Advanced Microlenses Fabrication Techniques

G. Basset, A. Luu-Dinh, C. Schneider, F. Herzog, F. Zanella, A. Mustaccio

A way to increase the quantum efficiency of image sensors is by adding a microlens array. The microlenses located on top of each pixel direct light preferentially into the active pixel volume, to offset the limited fill factor in front illuminated CMOS image sensors. Such microlens arrays are commonly produced using CMOS processes, which are best suitable for pixel pitches below 5 µm. At the opposite, larger microlens arrays, with pitches of a few tens of microns to several hundred microns in diameters are fabricated by the thermal reflow of photoresists.

This fabrication method gives excellent optical performance and much affordable fabrication for large microlenses. These dimensions matches the pixel pitches of some specialized image sensors such as Single-Photon Avalanche Photodiode (SPAD) arrays [1], scientific and space observation cameras. Additionally, several applications, such as 3D displays, digital optical processors, optical communication or optical security make use of high quality microlens arrays. CSEM has improved its capabilities to fabricate microlenses based on thermal reflow processes, opening the possibility for new shapes and flexibility.

Microlenses produced by reflow are made of a photoresist patterned by photolithography and thermal melting. They are limited to relatively low aspect ratio (sag to diameter) shapes. Arrays of high aspect ratio microlenses are unstable because of a risk of merging of adjacent microlenses during reflow that can result in the collapse of the array. By using a surface functionalization self-aligned to the photoresist, it is possible to control accurately the shape of the microlenses during the reflow to circumvent this limitation. This opens the possibility to produce very high aspect ratio microlenses as shown in Figure 1.

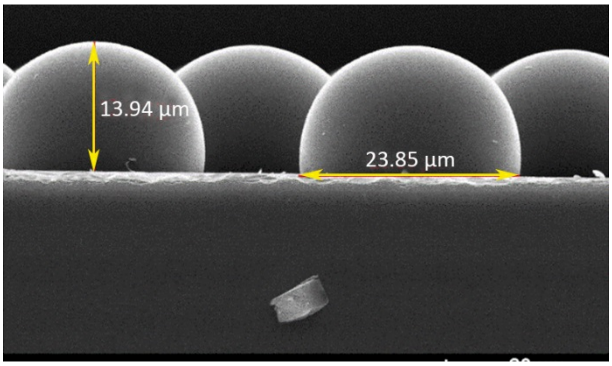

Figure 1: SEM image of more than hemispherical microlenses produced by reflow–cross-section view.

As other examples, this method allows the fabrication of high quality microlenses on heavily patterned surfaces such as optical diffuser as shown in Figure 2 and of arrays of high aspect ratio microlenses with inter-lens gaps well below 2 µm, as shown in Figure 3.

Finally we also demonstrate the possibility to directly inkjet print microlenses with high optical quality polymers on standard substrates as a digital and additive manufacturing approach as shown in Figure 4.

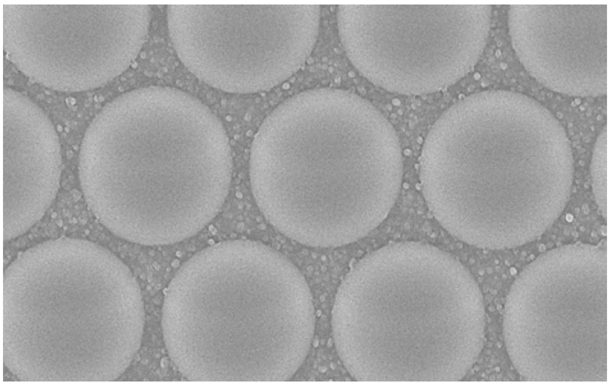

Figure 2: SEM image of a microlens array produced by reflow on a diffusive structure – top view.

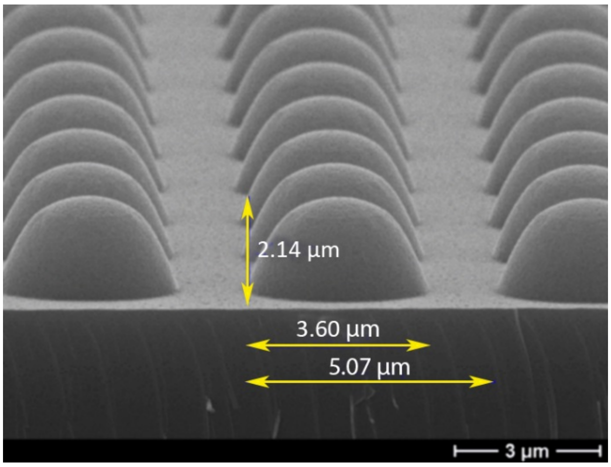

Figure 3: SEM image of an array of very small microlenses with high aspect ratio produced by reflow–oblique view. Diameter: 3.6 µm, height: 2.1 µm.

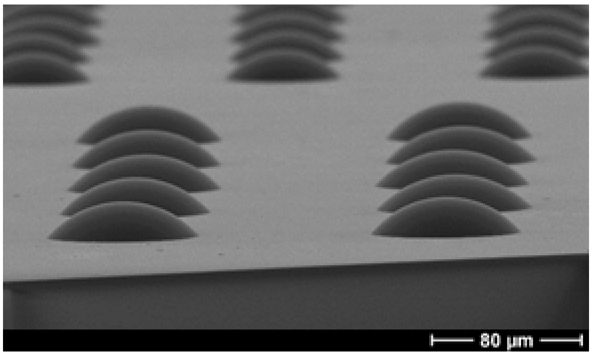

Figure 4: SEM image of directly inkjet printed microlenses on a glass substrate.

[1] J. M. Pavia, M. Wolf, E. Charbon (2014), "Measurement and modeling of microlenses fabricated on single-photon avalanche diode arrays for fill factor recovery", Optics express, 22(4), 4202-4213.