"Structured-Illumination-MAcroscopy"(SIMA) for high speed electronic inspection

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For high-speed electronic inspection, 3D metrology faces the challenges of extremely high space-bandwidth-speed-product (# voxels/sec) and at the same time high accuracy. To meet these requirements, we introduce a novel scanning method which enables Structured-Illumination-Microscopy (SIM) to measure macroscopic objects with high speed without sacrificing accuracy.

1 Introduction

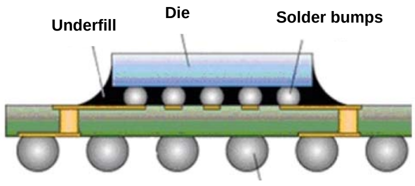

Fig. 1 wafer- and IC-packaging with flip chip.

Flip chip with solder bump array is the standard solution to package the wafer and integrated chip to external circuits, as illustrated in Fig. 1. During the automated packaging process, the lithographically produced wafer should be firstly interconnected to the pins of an intermediate chip with first-level solder bump array. Subsequently, the entire chip will be soldered to an external circuit with second-level solder balls. To ensure high packaging quality, the heights of all solder bumps and balls have to be individually inspected prior to the soldering process. Besides the necessary submicron accuracy, the bumps have to be 3D inspected with an extremely high speed (e.g. $40cm^2/s$ at a 5 µm lateral resolution). The corresponding space-bandwidth-speed-product of a 3d sensor is around 10^8 3d points/sec.

As the bumps can display both rough and specular surface finish, only few 3d methods, such as White-Light Interferometry (WLI), confocal microscopy and Structured-Illumination Microscopy (SIM) [1], are suited for this application. However, WLI and confocal microscopy are slow, in principle. WLI has to acquire the correlogram with a very small depth sampling distance (~ 100nm). Confocal microscopy is a point-wise method and needs both depth- and lateral scan. In contrast, SIM is inherently faster, because it is parallel in x- and y-direction and needs (at least) only three sampling points within the full-width-half-maximum of the depth signal. Moreover, SIM uses a spatially and temporally incoherent light source, so it is less prone to speckle noise on rough surfaces, compared to confocal microscopy. Due to these advantages, SIM appears to have the biggest potential to meet the requirements of high-speed bump inspection with respect to the speed and accuracy. In this paper, we will discuss options which enable SIM to approach the space-bandwidth-speed requirements.

2 Classical SIM with "stop-and-go" z-scan

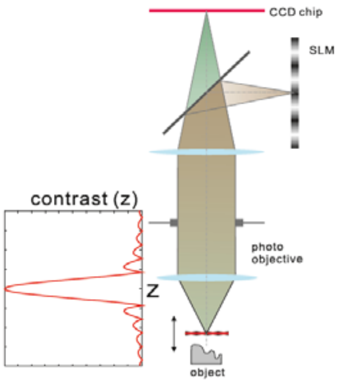

*Fig. 2 setup of **S**tructured-**I**llumination **M**icroscopy (SIM).*

SIM is an active focus searching method. As illustrated in *Fig. 2*, a sinusoidal grid is projected onto the object by imaging with a conventional bright field microscope. The focus plane of the observation is confocal with the projection. While scanning the object in z-direction, at least three phase shifted grating images are necessary at each z-position to calculate the "contrast curve" from which the height can be calculated. The needed three exposures at each depth position prevent from scanning continuously and the z-scan is quite slow due to the "stop-and-go". To solve this problem, several methods have been discussed, which still have some limitations. In [2], only two exposures are necessary by using the first derivative of the intensity as additional information which still does not allow for a continuous z-scan. The method described in [3] can get rid of "stop-and-go" by calculating the gradient of a travelling multi-line pattern, but it needs neighborhood information (not

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local) and can reduce the lateral resolution. In order to get rid of “stop-and-go” without any tradeoff, we still need a better solution.

