Results of Microlens Testing on Back-illuminated Image Sensors for Space

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CSEM has been mandated by the European Space Agency (ESA) to lead an activity with the objective to design, manufacture and test the application of microlenses on a back thinned Back-Illuminated CMOS Image Sensor (BI-CIS) under space environment conditions. The validation had to address the microlenses technology, their design, materials and involved processes.

Earth observation and scientific exploration missions rely on image sensors *i.e.*, cameras. One way to increase the quantum efficiency (QE) in Front-Illuminated CMOS Image Sensors (FI-CIS) is to add microlens arrays (MLA) which will direct light preferentially into the photosensitive volumes of the pixels. Because Back-Illuminated CIS (BI-CIS) already have almost 100% active surface (100% fill-factor), adding microlenses should not increase the QE significantly. However, they could enhance performance by reducing the parasitic light sensitivity (PLS) and improving the modulation transfer function (MTF) by focusing the light on the center of the photodiode well. The work reported so far on MLA deposition on BI-CIS were only addressed on consumer imaging products for the consumer electronics market where the pixel pitches are below 5 µm whereas space image sensors exhibit usually larger pixel pitches. Additionally, MLA foundries addressing this market are looking for large to very large volumes which is not compatible with space applications. Assessing the microlenses in the space environment is thus required for any integration on image sensors for space applications.

For this study the CAE302 "ELOIS" BI-CIS from Caeleste was selected on which the MLA was deposited. Indeed, this BI-CIS was developed with ESA and tested for space environment. The ELOIS sensor has 2048x256 pixels with 15.5 µm square pixels. This radiation tolerant BI-CIS was designed to use as hyperspectral imager in the wavelength range 350 – 900 nm. The ELOIS sensor exhibits (without MLA) a QE above 90% in most of the visible range and a MTF around 0.556 – 0.593 which is close to the theoretical limit (≈0.6). More specifications are available in ELOIS' datasheet [1].

The 3 main achievements of this study are:

- Successful replication of microlenses on **packaged** BI-CIS, see Figure 1. Indeed, the BI-CIS had first to be electro-optically characterized in order to deposit microlenses only on screened BI-CIS. Therefore, a dedicated process was developed by CSEM. According to CSEM's knowledge [2] this is actually a first, at least in Europe.
- BI-CIS performance improved due to microlenses: the PLS was improved by a factor 1.8 whereas the MTF and QE improvements were less significant. However large improvements are expected to happen on front-illuminated CIS as well as for MTF and QE.
- Robustness through space evaluation campaign: Total Ionization Dose, mechanical shocks ↔ vibrations, outgassing, thermal step stress, moisture and thermal cycling passed successfully. A challenge remains with the long-term UV stability of the microlens material.

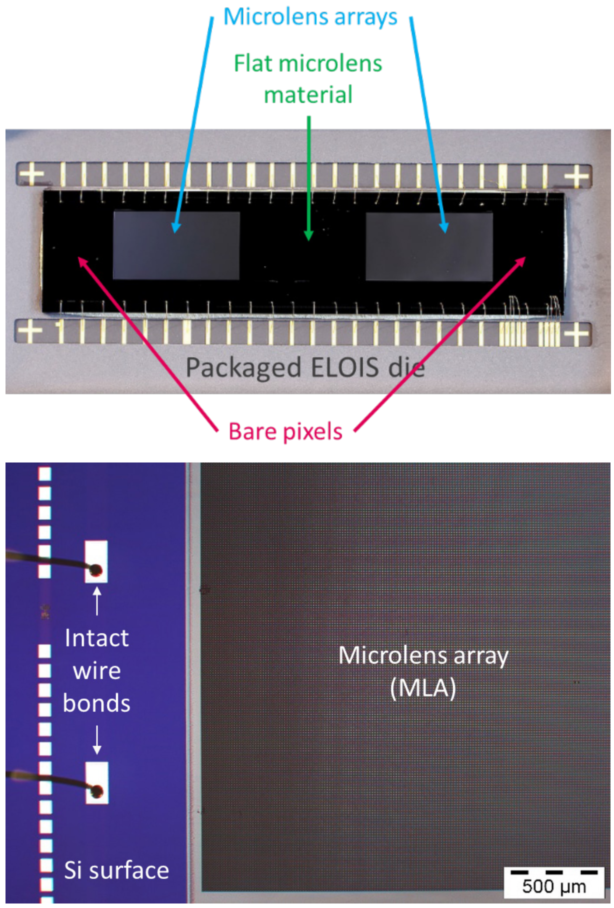

Figure 1: Microlens deposition on packaged BI-CIS from Caeleste.

Since CSEM can address any medium to very large pixel imagers (CIS, CCD, SPAD…), future space missions such as Earth observation and scientific exploration could benefit of the use of integrated MLA. This is especially the case for front-illuminated imagers but also for back-illuminated ones. At this stage, CSEM recommends the integration of microlenses only on imaging systems equipped with a UV filter, hence for missions imaging in the visible or near-infrared. In the meantime, CSEM continues screening new microlens materials having long UV stability while keeping all others highly robust properties. This in addition to moving back to CSEM's standard wafer or die processing (instead of packaged imagers) will hence increase the Technology Readiness Level (TRL).

These results clearly demonstrate the suitability of pixel-level microlens to improve imagers in a variety of cases in the space environment.

CSEM thanks ESA for funding this activity (TRP T123-501QT).

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[1] http://caeleste.be/wp-content/uploads/2018/04/datasheet-ELOIS.pdf

[2] Based on the feedback from customers and end-users.