TECHNOLOGY TRENDS OF MICROLENS IMPRINT LITHOGRAPHY AND WAFER LEVEL CAMERAS (WLC)

Reinhard Voelkel (1), Jacques Duparre (2), Frank Wippermann(2), Peter Dannberg(2), Andreas Bräuer(2), Ralph Zoberbier(3), Markus Gabriel(3), Michael Hornung(3), Sven Hansen(3), Ralf Suess(3)
(1) SUSS MicroOptics SA, Jaquet-Droz 7, CH-2000 Neuchâtel, Switzerland, +41-32-7205104, voelkel@suss.ch, www.suss.ch
(2) Fraunhofer-Institut für Angew. Optik und Feinmechanik IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany, www.microoptics.org
(3) Suss MicroTec Lithography GmbH, Schleissheimerstrasse 80, D-85748 Garching, Germany, www.suss.com

Abstract: *Wafer Level Cameras (WLC) are a novel technology to manufacture low-cost CMOS cameras for mobile phones. The optical components are fabricated on glass wafers by microlens imprint lithography using a SUSS MicroTec mask aligner. Opto-Wafers and the CMOS-Wafer are mounted by Wafer-Level Packaging (WLP). A technology overview and recent trends will be presented.*

1. Introduction

In 1994, about 20 years after the invention of the digital still camera and 10 years after first mobile phones appeared on the market, the first digital consumer camera, the “Apple Quick Take”, was introduced to the market. It took another 8 years until digital cameras were integrated into mobile phones. In the beginning, a mobile phone camera was just another gimmick with limited value for the mobile phone user. Memory was expensive, and the image quality was poor. Today, it is difficult to find a mobile phone without digital camera. Most mobile phones are now equipped with two cameras, a primary Mega-Pixel (MP) camera for photography and a secondary CIF or VGA camera for video calls. Far more than a billion mobile phone cameras were sold in 2007, and the numbers are still increasing rapidly.

2. Trends for Mobile Phone Cameras

It is difficult to predict long term developments in the field of mobile phone technology. Regarding mobile phone cameras, the situation is much easier, they will get better, they will get cheaper – but they remain to be an indispensable part of a mobile phone. Today, two main trends are observed:

a) High resolution cameras, providing autofocus, optical zoom, mechanical shutter, stabilization and Xenon flash. Mobile phones equipped with high resolution cameras are in direct competition with digital still cameras.

b) Wafer-Level Cameras, providing a high potential for cost-reduction in the low end camera market. The camera should be “reflowable”, i.e. it must survive standard SMT reflow soldering process at about 260°C.

Both trends will certainly have a tremendous impact on the current optics and digital camera industry.

3. Wafer-Level Camera (WLC)

Today’s mobile phone cameras consist of some 10 to 20 different components like plastic or glass molded lenses, pupils, baffles, actuators, lens holders, barrel, filters and the image sensor. These components are manufactured and assembled by different sub-suppliers.

The Wafer-Level Camera approach is rather simple: All components are manufactured on 8’’ wafer, the opto-wafers are mounted together with the CMOS wafer, and the wafer stack is diced into the individual camera modules. The complete mobile phone camera, including the optics, is manufactured and packaged on wafer-level using standard semiconductor technology.

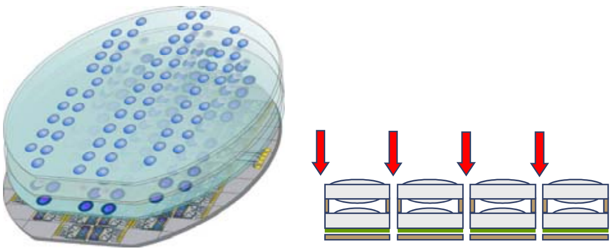

Fig. 1. Wafer-Level Camera (WLC) concept. Opto-wafers and CMOS wafer are mounted together (left) and diced into individual camera modules (right).

Wafer-level imaging systems for mobile phones were already proposed more than 10 years ago [1]. First prototypes were shown about 5 years ago [2]. Since then, WLC technology was developed by research institutes like the Fraunhofer IOF and small companies like Heptagon, Anteryon and DOC/Tessera. It is worth to mention that most WLC research and development was carried out by the micro-optics experts, and not by manufacturers of mobile phone cameras.

