

Technology Trends in the Manufacturing and Packaging of Wafer Level Cameras

Ralph Zoberbier⁽¹⁾, Marc Hennemeyer⁽¹⁾, Dietrich Toennies⁽¹⁾, Andreas Kraft⁽²⁾, Martin Eisner⁽³⁾ and Reinhard Völkel⁽³⁾

(1) SUSS MicroTec Lithography, Schleissheimerstr. 90, 85748 Garching, Germany

(*) Ralph.Zoberbier@suss.com. Tel.: +49 89 32007 382, Fax: +49 89 32007 167

(2) DELO Industrial Adhesives, DELO-Allee 1, 86949 Windach, Germany

(3) SUSS MicroOptics SA, Jaquet-Droz 7, CH-2000 Neuchatel, Switzerland

Abstract

For many years digital cameras have been integrated into mobile phones. In the beginning the camera phone was just another gimmick with limited value to the end user. Today, imaging is considered as a core feature by the user and major mobile phone manufacturers and most mobile phones are equipped with two cameras, a primary Mega-Pixel (MPxl) camera for photography and a secondary CIF or VGA camera for video calls. Far more than a billion mobile phone cameras were sold in 2009, and the numbers are still increasing rapidly. The increasing demand for more functions and features coming along with cost reduction plays a significant role in today's product design and manufacturing technologies of mobile phones and pushes the industry to continuously improve the performance and the manufacturing technologies.

Wafer Level Cameras (WLC) is supposed to be the technology of choice to address these requirements. This application currently drives many equipment and process innovations that will become key for cost effective 3D and MEMS packaging later on.

Within the manufacturing process of wafer level cameras one can identify two complementary technologies. One is the wafer-level packaging of image sensors and the other is the wafer-level manufacturing of camera objectives. Both the sensor device and the objectives will be finally assembled on wafer level by a wafer bonding process. However, today's reality is the wafer level manufacturing of the optical module and the chip-level assembly of optical module and image sensor chip.

Wafer level optics (WLO), part of the wafer-level manufacturing of cameras, is a novel technology that is designed to meet the demand for smaller form factors of the optical system and cost reduction in the next generation of camera phones. The optical components are fabricated by UV replicating the optics through a stamp material into a polymer layer, coated on a glass wafer. Another key challenge in the manufacturing is the alignment in the wafer bonding process step. Replicated lens wafers are aligned and adhesively bonded at the wafer level using a UV curing process in order to achieve excellent alignment results. Finally the bonded Opto Wafers are subsequently diced to form individual camera modules.

This paper explores the latest fabrication techniques used in the Wafer Level Camera manufacturing process (WLC) to support >3MPxl systems and describes main challenges and available solutions. The paper presents latest lithography results of TSV formation, the replication of micro lenses (Fig. 2) and the wafer level packaging of microlens wafers (Opto Wafers) via UV bonding are

depicted as well. Finally new UV curable materials for microlens replication and for Wafer Level Packaging of Opto Wafers (lens stacking) are presented.

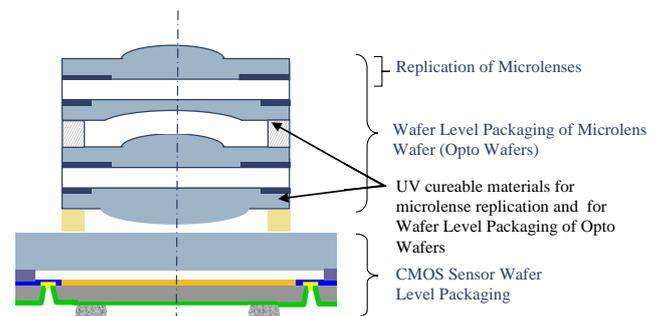


Figure 1. Schematic of Typical Wafer Level Camera Design

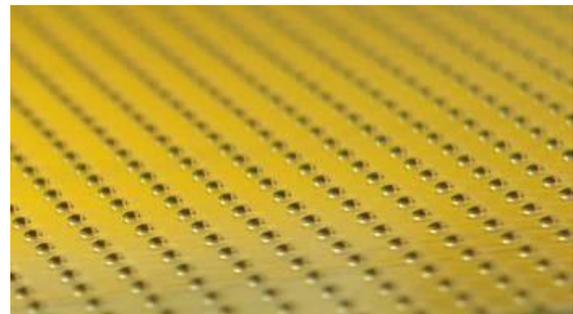


Figure 2. UV replicated micro lenses on a 200mm wafer, Material: Delo Katiobond 18499

Typical Wafer Level Camera Design

Typically a wafer level camera consists of two main pieces, the image sensor and the camera optics. Figure 1 shows such a schematic cross section of a classical wafer level camera.

