

VISUALIZATION OF PACKAGE INDUCED DEFORMATION OF INTEGRATED CIRCUITS

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ABSTRACT

Microelectronics makes live easier and safer. In modern automobiles micro electronic power devices are used increasingly to control the engine of the car and elevate the safety and comfort of its driver. But the increasing implementation of car electronics makes the vehicle also vulnerable to microelectronics failure. During his life a car is usually subjected to all kinds of environmental changes like differences in temperature and humidity or mechanical stress, therefore, electronic components need to have a reasonable robustness in order to match the longevity car.

A major reason for microelectronics failure is due to the way these components are fabricated: Within a microelectronic component containing an integrated circuit (IC) the interconnect structures establish a link between switching entities of the silicon chip and the component's outer pins designated to become soldered to a printed circuit board (PCB). The mechanical interaction between package and chip induces deformations which may become starting points of mechanical flaws [1-3], and hence bears the risk of passivation cracking over the metal lines and therefore the failure of the device because of corrosion. The knowledge of the real deformation of the chip is essential for calculations and predictions concerning nano fracture mechanics and hence to develop a device package with minimized IC deformation.

To visualize the real deformation of the chip (the thin Silicon crystal) we developed a new inspection method at the materials research beam line (BAMline) [4] at the Berliner Synchrotron Radiation Source BESSY. The method – Synchrotron Laue Contrast Radiography (SLCR) – is based on the coherent scattering of monochromatic synchrotron radiation by the net planes of the silicon single crystal of the electronic device. It can be considered as a new powerful inspection method to evaluate even minute degradation processes in electronic devices, which is an essential for any prognostic reliability work in the future.

INTRODUCTION

Within micro electronic power devices the integrated circuit (IC) is laid out as switching modules on a thin Silicon single crystal, encapsulated in epoxy resin and soldered to a copper sheet metal for cooling purposes. Temperature fluctuations lead to a flexural load of the Silicon crystal due to different thermal expansion coefficients of the constituent materials. The main reason for deformation of the chip is the layered structure of the overall system chip and package. To spread the heat from the chip switching currents of up to 1A the silicon is soldered at 328°C by lead on a copper heat slug (the use of lead is regulated by ROHS [4]). Cooling down to room temperature the shrinking copper will distort the thermally more inert silicon chip. In a similar way a mold compound is used to fix and to cover the construction. It is processed at 175°C as a liquid which shrinks and hardens after cooling down. As these interactions of different materials and temperatures influence the stability of the device, modern quality and reliability development ask for the degree of these interactions. The knowledge of the real deformation of the crystal is essential for the proof of Finite Element Method (FEM) calculations and

the associated predictions concerning nano fracture mechanics and hence to develop a device package with minimized IC deformation.

EXPERIMENT

To explore the final shape of the whole chip the micro electronic device is placed in front of a CCD camera system (pixel size $14.4\ \mu\text{m} \times 14.4\ \mu\text{m}$) and irradiated by a parallel and monochromatic beam (55keV) delivered by the Double Multilayer Monochromator (DMM) of the BAMline, which is furnished with synchrotron radiation by a 7 Tesla Wave Length Shifter (7T WLS). The surface normal of the chip is parallel to the beam axis and the beam cross-section covers the entire chip (fig. 2, left).

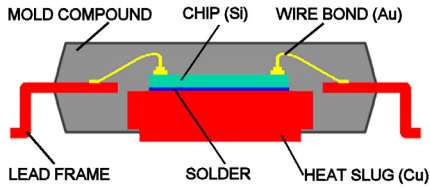


Fig. 1: Cross-section of a micro electronic power device.

