SUSS MICROTEC’S UNIQUE DSC300 GEN2 PLATFORM – COMBINED PROJECTION LITHOGRAPHY PERFORMANCE WITH ADVANTAGES OF FULL-FIELD EXPOSURE

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INTRODUCTION
For decades, photolithography is a fundamental process used in the fabrication and packaging of microelectronic devices. A key component of any photolithography process is the exposure tool, which uses light in the ultraviolet wavelength range to pattern a photosensitive resist or polymer. The exposure tool must be able to precisely create the desired feature in the photo resist and place it to previously fabricated structures in underlying layers. Several types of exposure technologies exist today: proximity or contact printing, laser direct imaging and projection lithography. These technologies and the equipment toolsets mainly differ in terms of technical capability like optical resolution, overlay performance and effective throughput but also heavily impact the costs related to the exposure process. Looking at the main drivers and trends in the semiconductor industry, it clearly shows that on the one hand innovation and performance improvements of microelectronic devices are required to meet future end user trends. For example, consumer electronic devices like tablets and smartphones getting thinner and thinner and at the same time have to have higher computing power with increasing data storage and communication capabilities. On the other hand manufacturing costs become more and more important for companies to maintain or improve their market position in a global and highly competitive environment.

The DSC300 Gen2 lithography system of SUSS MicroTec represents the latest generation of its projection scanner technology that is tailored to deliver high imaging performance at lowest cost of ownership. The system is designed to meet key requirements for advanced packaging applications both technically and economically. Its unique scanning exposure technology allows the use of large area photo masks that contain the full pattern image of the substrate which allows the production of non-repeatable features like edge exposure or test die structures. At the same time, a 1:1 projection lens provides high resolution patterning performance combined with a large depth of focus that is required to ensure high pattern fidelity when working with thick resists that are commonly used in advanced packaging or MEMS applications. The system is designed to automatically process 200 and/or 300 mm wafers and is based on a less complex system design compared to traditional step and repeat projection lithography systems that directly translates into lower cost of ownership.
As photolithography is a key manufacturing process and cost contributor, the careful selection of the right exposure solution is mandatory to achieve the best possible cost structure in today’s industrial lithography applications. SUSS Mask Aligner technology is by far the lowest cost exposure solution in the market that provides excellent patterning capability coupled with leading edge throughput. However, emerging applications in the semiconductor industry require increasing resolution and overlay performances that are beyond the physical capabilities of a mask aligner. Up to now the industry had the only selection to switch to expensive stepper technology. With the DSC300 Gen2 and its scanning lithography technology, engineers have an alternative choice of an exposure technology that uses the advantages of full-field lithography, well-known from mask aligners, but extends the capabilities as it provides projection lithography performance at a lower cost point. However, the right selection of the exposure technology requires a deep understanding of the pros and cons of each technology plus a good understanding of the application requirements.

TRENDS AND REQUIREMENTS IN ADVANCED PACKAGING APPLICATIONS

Today a wide variety of advanced packaging technologies exist to meet the different requirements of the semiconductor industry. The leading advanced packages, including chip-on-chip, wafer-level packages, chip-on-chip stacking, embedded IC, all have a need to structure thin substrates, redistribution layers and other package components like high resolution interconnects. The consumer’s constant push for higher functionality on smaller and thinner end devices – like smart phones or tablets – drives the need for next generation packages with finer features at increasing reliability of the package. In addition, cost considerations become more and more important to survive in the competitive landscape for all parties within the supply chain, from chip manufacturer, foundry, assembly and test suppliers to the device manufacturer. Therefore, the industry desperately strives for innovative approaches to lower manufacturing costs coupled with enabling technologies that meet the challenging technical requirements.

A very good example of this trend is the flip chip technology. While solder bumping and single RDL layer technology were mainstream several years back, Cu pillar interconnects and multilayer RDL are considered as one of the main growing application segments for the upcoming years. Cu pillar technology enables fine pitch interconnects needed for the adoption of wafer-level packaging technology for leading edge devices with high I/O count. Figure 1 shows a typical example of the Cu pillar process integration flow. However, the high number of interconnects limited to the chip scale area requires photo lithography of thick resist with almost vertical sidewalls and very good overlay of the pillar, opening to underlying metal pads.

Figure 1 Typical Cu pillar process flow (Source: Yole Development, Courtesy ASE)
The technical requirements of the lithography process define the best available exposure technology to meet the performance but also to provide lowest possible manufacturing costs. Figure 18 shows a typical example of a cost of ownership comparison in a wafer bump application.

**EXPOSURE TECHNOLOGIES IN TODAY’S PHOTOLITHOGRAPHY APPLICATIONS**

Full-field proximity printing and step and repeat projection lithography are the traditional exposure technologies of the electronic industry in applications fields such as wafer-level packaging, MEMS, LED and displays.

