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OPTICAL PROFILOMETER FOR QUALITY CONTROL OF SOLDERING JOINTS

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Abstract: A low cost 3D non–contacting profile scanning method for both specular and diffuse reflecting surfaces will be presented. The resolution in $x-$ and y–directions is about 650 nm and 1 µm in out of plane direction. The method is based on a commercially available CD pickup head. The CD pickup head will be driven in a way that the error of focus signal is used for an out of plane measurement (optical profilometer). Theoretical relations as well as measurement results will be shown in this proposed paper.

Keywords: optical profilometer, non–contacting measurement, optical inspection technique

1. INTRODUCTION

The semiconductor industry produces ever smaller package sizes for integrated circuits with more and more I/O pins. Therefore the surface mounted device technology was introduced (ball grid arrays) and in this technology the connection between pin and printed circuit board is done by small solder beads. These solder beads are arranged in a regular grid. During reflow soldering the solder balls melt thus connecting the IC to the printed circuit board. To further reduce the size of the packages ever smaller ball grids are introduced thus requiring an ever increasing demand for optical quality control.

Due to the fact that varying heights of the solder beads over the planar surface might degrade bonding quality seriously their evenness has great impact on the contact quality. The optical measurement of the solder beads profile is a necessary quality assurance step before soldering. There are several methods proposed in literature. [1] and [2] use an image of the device under test taken under an oblique angle to cast shadows that are evaluated. This allows for an error detection of oversized, undersized, deformed or missing solder beads and their pitch and offset. By using the threshold method of [3] the image information of solder beads and printed circuit board will be separated and further processed.

Theoretically the height information of the solder beads can only be obtained by an oblique illumination or viewing. Therefore in [4] it is proposed to illuminate the sample under an oblique angle between the optical axis of the camera and the surface normal of the reflective specimen. In this case the length of the shadow cast will be used for height calculation of the solder beads. The illumination of the solder beads in a number of different directions can be used for an improvement in the height estimation. The disadvantage of those methods can be seen by the limited spatial resolution and rather limited frame rates. Another approach is presented in [5] where the frequency–shift moiré fringe technique is accomplished with three light sources creating fringes that are subsequently processed accordingly.

A further possibility of optical inspection is described in [6] where a laser vision system is used and the whole chip is scanned. [7] uses a Twyman Green interferometer and by varying the wavelength of a tuneable laser source the height of the solder beads can be evaluated by a phase shifting algorithm. The problem of this algorithm is the ambiguity of steps which are higher than the wavelength of the illuminating laser source.

The measurement principles described above are suitable for an inspection of the solder beads before reflow soldering. A further group of inspection methods using two–dimensional [8] or three–dimensional [9] X–ray laminography for detecting inner structures and defects of the soldered chip on the printed circuit board. [10] uses X–ray cross sectional images from a digital to-

mosynthesis to classify the various defects of the soldered chip.
In this paper a low cost method will be presented which uses a simple CD pickup head. The measurement principle is not suitable for tomographical inspections because only the surface will be scanned. Deduced from this measurement the classification of the solder beads will be done. First measurements have shown a rather good resolution in the µm range.

2. THEORY AND MEASUREMENT PRINCIPLE

The basis of this measurement principle is a commercially available CD pickup head. This CD pickup head is the key component of a compact disc drive and originally reads out data from an optical storage medium. For this purpose the laser beam emitted by the semiconductor laser is focussed by the main lens. To accomplish that the reflection of the laser beam at the data layer of the CD is taking place in the focal plane of the main lens, the lens' perpendicular position is adjusted by the so called voice coil motors. Further control mechanisms for keeping track on a CD are implemented in a CD drive but are not essential in this contribution. In Fig. 1 the components of a CD pickup

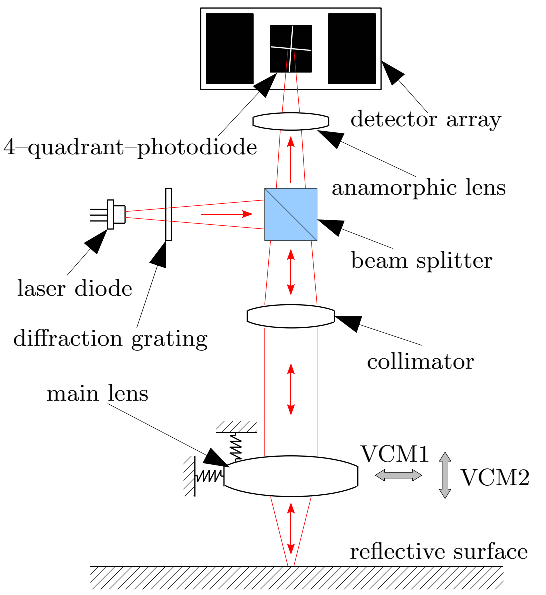

Fig. 1: Schematic of the CD pickup principle operating in a compact disc.