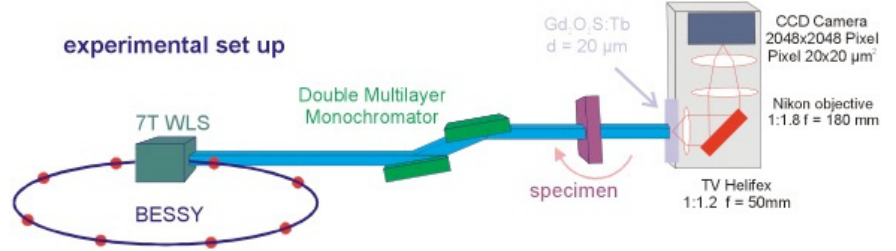


Fig. 2: Experimental set up for SLCR measurements at the BAMline.

The measurement is performed by rotating the device around an axis while recording in parallel the radiographs of the device. The axis is oriented perpendicular to the beam. In most cases the CCD camera displays the radiograph of the absorbing gold bonding wires (fig. 3, left). But for specific orientations of the device dark bands across the silicon crystal become visible (fig. 3, right).

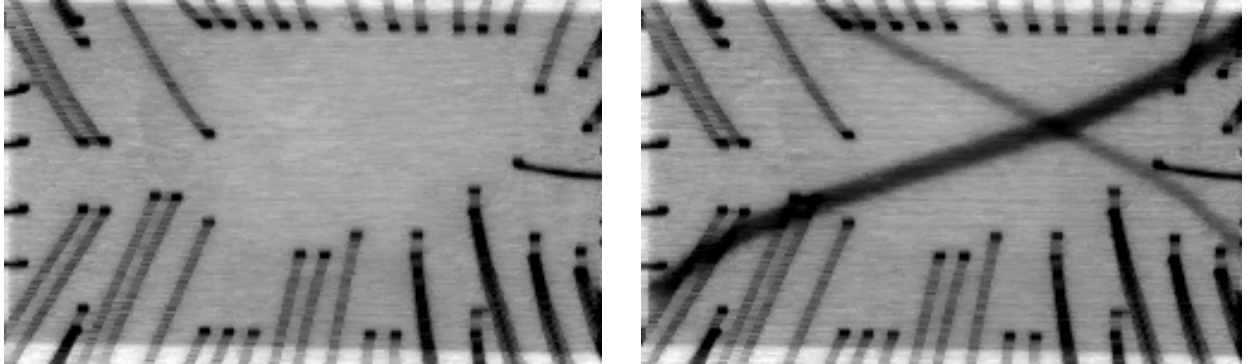


Fig. 3: Radiograph of the bonding wires, (left) without and (right) with dark bands, respective

The observed phenomenon can be explained with the help of fig. 4. X-rays will be deflected by a single crystal if d (the spacing between the planes in the atomic lattice of the single crystal), λ (the wavelength of the synchrotron beam) and Θ (the angle between the incident beam and the scattering planes) fulfil the Bragg condition $n\lambda = 2d \cdot \sin(\Theta)$. For a perfectly flat single crystal the condition is fulfilled across the entire crystal simultaneously (fig. 4, left). Thus the whole radiograph becomes dark (pseudo absorption), but not because of absorption. In flexural loaded single crystals the scattering planes are distorted. Thus the Bragg condition is only fulfilled in some local areas of the crystal (fig. 4, right).

This leads to more or less small dark bands in the radiograph (local pseudo absorption, fig. 3, right). The shape and the width of the local pseudo absorption bands depend on the shape and the radius of curvature of the flexural loaded crystal, respectively. By rotating the curved crystal the dark bands are moving across the radiograph. The measurement of one device takes a few minutes, so that e.g. time dependent (temperature) experiments can be performed.