**Mask Aligners** (also known as proximity or contact printers) are used for transferring a geometric pattern of microstructures from a full-field photomask to a light-sensitive photoresist coated on a wafer or substrate by exposing with collimated ultraviolet light. The mask and the wafer are aligned to each other and are in close contact or proximity. A mask aligner typically includes an illumination system, a mask stage for aligning the mask and a wafer stage for aligning the wafer.

Contact lithography in theory offers the highest resolution down to the sub-micron range, in the order of the wavelength of the illumination light. However, practical problems such as mask contamination make this process difficult to use for mass production. Proximity lithography, as shown in figure 4, where the photomask and the wafer are physically separated by a typical proximity gap of 20 to 50 microns, is well suited for mass production and achieves resolution down to 3μm on a 300 mm wafer.

The mask aligner is by far the exposure technology with highest throughput available on the market, since one wafer is exposed in a single shot. At the same time these exposure systems are available at lowest capex due to lower equipment complexity compared to projection lithography and UV stepper tools which results in the lowest cost of ownership.
Latest developments in innovative and unique illumination systems for mask aligners allow the optimization of exposure results. As an example, the SUSS MO Exposure Optics, illustrated in figure 5, allows the use of front-end like lithography techniques as illumination shaping, and the use of assistant features on the photo mask, to provide the best possible result.

However, limitations can still arise in cases when thick resist processes require very straight resist sidewalls and when practical overlay requirements reach a level of 1-2 microns or below on 300mm wafers.

**Step and Repeat Projection Systems**, also known in the industry as UV Stepper, have been selected by users whenever they reached the process limitations of mask aligners. The type of a UV stepper is typically defined by the optical layout used. In semiconductor back-end applications today, steppers are either built with 1X or 2X demagnification coupled with a corresponding stepping stage. Depending on the available field size of the optics, the system exposes a certain area of the wafer at a time and performs a step and repeat process to cover the whole wafer area. The main advantages of using a stepper lie in its overlay capability and, when 2X demagnification systems are used, in its enhanced resolution. A 2μm resolution capability with 0.5μm overlay performance is state-of-the-art technology. However, this performance is usually not required for the main applications in wafer-level packaging applications and comes together with higher capex which is typically a factor of 3-4x compared to 300mm mask aligner systems.

Another limitation of a step and repeat system is the limitation of the field size. The maximum die or package size that can be exposed is limited by the lens design itself. The larger the lens design the higher the costs of the lens and the more complex is the optical design to correct for optical aberrations.
The field size that is usable, is limited to be a multiple of a die size, to allow for step and repeat. With the limited usable field size these systems typically require 80 or more exposure steps to pattern a complete 300mm wafer with the corresponding sacrifice in throughput. Furthermore a step and repeat systems cannot expose non-repeated features on a wafer or substrate. For example, flip chip or RDL layers require the exposure of the wafer edge to enable electrical connection of electrodes for the sub-sequent plating processes as shown in figure 7.

Figure 7  Edge exposed substrate for plating electrode connection

To overcome this limitation, UV steppers use either an edge exposure function on the pre-alignment station that further reduces the effective throughput of the exposure tool itself or require additional edge exposure equipment that adds capex and complexity to the manufacturing line.

The DSC300 Gen2 with its Full-Field Projection Scanning technology promises to be the missing piece that offers projection lithography performance, coupled with the advantages of a full-field exposure tool at a lower cost point compared to a traditional UV stepper. This unique exposure concept meets the majority of process requirements and is built on a less complex projection lens design without the requirement of a highly sophisticated step and repeat stage. Figure 8 shows a full field scan exposure setting for the DSC300 Gen2.

Figure 8  Full-field scan exposure setup

The projection scanner uses a 1X catadioptric lens design with a field size of approx. 30x30mm. This area is used to image the features from a full-field mask onto the wafer in a continuous scan process.

Figure 9  Continuous scan operation for the exposure of an entire 300mm wafer

The complete wafer layout, including non-repeated features like the edge exposure ring can be implemented into the mask design. The alignment of the mask to wafer is performed either through on-axis or TTL (through the lens) alignment or by off-axis
alignment, depending on the process conditions. Thermal management of the mask itself has to be considered when operating a 14" soda lime mask to process 300mm wafers.

It is important to understand that mask contamination or intensive mask cleaning is not a requirement or limitation for this full-field exposure technology as mask and wafer are operated with a large separation of about 200mm, shown in figure 10.

**DSC300 GEN2 KEY FEATURES**

The processing of thick resists is very common in Advanced Packaging applications. As mentioned, today’s emerging bump applications require often straight sidewalls to enable a high pin count. However, this requires a high depth of focus (DOF) of the projection exposure tool. The projection scanner technology from SUSS MicroTec provides the optimal combination of high DOF and resolution performance at a reasonable cost level. A flexible and interchangeable NA setting of the system allows the selection of the ideal combination of resolution and DOF. The correlation between NA, DOF and resolution capability of the DSC300 Gen2 is shown in figure 11. In addition, focus adjustments as one of the key process parameters can be used to adjust sidewall performance to the application requirements.

