Scalable fabrication approach for single pixel microlens arrays

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Microlenses are a suitable approach to improve the performance of optical systems for applications like imaging (i.e., scanners or microscopes), photosensitive sensing (i.e. CCDs) or light-emitting devices (i.e. micro-LED displays) [1]. For CCD devices the light is condensed by the microlens to the photosensitive area, which results in a better signal-to-noise ratio and higher sensitivity. For micro-LED displays the brightness and overall light output can be increased[1]. Important parameters of microlenses are their material, the shape, a high fill factor and a low surface roughness. Material and shape determine the optical properties. A high fill factor, that means a minimized gap between the lenses, increase the optical efficiency[2] and a low surface roughness reduce the light scattering.

A prominent approach to fabricate microlenses as 2.5D structures, is the use of i-line stepper lithography, thermal reflow of photoresist and subsequent 1:1 pattern transfer in the lens material by Reactive Ion etching (RIE). This represents a reproducible and high throughput production technology which enables a direct integration of parabolic microlenses in any optical device (Figure 1). For this method, however, the minimum lens gap and thus the optical efficiency is strongly limited by the resolution limit of the i-line lithography (300-400 nm). Goal of this investigation is to achieve the lowest possible lens gap below the stepper based resolution limit by optimizing each single process step. Therefore, the impact of lithography and reflow process parameter are investigated. By choosing the right parameters, a gap significantly below the resolution limit is possible after reflow. Various lens dimensions from 1 to 10 µm are shown (Figure 2) to demonstrate the scalability of this approach.

A crucial process step is the etching of the lenses. As described above, the lenses are structured by 1:1 pattern transfer from photoresist into the lens material. It is important to minimize the lateral etching component to reduce a shrinkage of the lenses during etching. Regarding this point, the etching process itself were optimized and the behavior of different SiN types as microlens materials investigated. Figure 3 compares the microlens gap of these two SiN types after etching. SiN A shows significant lower lateral etching, resulting in a gap below the stepper resolution limit, which was not achieved for SiN B.

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[1] S. Cai, Y. Sun, H. Chu, W. Yang, H. Yu, L. Liu, Microscopy Research and Technique, Vol. 84, Issue 11, 2784, 2021

[2] Y. Motoyama, K. Sugiyama, H. Tanaka, H. Tsuchioka, K. Matsusaki, H. Fukumoto, J Soc Info Display, Vol. 27, Issue 6, 354, 2019

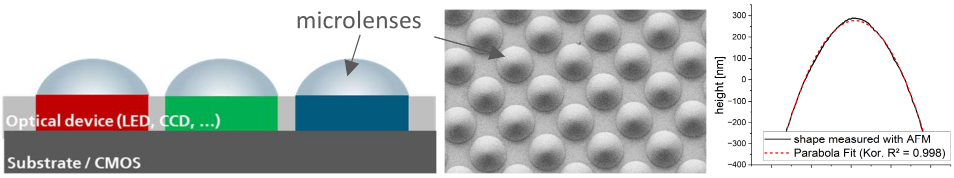

Figure 1: Principal sketch of an integration scheme into microoptical devices like µLEDs or photosensitive devices and SEM Image of a microlens array with parabolic lenses (measured by AFM)

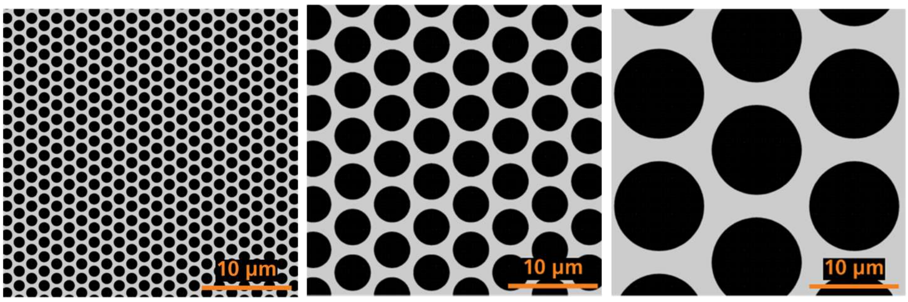

Figure 2: Various microlens dimensions. Examples show mask data of following diameter/gap combinations: 1.25/0.35 µm, 4/1 µm and 10/2.5 µm

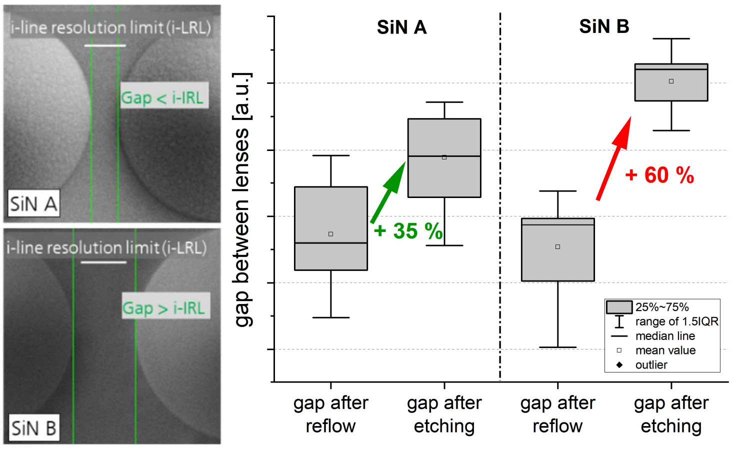

Figure 3: Gap between microlenses after lithography, reflow and subsequent etching of two different silicon nitrides as lens material. SiN A shows significant lower lateral etching, resulting in a smaller gap (SEM images). Statistical evaluation shows a gap increase after etching of 35% for SiN A compared to 60% for SiN B (graph).