head and the basic functionality of the device are shown. The laser emits a beam which is directed at the beam splitter towards the focusing lens. This lens focuses the beam on the reflective surface of the device under test. The main lens can be traversed by two voice coil motors VCM1 and VCM2 as seen in Fig. 1. VCM1 moves the lens perpendicular to and VCM2 along the optical axis. The position of the lens can be controlled via the drive voltage of the voice coil motors. The reflected light is again collimated by the main lens and subsequently illuminates the 4–quadrant–photodiode after passing the beam splitter again and the astigmatic lens. Reflecting surface positions out of focus of the asymmetric lens causes an uneven illumination of the 4–quadrant–photodiode that can be evaluated. The photo of the CD pickup head shown in

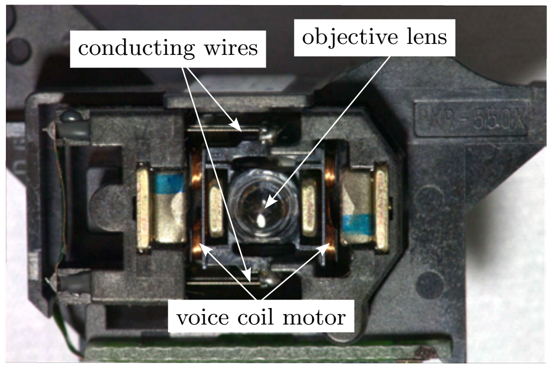

Fig. 2: Photo of the pickup head PXR–550X used in a compact disc drive. The main lens in the middle is mounted on the voice coil motors where the four coils can be seen. The electrical connection is done by wires which also act as mechanical springs. The resulting spring force is the antagonist of the electromagnetic force of the voice coil motors.

Fig. 2 is taken from the back side of the pickup so that the main lens as well as the four coils of the voice coil motors can be seen. The horizontal conducting wires above and below the main lens have two functions. They are connections to the voice coil motors and also act as mechanical return springs for the main lens. The travel in x–direction is limited mechanically to approximately ± 0.5 mm with a sensivity of 0.8 mm/V. The sensivity of the voice coil motor for the vertical direction is 1.1 mm/V and the maximum travel is about 1 mm. In Fig. 3 the detector array is shown. The two black rectangles on the left and right hand side (E and F) are used for the optical track guiding system, they are not used here. The first order diffraction of beams will be registered and because of the differential signal the position over the track can be controlled. The optical focusing and data reading process will be done by the 4–quadrant–photodiode which is the rectangle indicated by A,B,C and D in the center of Fig. 3. The focus error signal FES can be calculated by

$$FES = (A + C) - (B + D) \,. \qquad (1)$$

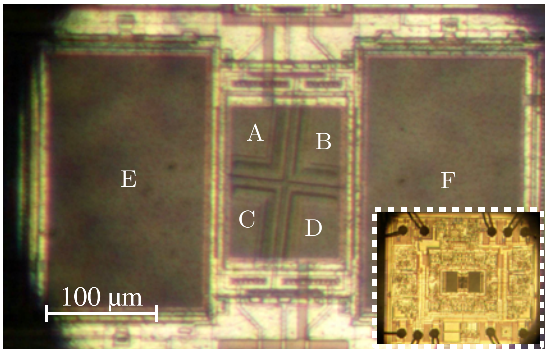

Fig. 3: Detector array of the pickup head PXR–550X. The photodiodes E und F are used for the optical track guiding system. The four quadrants A,B,C and D of the 4–quadrant–photodiode is used for focusing and optical data reading.

Because of the anamorphic lens in the optical path the distance and direction of the defocusing can be calculated as described in detail in [11].
During the measurement the CD pickup head is used in a slightly different way as compared to the data reading process in the compact disc drive. The two photodiodes for the tracking system are not used in our system. The CD pickup head is mounted rigidly and the sample will be positioned by two orthogonal linear stages. Therefore in plane movements of the main lens orthogonal to the optical axis cause errors at the positioning of the sample. To avoid or attenuate such movements the voice coil motor was shorted and in case of movements a magnetic force will be superposed to the mechanical force of the spring. A triangular drive voltage needs to be applied to the VCM2 so that the main lens is moving along its optical axis (out of plane movement) with constant velocity. So in every cycle the focal plane is crossed twice, once while moving up and once while moving down the lens. Also a sawtooth–type control voltage was used because it would allow higher sampling rates but a lot of deteriorating mechanical vibrations happened to the measurement setup and this idea was therefore rejected.
For evaluation of the acquired data the summed up signals I_A, I_B, I_C and I_D of the 4–quadrant–photodiode were used because this method delivers better results in weakly reflecting areas of the specimen's surface than using the focus error signal directly. The intensity of the sum signal of the 4–quadrant–photodiode becomes a maximum when the reflective surface is placed exactly in the focal plane of the lens. From the drive voltage of the voice coil motor the relative height information can be inferred.