Recently, major mobile phone companies promoted WLCs as being the ultimate technology for next generation low-cost mobile phone cameras. Despite WLC technology is still not mature; all major camera suppliers are now investigating WLC solutions.

The simplicity of the WLC concept often leads to the conclusion that CMOS manufacturers just have to use their highly developed semiconductor technology to manufacture the 8’’ opto-wafers.

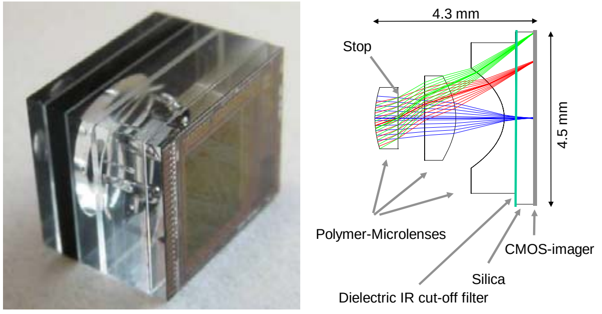

Fig.2. Wafer-Level Camera built in WALORI EU-IST Project [1]. Backside illumination through thinned CMOS image sensor and ball grid for bonding.

Compared to the 150 different process steps to manufacture a CMOS imager, the opto-wafers with some bulky lenses should be rather simple to do. In semiconductor industry “everything is possible” and further miniaturization is only a question of time. However, these assumptions are not valid for wafer-level optics:

- Standard semiconductor technology is not suitable for the manufacturing of bi-convex aspherical lenses on 8’’ wafer level.
- Well established materials from semiconductor industry can’t be used for wafer optics.
- Most materials used for plastic optics do not survive reflow processes at 260°C.
- In WLC the CMOS sensor is covered by the glass opto-wafers. Electric contact pads have to be place on the backside of the CMOS chip and Through Silicon Via (TSV) technology or backside thinning of the CMOS are required.
- Fundamental physical laws limit a scaling down to ultra small cameras with high resolution.

The WLC approach requires a close co-operation of optics and semiconductor industry with equipment suppliers. Novel technology has to be developed and existing production tools have to be modified.

4. Microlens Imprint Lithography

8’’ wafer technology for refractive and diffractive micro-optics was first implemented by SUSS MicroOptics in 1999. Standard manufacturing technology from semiconductor industry, like resist coating, lithography, reactive ion etching (RIE), deposition, sputtering, and lift-off were optimized to manufacture high-quality micro-optics in 8’’ Fused Silica, Silicon and Borofloat wafers. Unfortunately, the well-established 8’’ wafer technology is not suitable for WLC. Resist melting and RIE transfer do not allow manufacturing of microlenses with more than 100 µm lens sag. RIE speed of some microns per minute does not allow cost-efficient etching of bi-convex lenses on wafer level.

The most promising technology is imprinting or UV-embossing of polymer lens structures on glass wafers by soft PDMS stamps. First experiments to imprint micro-optics on wafer level using a modified SUSS Mask Aligner MA6 have been carried out at the CSEM about 10 years ago. [3, 4]

Fig. 3. UV-embossed micro-optics using a SUSS Mask Aligner. Sol-gel microlenses for collimation are imprinted on top of VCSELs (photos CSEM Zurich).

CSEM’s microlens imprint technology has been transferred to Heptagon, also based in the Zurich area in Switzerland. Heptagon developed proprietary processes for reflowable micro-optics and is regarded as one of the pioneers in WLC technology. Recently Heptagon opened a WLC manufacturing facility in Singapore. Another pioneer in this field is the Fraunhofer IOF in Jena, Germany. They successfully developed replication and imprint technologies for low-cost wafer-level optics. Fully operable prototypes of ultra-flat cameras, endoscopes cameras and WLC systems have been presented.

Microlens Imprint Lithography allows the manufacturing of lens arrays with a lateral accuracy of ± 1 µm on 8’’ wafer level.

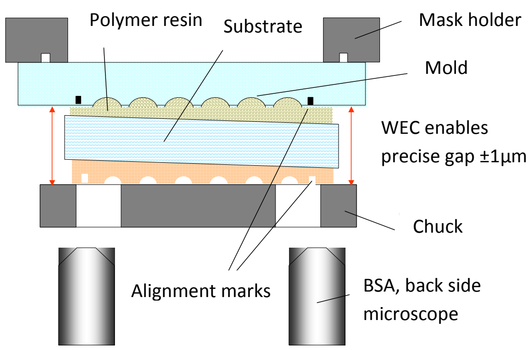

Fig. 4. Microlens Imprint Lithography using a soft mold to imprint double-sided lens arrays onto opto-wafers.

