Mastering of Multi-sag Microlens Arrays at Wafer Scale

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CSEM offers to its customers an engineering and foundry service of microlens arrays (MLA), ranging from design, origination and prototyping up to small-series production on bare dies of few mm^2, arrays of dies or wafers. The sag, the distance between the top microlens vertex to its base, provides the lens focal length when combined with the lens diameter and the material used. CSEM is improving its MLA wafer-scale origination process from mono-sag to multi-sag as reported here.

Microlens arrays (MLA) are extensively used in optical systems. They are present in cameras and other light sensors to enhance the light collection efficiency by focusing the light onto small photodetectors. They are also used in optical interconnects like fiber optics to improve light coupling and transmission. They can also be integrated in display technologies to improve image quality, brightness, viewing angles or producing 3D images. In addition, MLAs can be found in security documents such as banknotes, ID cards and passports.

At CSEM, MLAs are originated at wafer scale by a photolithography step to get photoresist pillars, followed by a thermal reflow process which melts those pillars into microlenses with spherical profiles. Then, the opposite MLA polarity (i.e., from convex to concave) is obtained by UV replication/imprint on a photomask, resulting in a so-called mold or stamp. Finally, the same UV-imprint process is used to replicate the MLA of the mold onto the final substrate. This process step is performed in a mask aligner to accurately align the MLA with the devices on the final substrate (e.g., photodiodes).

The question rises how to deal with multi-project wafers where multiple detectors or imagers, with different photodiode sizes and pitches are present on the same CMOS wafer. Indeed, the process described above can only yield a single common sag. With different photodiode pitches, i.e., microlens diameters, this translates to multiple radii of curvatures hence focal lengths. Therefore, with the current process limitation, either a trade-off must be made on the performance by identifying a suitable common sag, or different molds must be fabricated, one per sag [1]. In the latter case, only the detector(s) corresponding to the selected mono-sag mold will be equipped with MLAs, meaning sacrificing the others of this substrate, which is detrimental in terms of costs. The best way to address this issue is to maintain a constant focal length among the different photodetectors present on the wafer with different pixel pitches and therefore, originate MLAs with multiple sags, as depicted in Figure 1.

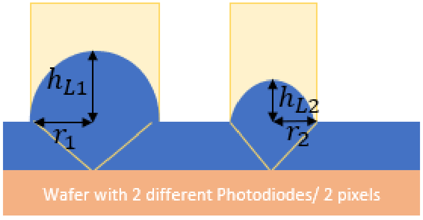

Figure 1: Two microlenses sharing the same focal length despite having different diameters thanks to their distinct sags.

The origination of dual-sag microlens arrays (DS-MLAs) is here demonstrated with two approaches yielding photoresist pillars with two different heights, both followed by a thermal reflow process. Both approaches can be extended to originate multi-sag MLAs. The first approach relies on a multi-layer photolithography technique with a negative photoresist [2] and the second one on a multi-step/dose photolithography with a positive photoresist. The results are shown in Figures 2 and 3, respectively.

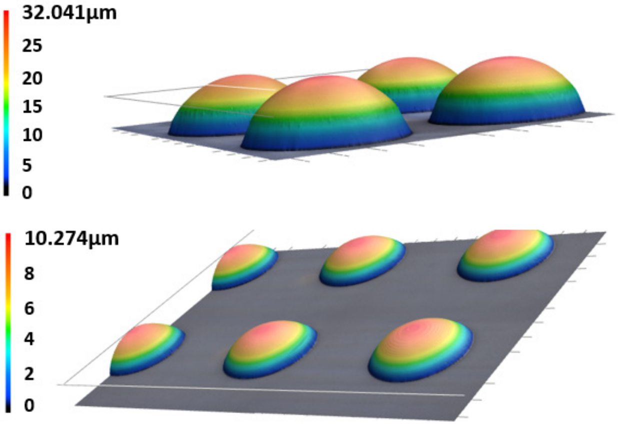

Figure 2: 3D images obtained by confocal laser microscopy showing two MLAs with different sags made on the same substrate from a negative photoresist. Top MLA: Sag = 32 µm & Ø = 85 µm. Bottom MLA: Sag = 10 µm & Ø = 39 µm.

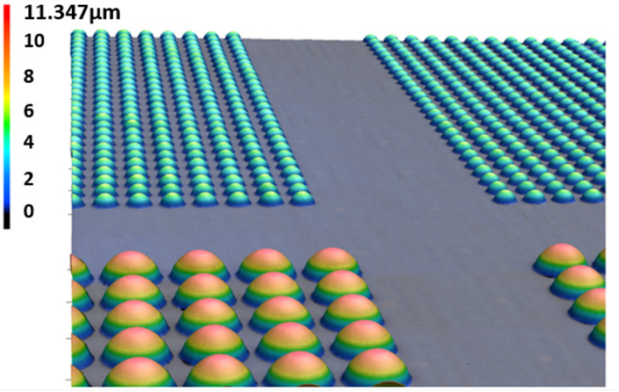

Figure 3: 3D image obtained by confocal laser microscopy showing DS-MLAs made of a positive photoresist. Front MLA: Sag = 11 µm & Ø = 34 µm. Back MLA: Sag = 6 µm & Ø = 16 µm.

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[1] C. Bruschini, *et al*., "Challenges and prospects for multi-chip microlens imprints on front-side illuminated SPAD imagers", Opt. Express 31 (2023) 21935

[2] S.-I. Bae, *et al*., "Multifocal microlens arrays using multilayer photolithography", Opt. Express 28 (2020) 9082.