3 Continuous z-scan with “travelling grating”

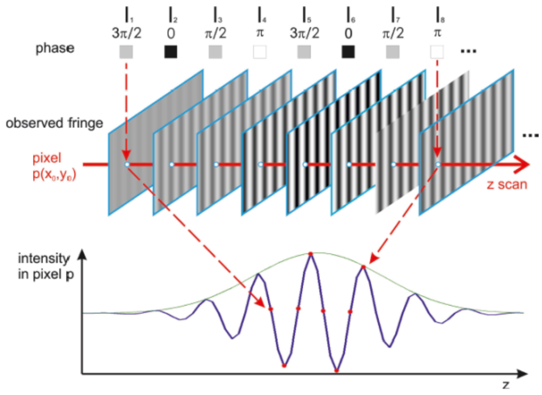

Fig. 3 continuous z-scan with “travelling grating”.

As illustrated in Fig. 3, in [4] we introduced a novel depth scan method where we adapted the phase shift method to allow for a continuous movement in z-direction by using a travelling sinusoidal pattern. This method can improve the measurement speed by a factor of 20. However, for the application of high-speed bump inspection, due to the limited space-bandwidth-product of the objective we have to extend the FOV by lateral stitching. The inevitable “stop-and-go” of lateral stitching still strongly limits the measurements speed.

4 Lateral scanning SIMA without z-scan

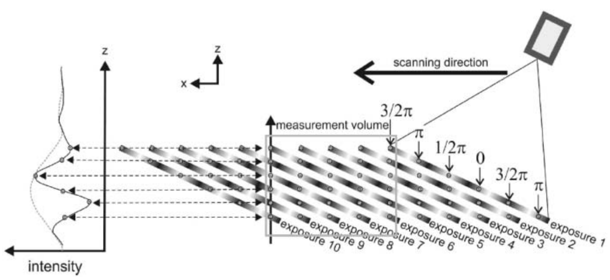

*Fig. 4 lateral scanning **S**tructured-**I**llumination **MA**croscopy (SIMA).*

As a solution, we extended the method mentioned above and avoid the z-scan completely. We further achieve a continuous lateral scan of the object in one direction. By this strategy, the measurement speed is only limited by the camera speed and not by the mechanics.

As illustrated in Fig. 4, a static sinusoidal fringe is projected onto the focal plane of the imager. The key trick is to tilt the focal plane to cover the entire depth range and to move the object laterally through the focal plane. The lateral step size should be carefully selected so that each object point will be sequentially illuminated and observed with phase 0, $1/2\pi$, π, $3/2\pi$ ···. After data acquisition, the acquired images have to be virtually pipelined backwards to generate an intensity stack. The intensity signal in each pixel of this stack will show a modulated signal as in the method of section 3, where the contrast curve is encoded in the envelope as well.

If several lateral scanning systems are placed in parallel, we can continuously scan the sample with arbitrary size, without taking care of the acceleration and stabilization of mechanics as well as the limited FOV. This concept can be demonstrated by a measurement example shown in Fig. 5, where a BGA chip with size of 22x22 mm^2 is measured with 7 lateral scans stitched together.

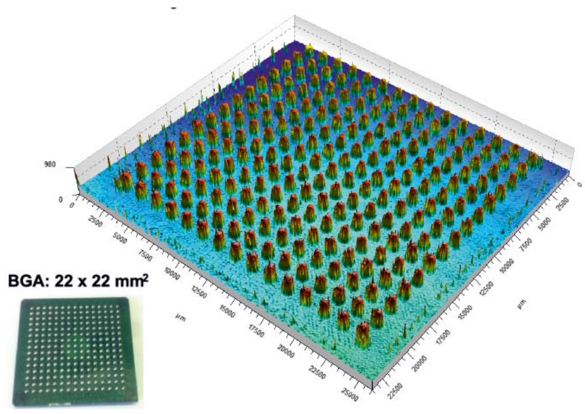

Fig. 5 BGA chip measured with seven lateral SIMA scans. The FOV of the objective is only 4.9x3.6 mm^2.

5 Conclusion

By using the introduced lateral scanning method, we can avoid the z-scan and realize a continuous line-scan mechanism for 3d acquisition. Specially, for high-speed bump inspection the desired space-bandwidth-speed-product and a high accuracy can be achieved at same time by parallelization of several systems and faster electronics, rather than by purchasing an expensive objective and faster mechanics.

References

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