However, Microlens Imprint Lithography is not a technology that could be easily and fast integrated into a semiconductor manufacturing process. Major problems are the lack of suitable polymer materials and the availability of wafer-scale master arrays.

The WLC lens material must be suitable for high throughput imprint lithography, reflowable at 260°C and must have long-time stability in harsh environment (heat, humidity and sunlight). For the lens design, a choice of different lens materials (refractive index, Abbé number) is required. Today, the commercially available materials do not fulfill these conditions. Companies have developed their own material, but do not share information.

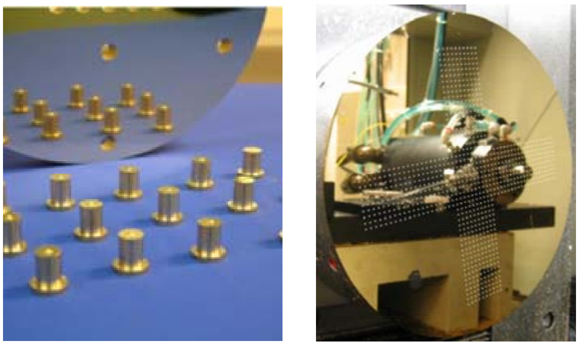

Fig. 5. (Left) Lens master composed by single diamond-turned pins. (Right) 8'' lens master obtained by diamond turning. (Photos Fresnel Optics, Kaleido Technology).

Usually, smaller master arrays are used to build a larger lens master in a step-and-repeat procedure on SUSS NPS 300 Nano-Imprint-Stepper. Recently Kaleido Technology presented a first 8'' diamond turned lens master in brass, providing spherical, aspherical and free-form lenses with better than 2 µm lateral position accuracy. The wafer-scale master arrays are then transferred into a soft stamp, usually made of Polydimethylsiloxane (PDMS) by casting. The PDMS layer serves as stamp.

5. Wafer-Level Packaging for Opto-Wafers

SUSS MicroOptics, a spin-off from IMT Neuchâtel, Switzerland, and the Institute of Applied Optics Erlangen, Germany, started the manufacturing of high-quality micro-optics on 8'' wafer level in 1999.

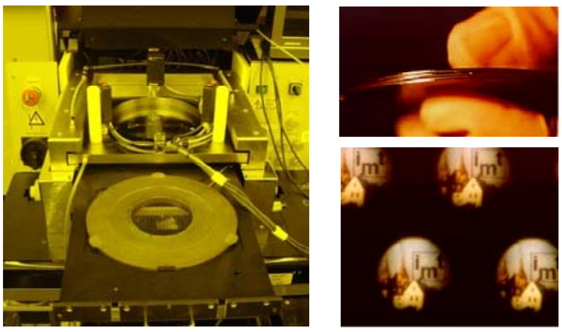

Fig. 6. SUSS Mask Aligner modified for wafer-level packaging of 8'' microlens wafers. A stack of 4 microlens wafers (4'') serving as a 1:1 array imaging system.

At the beginning, the focus was on Microlens Projection Lithography (MPL), a novel technology using an ultra-flat microlens-based projection systems consisting of 4 wafers (Fused Silica) of densely packed microlens arrays, pupil and baffle arrays.[5] Wafer-level packaging was done in a modified SUSS MA8/BA6 Mask Aligner providing active gap setting, stiff wafer holders, UV curing and wafer-to-wafer accuracy of ±1 µm.

SUSS MicroTec has now launched a new mask aligner dedicated for WLC. The new MA8 combines all three non-semiconductor technologies required for WLC:

- Stamp manufacturing
- SUSS Microlens Imprint Lithography (SMILE)
- Wafer Level Packaging of 8'' opto-wafers

In production, the MA8 Mask Aligner is combined with a SUSS DSM8 or DSM200 for double-side imprint and wafer-to-wafer alignment accuracy testing.