3. MEASUREMENT SETUP

Fig. 4 shows a photo of the measurement setup and Fig. 5 shows the correspondending schematic. The nominal position of the main

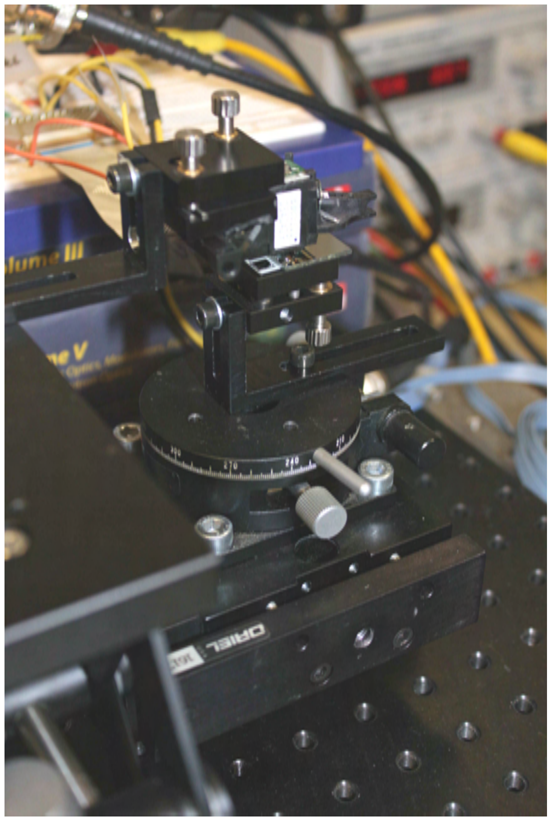

Fig. 4: Measurement setup for optical quality control of a reflecting surface by using a CD pickup head.

lens is transferred into a voltage of the voice coil motor, calculated on the PC, output by a data acquisition device containing an analog output, amplified by a power amplifier and applied to the voice coil motor. The data acquisition card also measures the signal levels of the four segments of the 4–quadrant–photodiode as well as their sum. The acquisition rate of all the signals in parallel is 6 kHz with 16 bit resolution. Both high sampling rates as well as a high resolution are necessary for reaching the theoretically achievable resolution of the height information.
The bandwidth of the drive voltage of the voice coil motor is 10 Hz and is thus as close to its mechanical cut–off frequency [12] as possible. Additionally a power amplifier is used since the data acquisition card can not deliver sufficient current to drive the voice coil motor (with high fidelity) directly. There is a difference between the nominal position and the current position of the voice coil motor due to mechanical inertia. Therefore only the rising voltage ramps were

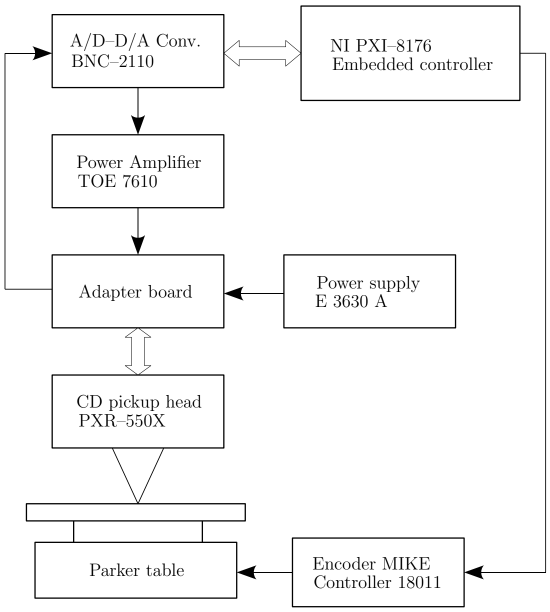

Fig. 5: Measurement setup for optical quality control of a reflecting surface by using a CD pickup head.

used for the evaluation of the height information. For a further evaluation the compensation method for the hysteresis error by [13] will be implemented. The device under test is fixed on a 2D linear translation stage so that the specimen can be scanned line by line. The entire measurement setup is placed on an air–damped table to reduce the impact of mechanical vibrations caused by the environment.