For leading edge MPxl cameras the optical design typically requires min 4 lens layer. This is realized with two double sided lens wafers that are assembled via a spacer wafer to ensure the correct focal length of the optical module. Apertures and anti-reflecting coating concludes the typical design of a WLC.

UV replication and molding of micro lenses

The replication of optical parts like lenses for WLC is mostly done by molding them from a stamp. Dependent on the method to be used while replicating the lenses, two different stamps are used.

Hard stamps mainly produced from glass, when the process involves squeezing a dispensed polymer droplet over the wafer area or the structures are embossed into a polymer layer spread over the wafer surface in advance as it is frequently found in hot embossing. Soft stamps usually produced from silicone rubbers (i.e. PDMS), when the polymer is dispensed into the single lens molds and the lenses are casted by transfer of these polymer droplets onto the supporting wafer (depicted in figure 3). Both methods have their pros and cons.

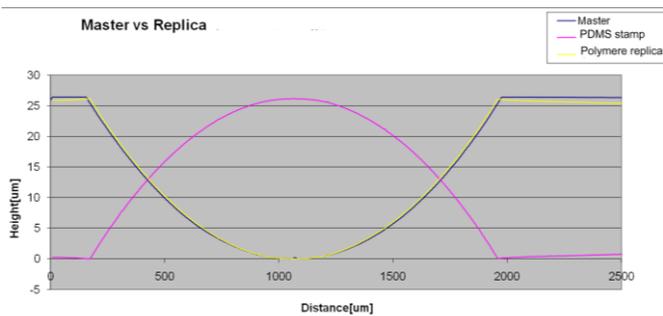


Figure 3: Master vs. replica (PDMS stamp and final UV replication in UV curable polymere)

The glass stamp provides a very good control about its total thickness variation (important for the uniformity of the molding result and for the alignment accuracy, as described below) and enables the replication of even the smallest structures due to its high stiffness and resulting contour accuracy. On the other hand the hard stamp requires a base layer as a conformal printing over the whole wafer area is impossible between two hard surfaces. Additionally, imprinting into a predisposed layer requires big forces to displace the material. Machines supporting this imprint method have to be very warping resistant and need actuators that can provide these high forces and allow an active control of wedge errors.

The silicone rubber stamp shows drawbacks as the hard to control total thickness variation, the shrinkage that can appear during stamp production and the worse resolution due to possible deformations in the stamp during imprinting. However, due to its soft surface that adapts to the wafer surface it can produce lenses without the presence of a residual layer. Therefore wafer warpage due to shrinkage of the lens material is strongly reduced. As a side effect also particle contamination is a less serious problem with soft stamps, leading to reduced clean room costs.

As mentioned above, the total thickness variation is not only a problem for the uniformity of the imprint result, but can also cause problems as soon as the replication process includes alignment between the lens layer and the wafer. While a wedge in the stamp can still be compensated by the wedge error correction system of modern mask aligners, substrate warpage or deformations of even higher polynomial grade can not be compensated by the machines. Therefore contact between different points on the wafer area

is established at different times and leads to lateral forces between wafer and stamp which are hard to control. These lateral forces are mainly caused by shearing of the stamp material due to the non-uniform load or by viscous forces caused by the non-isotropic flow of glue between the stamp and the wafer.

Due to these forces shifts between stamp and wafer can occur during the imprint process. To compensate for the shifts, processes with multiple approaching and realigning steps are necessary. Especially during the last steps of such an imprinting process the contrast of the fiducials, which are typically produced in polymer during the imprinting process themselves, can be very weak. Here only the combination of well chosen microscopic techniques and made to purpose fiducial design can provide images offering sufficient reliability for automated alignment. Fiducial geometry should take care about reducing deformations of the polymer pattern as well as about the needs of the pattern recognition systems.

To achieve highest reliability, the pattern recognition systems need expanded structures. Those expanded polymer fiducials may be created by dispensing opaque polymers onto the fiducial region or by creating rough surfaces which cause increased scattering, but further development is needed at this point (figure 4).

Also transmitted light microscopy can help to increase structure contrast. Besides that, the use of microscopy optics with small numerical apertures and advanced illumination techniques as dark field or DIC (Differential Interference Contrast) may be useful and are therefore options in SUSS machines.

Wafer Level Assembly of Opto-Wafers

Certainly camera systems consist of several optical elements that need to be assembled quite accurately to provide the best possible optical performance. Until today camera systems have been manufactured by manually assembling lenses into a barrel. This procedure is very costly, time consuming and doesn't seem to be a reasonable approach for the manufacturing of multi level, miniaturized lens stacks that are supposed to be use in modern camera systems.