Fig. 7. SUSS Mask Aligner MA8 dedicated for Wafer-Level Camera (WLC) development and production. SUSS DSM8 for testing the alignment accuracy of double-sided Opto-wafers and mounted WLC stacks.

Today, the equipment base for WLC production is still very narrow. However, in the case that the WLC approach fulfills the very high expectations of the mobile phone industry, other equipment manufacturers will quickly follow and also provide equipment for WLC.

6. Summary

As result of quite a few years of research and development, executed by research institutes and small micro-optics companies, first Wafer-Level Cameras get on the market now. The proof of principle was successful. However, the WLC technology is not yet mature and a fast ramp-up of the camera industry to WLC manufacturing is not very likely. The most critical problems and potential show-stoppers are the following:

OPTICAL DESIGN

- Wafer-Level Cameras require novel strategies for optical design and straylight management. Only a few optical designers have already WLC experience.
- Integration of actuators for mechanical zoom or shutters is difficult or impossible.

- The CMOS packing density must be adapted to the packing density of the opto-wafers. Thus the number of CMOS chips per wafer might decrease.

LENS MATERIAL
- The lens material must be suitable for high-throughput imprint lithography, UV-curable, reflowable at 260°C and must have a long-time stability in harsh environment (heat, humidity and sunlight).
- For chromatic correction different lens materials (crown and flint glass type) must be available.

MICROLENS IMPRINT LITHOGRAPHY
- Current Microlens Imprint Lithography suffers from long process cycles, short stamp lifetime, wafer bending (bow, warp) and significant yield problems.

METROLOGY
- Optical testing of aspherical and free-form microlenses is difficult and sometimes impossible.
- High-throughput lens testing on wafer-level is mandatory to maintain a high yield in production.

WAFER-LEVEL PACKAGING
- Opto-wafers are usually not perfectly planar. Bow, warp and double-sided optics make it difficult to mount a stack of 3-4 different wafers.
- Gluing and sealing for the wafer stack is not trivial regarding reflow temperature restrictions.
- Dicing of the complete WLC stack is tricky and has a high impact on the overall yield.

LEGAL ASPECTS
- WLC technology is protected by many patents. TSV (Through Silica Via) technology is also mandatory for WLC. The patent situation for these two key technologies might not be clarified soon.
- The profit margins for mobile phone camera suppliers are already very tight. WLC manufacturers might simply not earn enough to finance the new technology and to pay the license fees.

7. Outlook

The big players in the mobile phone and imager industry are getting excited about WLCs. Driven by harsh cost-reduction demands; all major players are currently evaluating plans to quickly ramp-up WLC manufacturing. Several scenarios are feasible:

A) Today's WLC players, small micro-optics companies that have successfully developed WLC technology, will grow fast and take over the low-end camera market.

B) Today's phone camera manufacturers will upgrade from single lens mounting to wafer-level technology.

C) Semiconductor industry will implement WLC technology in their CMOS lines. Current camera suppliers will be pushed out of the supply chain.

Very likely, none of these scenarios will happen like this. Today's WLC players might not be able to ramp-up fast enough. They will try to find partners to sell their technology or IP. Today's camera manufacturers will have a hard time to change from single lens molding to 8'' wafer technology. They will try to find other solutions to reduce their costs without major changes. Semiconductor industry underestimates the challenge of lens manufacturing. The most likely scenario is a mix and match of different technologies and strategies:
- Both molded plastic and glass lenses and 8'' wafers of imprinted lens structures will be used together.
- Die-to-wafer, reconstitute wafer or carrier integration strategies as shown in Figure 8.

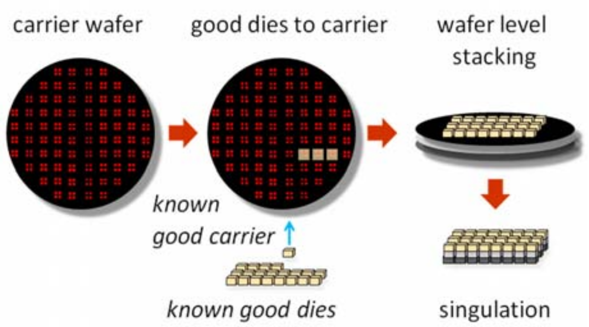

Fig. 8. WLC concept using separation and carrier wafers as proposed by A*Star, Singapore.

Acknowledgement
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