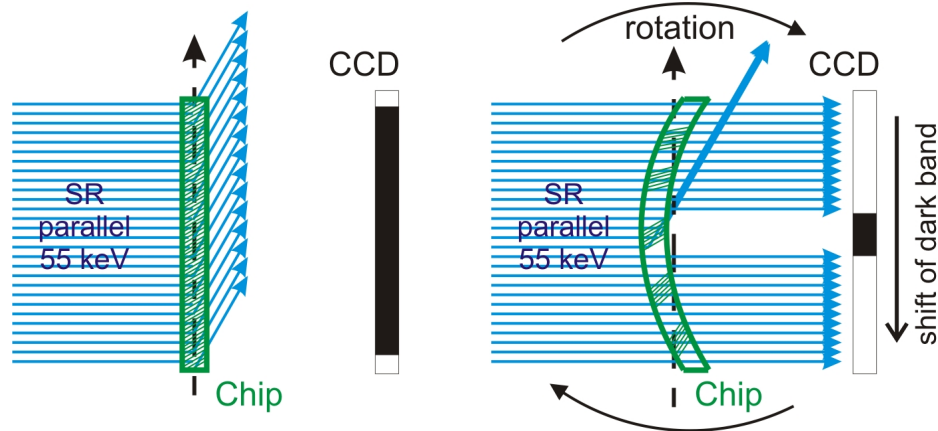


Fig. 4: Illustration of the pseudo absorption of single crystals. Left: x-rays are deflected across the whole flat single crystal due to diffraction. No x-rays arrive at the detector (the radiograph would be dark). Right: for curved crystals the Bragg condition is only fulfilled in local parts. This leads to dark bands in the radiograph (local pseudo absorption, see fig. 3, right). The position of the dark band can be moved by rotating the crystal.

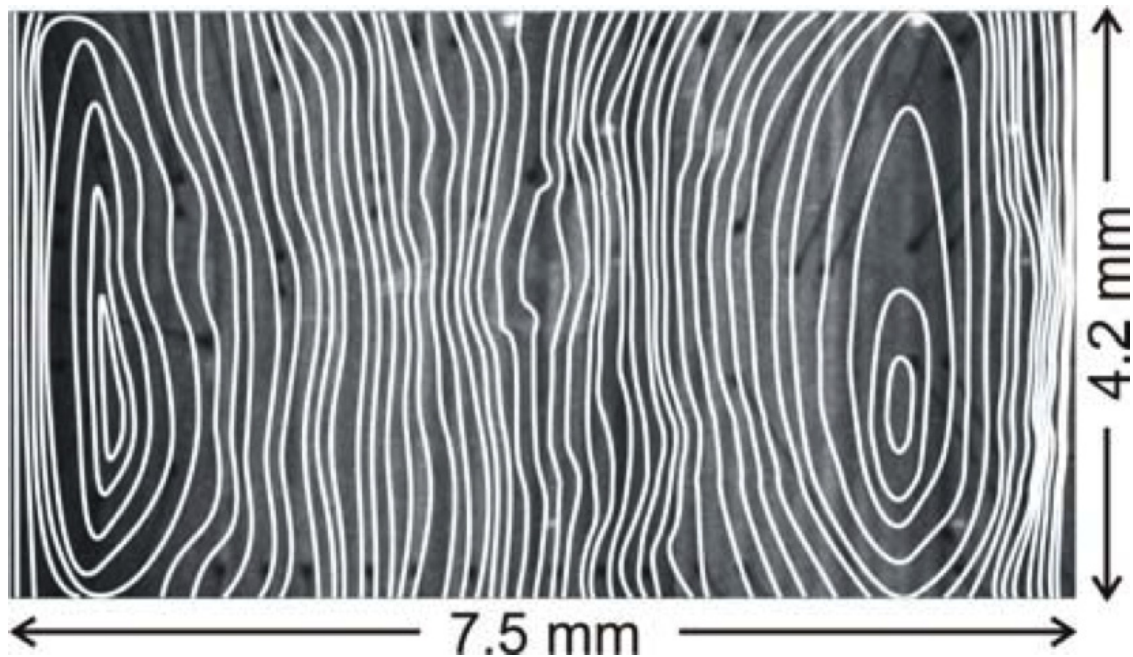


Fig.5: Aggregation of all dark band positions (isoclines) during rotation (angle range 0.11° , step width 0.001°). In the background the radiograph of the chip is shown. In the centre part of the radiograph a lead void is visible by the brighter grey coloured area

The measurement of the electronic devices (photon energy 55 keV ($\lambda = 0.022$ nm), angle scan range 0.11° , step width 0.001°) yields a series of dark band positions (isoclines) across the whole crystal. They are aggregated in a 2D plot (fig. 5). The isoclines density represents the local radius of curvature of the crystal. It typically ranges between 5 m and 50 m (the higher the density the smaller the radius of curvature). A 3D surface profile of the flexural loaded Silicon crystal can be derived from the 2D isoclines plot with a very high resolution of about ± 1 nm in height (fig. 6).