Wafer level bonding technologies seem to solve this issue. The industry started to use wafer bonding equipment platforms to bond lens wafers with spacer wafers or a second lens wafer with thermal curable adhesives. For this technology state of the art bond aligning and bonding tools can be used. The wafers with applied adhesive on one of the wafers get aligned, get clamped in a transport fixture and get finally bonded in a substrate bonder. However, this process has limits in terms of the achievable alignment accuracy. The reason is that thermal stress in the bond process and the required handlings from the bond align to the bond tool impacts the final alignment accuracy and limits process reliability.

As lens wafers are transparent for UV light the usage of UV curable adhesives seems to be the solution of choice for a cost effective and highly accurate wafer level assembly with "in-situ" alignment on a mask aligner type of equipment. Leading edge mask aligner technologies allow alignment accuracies well below $0.5\mu\text{m}$ and offer high

intensity UV illumination for effective UV curing processes. The sequence of a UV bond is very similar to common mask aligner photolithography. Two substrates have to be aligned in an accurately controlled alignment gap and UV exposure finalizes the process step. However, for UV bonding the Mask Aligner requires a specific substrate holder that includes a UV transparent chucking plate to hold the top lens wafer. This is shown in figure 5. The lower lens wafer is handled onto an exposure chuck which is typically designed for wafer edge handling or for the usage of “buffer wafer”. Buffer wafers are typical spacer wafers (glass wafers with holes at the position and with the size of the lenses) that are needed and used to ensure a well defined and controlled distance between lens wafers. Both are dedicated to safely handle the wafers with replicated convex lenses.

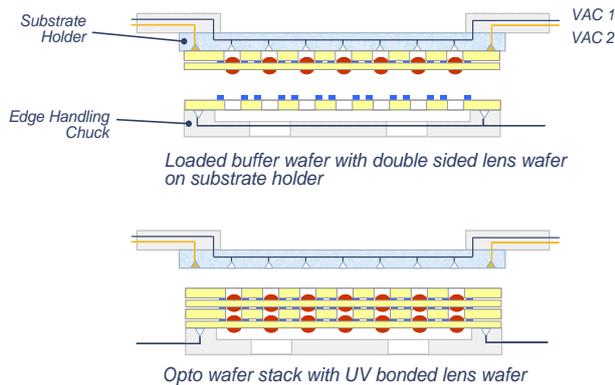


Figure 4: UV bonding incl. in-situ alignment on the SUSS MA8 Gen3 with the usage of buffer wafers

Besides the alignment and bond equipment, the dispense technology and process play a significant role in the manufacturing of WLC. The dispense volume and pattern of the adhesive need to be controlled to achieve a void free and reliable bond interface. Too much material results in contaminated optical elements while too less material results in leakages of the module itself. Low level vacuum encapsulation is also considered to ensure higher reliability and temperature stability of the final device. The adhesive itself needs to be chosen carefully to fit to the general requirements to be a fast curing, highly reliable, dispensable and last but not least reflow compatible material. In addition material suppliers like DELO offer material with integrated filler particles to achieve a uniform and automatic residual thickness control by the material itself.

With the use of opto wafers with lenses that are embedded in the polymer, roll-coating techniques can be adopted. This offers much easier glue dispense process but limits the design of the lens wafer.

High accuracy alignment of opto wafers can be achieved on manual and automatic mask aligners from SUSS MicroTec. As described above, sophisticated toolsets are used to safely handle the lens wafers and to ensure an excellent leveling of both wafers during the gap setting and alignment step. One of the key challenges at the alignment process is the very large distance between alignment fiducials. Depending on the number of wafers to stack, the distance between the alignment targets can get up to several mm. The optical alignment system incl. the microscope and focus settings need to be highly accurate in design and

setup. In addition, leading edge technologies like SUSS “Assisted Alignment”, which provides live overlay measurements and direct operator feedback, are required to achieve the required alignment accuracies. Today, WLC lens stacks with sub-micron post bond accuracy are within reach when adopting UV bonding. Material properties like shrinkage and curing rate impact the final post bond accuracy and need further developments and optimization. Some materials even require a post exposure bake for the final curing.

Latest test results on 200mm substrates show an excellent post-bond accuracy of less than 3µm that is required for the manufacturing of state of the art MPxl cameras.