The DOF of the exposure tool also defines the process window when processing highly warped substrates. Wafer bow and warpage becomes more and more an issue when the substrate contains different types of materials with various CTE. New packaging concepts like Fan-Out Wafer-Level Packaging (FO-WLP) use artificial wafer substrates based on compound materials. The trend to thinner packages and wafer can result in significant warpages up to several mm. The effective exposure of these substrates now requires pulling the substrate as flat as possible to stay inside the DOF of the systems. Only then acceptable resolution and CD uniformity of the exposure process can be expected.
Latest developments and improvements show that i.e. eWLB (FOWLP) wafers with initial 5mm bow can be pulled flat down to a remaining high-low variation of <20μm on the exposure station which is well inside the DOF for targeted feature sizes.

Finally, thermal control of the exposure mask during the process is a key requirement for full-field exposure systems. The exposure of a 300mm wafer requires a 14" photo mask that is typically made of soda lime to maintain reasonable pricing while UV steppers use 6" reticles made of Quartz. As soda lime has a much different CTE compared to the typical Silicon substrate, temperature changes result in a run-out effect between mask and wafer. Run-out is a magnification mismatch between the mask and the wafer which would lead to overlay inaccuracies, illustrated in figure 13. Adjustments and tight control of the mask temperature is needed to maintain a minimum runout and high overlay performance.

The DSC300 Gen2 utilizes very effective measures to either cool or heat the mask. This ensures that the system adjusts the level of mask magnification before the first exposure and maintains this level even though high exposure dose processes are performed on the exposure tool (Figure 14).

The final overlay performance on the DSC300 Gen2 for a typical lithography process that requires 300 - 1000mJ/cm² is in the range of 1 - 2μm which meets the application requirements (Figure 15-17).
The features of the DSC300Gen2 can also be applied to achieve overlay targets for Fan-Out-Wafers, where dies may be shifted due to runout effects during the molding process or die position variations occur due to pick-and-place-robot accuracy. The closed-loop mask heating and cooling allows compensating for up to 30ppm runout (this corresponds to ~5 μm die shift on a 300 mm wafer). In addition, an averaging algorithm applied to multi-point alignment data allows the system to perform best fit overlay of the full-field mask to the wafer. A third method to achieve good overlay results for Fan-Out-Wafers, that is only applicable for full-field masks, is the use of a biased mask, which is an efficient way in case the placement pattern on the wafer is repeatable and known.

**COST OF OWNERSHIP CONSIDERATIONS**

The reduction of manufacturing costs and optimization of the equipment park is a key topic in every modern fab for semiconductor devices and packaging services. Therefore cost effective equipment that meets the technical requirements but is not over engineered is a key to maintain profit margins and to grow market share. Depending on the process requirements a careful selection of the exposure technology helps improve the cost structure. A cost of ownership comparison between the different selections should help to demonstrate the cost impact that come along with each of the technologies (industry example shown in Figure 18).

Obviously the mask aligner technology provides the best CoO due to the low capex required and high throughput. The SUSS DSC300 Gen2 with its superior technical properties still offers a ~50% cost advantage over a traditional UV Stepper. This additional alternative helps users to lower their manufacturing costs for the majority of today’s processes and ensures availability of existing UV steppers for more critical layers.

**SUMMARY**

With the DSC300 Gen2 projection scanner, SUSS MicroTec offers an alternative exposure solution to UV steppers that provides projection lithography performance coupled with the advantages of a full-field exposure system. The system is designed to extend the mask aligner capabilities and to address the unique challenges of emerging packaging applications at lowest cost of ownership within the projection lithography equipment market.

The projection scanning technology is available in two different equipment models to address different substrate sizes. The SUSS DSC300 Gen2 is capable to run up to 300 mm wafers while the SUSS DSC500 is designed to process substrates or panels up to 450x500 mm.
Typical Exposure Results:

**Figure 19** DSC300 performance using TOK TMMR P-W1000T, 3μm L/S, 7μm thick

**Figure 20** DSC300 performance using TOK-PMER-CR4000, 80μm via with side wall angle ~87°

**Figure 21** DSC300 performance using HD PBO 8820, 20μm via, 10μm thick

**Figure 22** DSC300 performance using AZ4620, 20μm via, 10μm thick

**Figure 23** DSC300 performance using AZ4620, 20μm via and wafer-to-wafer/within wafer uniformity

Ralph Zoberbier graduated in Precision Engineering and Microsystems Technology from the University of Applied Sciences in Nuremberg. He joined SUSS MicroTec in 2001 as R&D Project Manager. In 2005 he became International Product Manager Aligner. From 2010 – 2014, he led the Aligner Product Management team as Director Product Management. With the acquisition of Tamarack Scientific Inc. his responsibility was extended by complementary projection lithography and laser process technology. In 2014 he was appointed to General Manager Exposure and Laser Processing. Ralph gained his MBA degree in Entrepreneurship at Louisville University, Kentucky.