RESULT

The 3D surface profile of a chip just after packaging is shown in fig.6, left. As mentioned above, the temperature dependent shrinkage of the heat slug, which is situated beneath the profile, exceeds that of the chip and the mold compound. This leads to a smooth convex shape of the chip. The amplitude between the minimal and maximal height is about 1500 nm, which may not harm the functionality of the electronic device. A second device was measured after a stress treatment of 1000 temperature cycles from -55°C to $+150^\circ\text{C}$. The result is shown in fig.6, right. The shape has changed to a more irregularly profile (like a magic carpet) with a reduced height amplitude of about 300 nm. This is explained by a partial loss of the adhesive strength between the package and the chip caused by degradation e.g. of the solder during stress treatment.

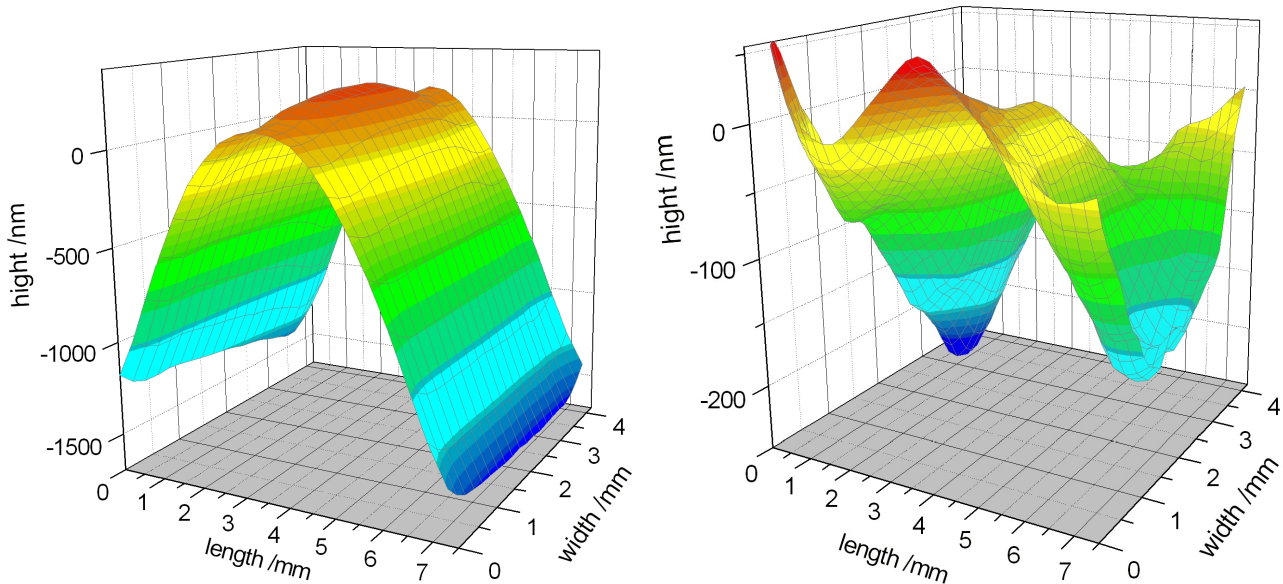


Fig. 6: 3D surface profiles (lateral resolution: $14.4\ \mu\text{m} \times 14.4\ \mu\text{m}$, height resolution: ± 1 nm) deduced from the isoclines plots (fig. 5). The Cu heat slug is situated beneath the profile. Left; chip just after packaging, right; chip after a stress treatment of 1000 temperature cycles from -55°C to $+150^\circ\text{C}$.