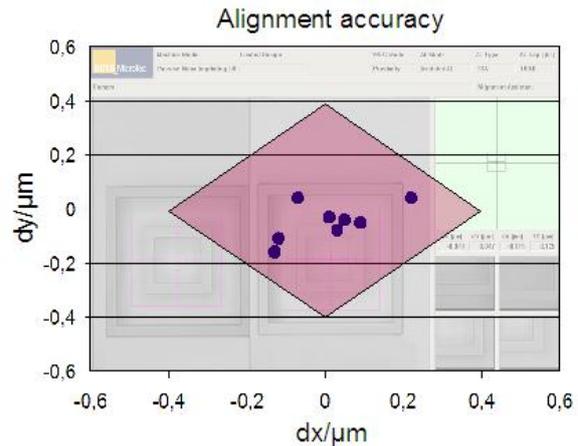


Figure 5: Alignment results obtained during UV-stacking on a SUSS MA8 Gen3. The points represent results measured with the cognex system in the machine. Vernier measurements resulted in alignment accuracy better than the 0.4 µm resolution of the Vernier (red area)

Fast UV-curable materials for Lead-free reflow processes in Wafer Level Camera Manufacturing

UV curing adhesives are currently widely used for mass production in the electronics and optics assembly industries. Depending on the chemical basis – acrylic or epoxy- these materials differ in some of the basic parameters.

Acrylic adhesives are known to be very fast curing, but are limited at high temperature processes and have high polymerization shrinkage. On the other hand, epoxy based system are known for good thermal stability and low shrinkage. Therefore they are used in high reliability applications, like automotive and optical assembly.

The challenge for Wafer Level Optics (WLO) manufacturing is to develop materials with fast curing mechanism, high optical transmission and high thermal stability (reflowable optics).

a. Fast curing with good adhesion

Due to the lead-free reflow requirements in the WLC module and the high throughput needed for low cost wafer level manufacturing. DELO has developed new fast UV-curing epoxy-based adhesives, as well as high temperature stable acrylic adhesives. Referring to figure 7 initial strength of Glass/ Glass samples is reached exceptional fast, at 10 sec after exposure with an epoxy based adhesive.

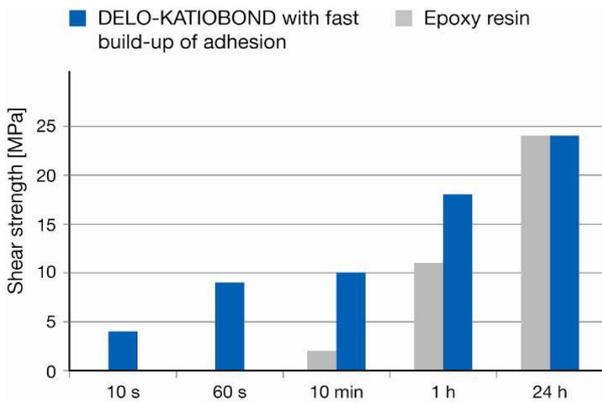


Figure 6. Time of reaching initial Shear Strength after UV exposure, compared to standard UV curing epoxy

b. Adhesion to Stamp Material

For imprint materials, it is very important to have excellent adhesion to glass (wafer), whereby the adhesion to the stamp material should be as low as possible. In our tests, all printed optics wafers could be easily removed from the used stamp material (2 component - silicone), even up to 8" wafers.

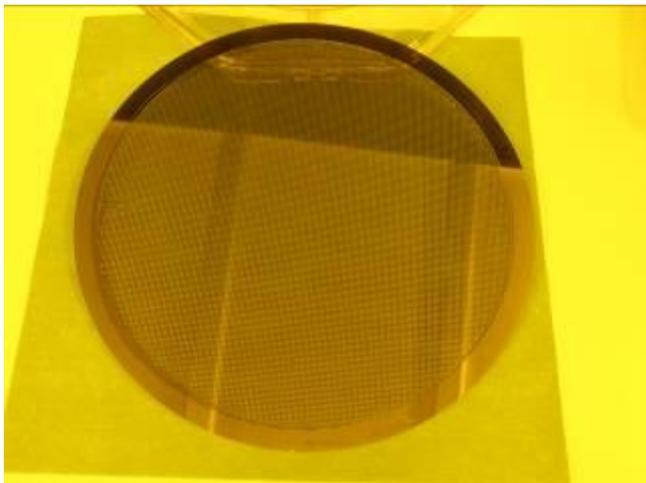


Figure 7. Lenses imprinted on a 8" Wafer using DELO-KATIOBOND AD VE 18499

c. Low Outgasing and Low Shrinkage

Another important parameter in optics applications is the outgasing of the adhesive at high temperatures. Looking at process temperatures up to 260°C, one can see, that the weight loss of the DELO KATIOBOND AD VE 18499 is < 2% @ 260°C (Fig. 8).