4. MEASUREMENT RESULTS

The device under test is an integrated circuit package with 72 solder beads placed in a square along the edges, shown in Fig. 6. The diameter

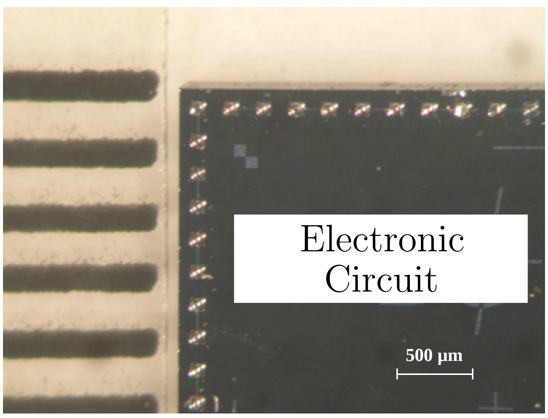

Fig. 6: Picture of the device under test for optical inspection. On the left hand side one can see a ruler with a scale division of 0.5 mm in comparison.

of the balls is about 120 µm assembled on solder pads, sized 120 µm × 120 µm square. The chipsize is 4.5 mm × 4.5 mm and the chip is held fixed by a double–faced tape on the measurement setup so that the solder beads are facing towards the CD pickup head. In Fig. 7 the image obtained by the processed measurement data is depicted. For better visibility only a detail of the measurement result is shown. Besides the solder beads one can also identify the solder pads and the connections between the solder pads. The well resolved topographical height in-

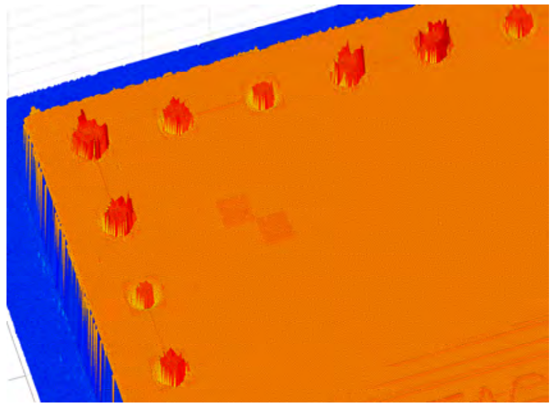

Fig. 7: Measurement results of the focus error measurement by using a CD pickup head.

formation of the solder pads as well as the connections between them are about 10 µm. One can also clearly identify the chamfer on the vertical side of the chip (on the left of Fig. 7). At the horizontal side the chamfer is superposed with a small jitter that can be discerned and which is attributed to the PC not running a real time operating system. The measurement principle is theoretically only reasonable for reflecting surfaces oriented perpendicularly to the optical axis. If this requirement is not met systematic errors might occur. In Fig. 8 a zoomed in view of the solder beads is shown where the angle between the optical axis and the surface normal is unequal zero. The encountered systematic error depends on the obliqueness of the surface as compared to the optical axis. To solve this problem further calculations and measurements are necessary and will be done.

5. SUMMARY

A measurement principle for determining the topography of reflecting surfaces in the µm range was proposed. The principle is very simple and basing on a commercially available CD pickup head normally used in a compact disc drive. The light of the laser diode is diffracted, directed and focused by the main lens on the probe. The

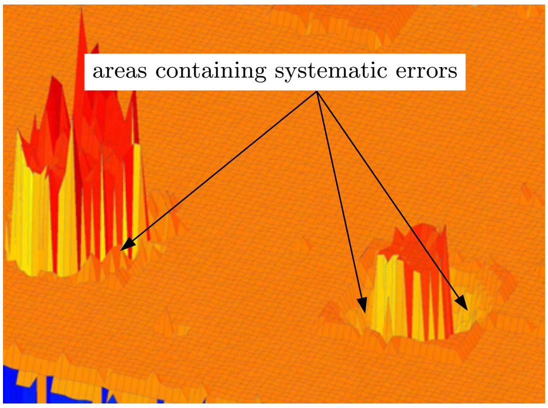

Fig. 8: Detail of the measurement results showing two solder beads. The height information of the steeply sloping areas of the solder beads contains a systematic error.

focus error can be evaluated from the signals of the 4–quadrant–photodiode. The measurement of an electronic circuit with solder beads shows good results. Also, height differences in the µm range can be measured properly. Further work will base on a better evaluation of the signals of the inclined regions of the solder beads.

6. ACKNOWLEDGEMENT

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