It remains, however, to ask for the limit of detect ability of more minute mechanical influences of the package. Thus, we choose the following influences:

- Gold wire bonds
- Voids within the solder die attach to fix the chip to the copper heat slug
- Higher order influences

A void was found within the lead solder from X-ray absorption radiography (background of fig. 7, left). The SLCR measurement discovers the mechanical effect of the gold wire bonds and the lead solder void on the surface of the silicon crystal impressively (fig. 7, left, distorted local pseudo absorption

isoclines). Fig. 7, right shows the residual 3D surface profile of the crystal where a parabolic underground was subtracted. Notice, the height range is only within 10 nm. Finally even higher order effects such as interaction between void and bonding wires can be detected. From these results SLCR can be considered as a new powerful inspection method to evaluate even minute degradation processes in electronic devices. This is an essential for any prognostic reliability work in the future.

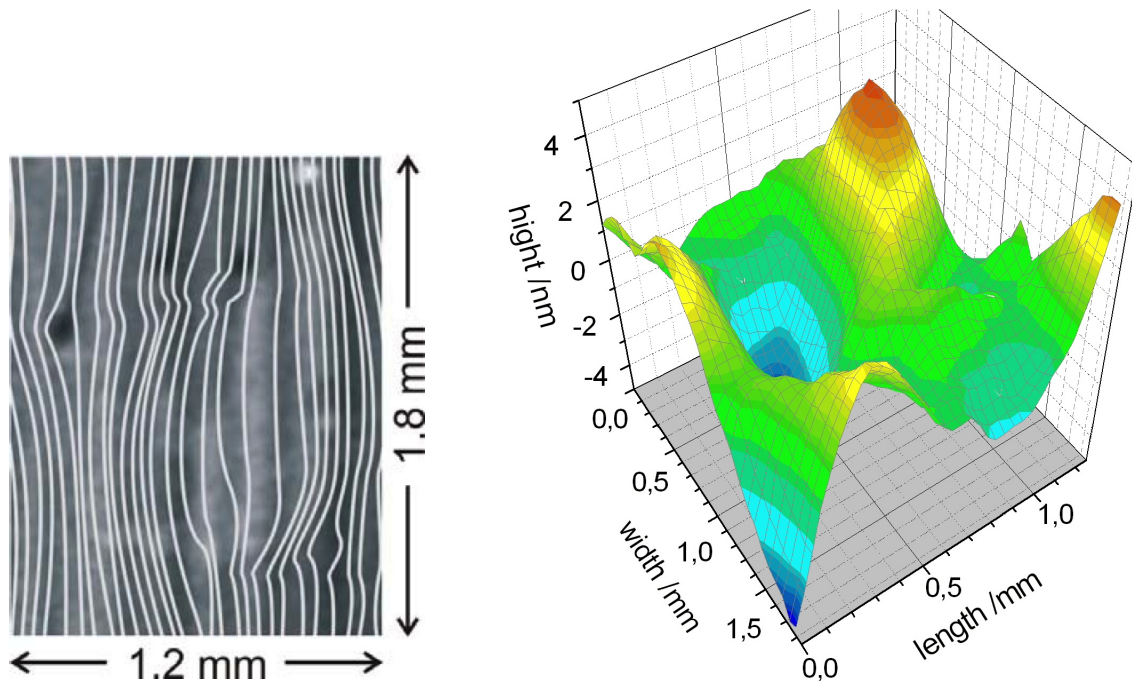


Fig. 7: left: Detection of a void in the lead solder by x-ray absorption (heightened centre part of fig 5). The SLCR measurement discovers the impact of the gold wire bonds and the lead solder void on the silicon crystal, left: 2D plot of the local pseudo absorption isoclines, right: 3D surface profile deduced from left plot. A parabolic underground is subtracted.

References

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