusion

The established thin film technology for preparation of polymer optical elements is a reliable base for the subsequent transfer to silicon, fused silica or borosilica glass.
Corresponding RIE processes have been developed for the transfer of reflow structures. They will be extended in the next future to arbitrarily shaped grey scale structures and, eventually, to other mask/substrate material combinations.

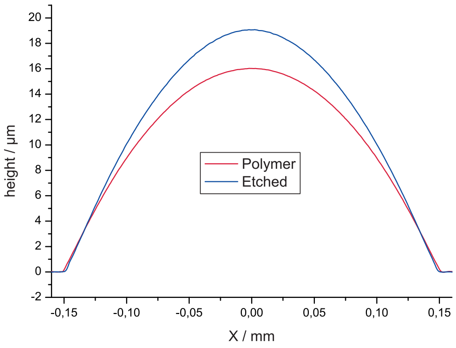

Fig. 4:
Profiles of polymer and etched borosilica lens.

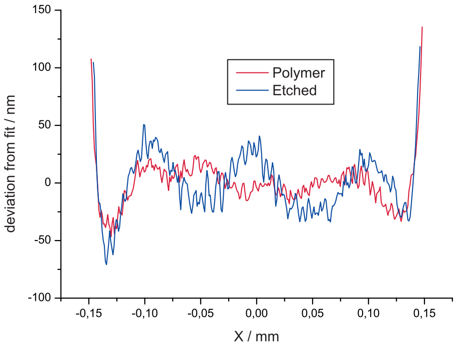

Fig. 5:
Etch transfer of profile, deviation from ideal profiles.

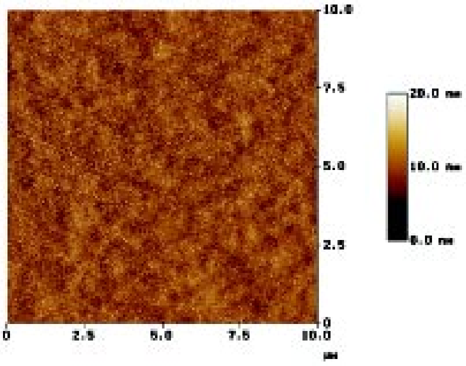

Fig. 6:
AFM measurement of etched borosilica lens surface, rms roughness: 2.7 nm.