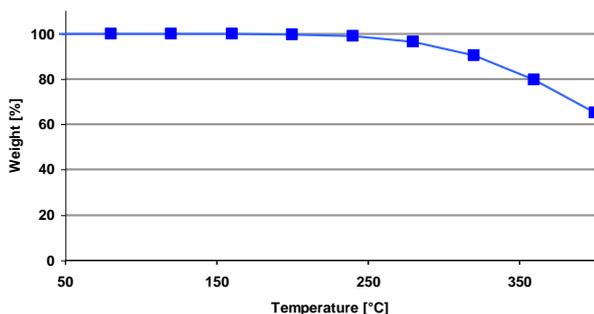


Figure 8. TGA Curve of DELO KATIOBOND AD VE 18499

The shrinkage was measured according to an internal norm (DELO Standard 13) using cylindrical test specimens with a diameter of 20 mm and a height of 4 mm. It can be seen, that a volume shrinkage of < 2.5% can be achieved.

Optical Material	Type	index of refraction @589 nm	Abbe number	Volume-Shrinkage [%]
Low Refractive Index/ High Abbe				
DELO-KATIOBOND AD VE 18499	Epoxy	1.514	47	4.5
DELO-KATIOBOND OM VE 110021	Epoxy	1.516	55	2.3
High Refractive Index/ Low Abbe				
DELO-KATIOBOND OM VE 19923	Epoxy	1.572	35	3.2
DELO-PHOTOBOND OM VE 510968	Acrylic	1.578	31	5.5

Table 1. Shrinkage and optical parameters of Optical Materials

d. Reliability Testing

Optical stability

One of the most critical processes for optical transmission is the new lead-free reflow process (3* 260°C). Transmission Measurements were done on 100µm thick foils of cured adhesive with no protection. As can be seen on Figure 10, an optical transmission of larger than 95% @ 400nm is achieved with all adhesives.

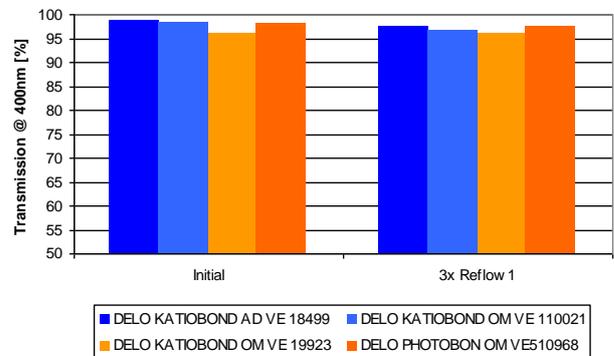


Figure 9. Transmission of 100µm thick foils of different DELO adhesives

Thermal stability

In order to simulate the mechanical stress in a wafer level optics module, the adhesives were cured on 2 different samples (A, B) with no adhesion promoter:

- A:** 20mm x 20mm x 5mm glass plates with a 500µm adhesive layer
- B :** 4mm x 4mm x 4mm glass cubes with a 100µm adhesive layer

Stress on both samples was introduced by a grinding process to simulate the sawing process and to generate possible micro cracks at the edges of the sample.

- **Samples A** were tested after 500h 85°C/ 85% r.H.

All new DELO adhesives did not show any delamination, in contrast to some of the standard adhesives.

- **Samples B were run through the following conditions:**

- **Temperature shock test: -40°C → 85°C**

The left picture in figure 10 shows delamination of a standard adhesive at the edge of the sample. The right picture in figure 10 shows optimized adhesive, where no delamination occurs.

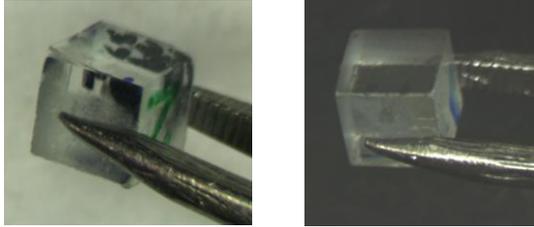


Figure 10. Images after 300 temperature shock cycles

- **Reflow Condition**

A typical reflow profile was simulated in a temperature controlled chamber. None of the samples did show delamination.

Technology Outlook

Full wafer level packaging of the camera module is still the development target of the main industry leaders. This includes the manufacturing of wafer level optics (UV replication and assembly) plus the wafer level assembly of optics onto the chip before chip singulation. 3D TSV technology will be used to attach signal processing and/or memory to the final module. In addition, it is expected that the industry will move to 300mm within the next two years which will also challenge device manufacturers and equipment suppliers.

Acknowledgments

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