X-ray imaging of silicon die within fully packaged semiconductor devices

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We present X-ray Diffraction Imaging (Topography) measurements of die warpage and thermal strains at individual devices, *in operando*, within fully packaged silicon devices. Using synchrotron radiation, warpage in devices within commercial micro Quad Flat No-Lead (uQFN) format packages has been measured as a function of position from the deformation and displacement of the section topograph position and diffraction stripe under white beam and monochromatic conditions respectively. The Microchip PIC16LF1827 microcontroller shows a simple quadratic displacement with respect to position across the 2.1 mm square silicon die. Displacements in an interconnected die stack of three 50 µm thick and one 200 µm thick pieces of silicon are much more complex, the three thin die showing both convex and concave curvature as a function of position. Relaxation on heating, at the same position across the die, in an Analog Devices AD9253 uQFN analogue to digital converter chip is illustrated in Fig.1. Note both the flattening and displacement of the image, towards the straight line seen for an undistorted crystal, relating in the figure to the horizontal and vertical warpage respectively.

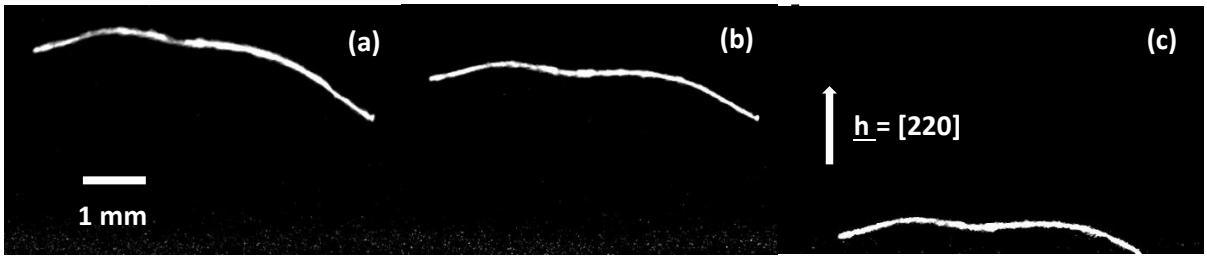

Fig. 1 Section topographs from the centre of an AD9253 die at (a) 50°C (b) 150°C (c) 200°C. 220 reflection

We present measurements taken on Bruker JV Sensus and JV QC-TT X-ray Diffraction Imaging tools, showing that, using a quasi-monochromatic divergent beam, similar warpage mapping can be made on a timescale of minutes, compatible with in-fab off-line monitoring.

In operando measurements of the thermal strain around individual transistors, in an LM3046 Small Outline Integrated Circuit (SOIC) packaged device of total thickness 1.5 mm, were undertaken under accelerated ageing conditions of high-power load. Fig. 2 illustrates the increase in strained area around the n-p-n transistor under increasing power and subsequent failure. The asymmetry in the length of the intense (white) direct image, in this device linear with power load, appears to be associated with the device behaviour, rather than being a diffraction effect. Simultaneous measurement of the package surface temperature during these measurements permits the deduction of the local component temperature from the extent of the contrast in the X-ray image.

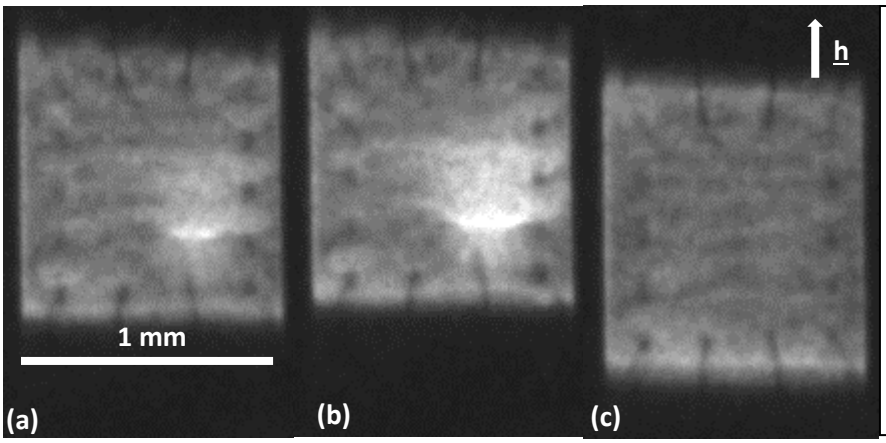

Fig 2 Diffraction images of strains at a packaged transistor under (a) 1.8W, (b) 2.4W load and (c) after short circuit failure. Silicon die is 400µm thick. Diffraction vector h = [220]

B.K.Tanner, A.N.Danilewsky, R.K.Vijayaraghavan, A.Cowley & P.J.McNally, 2017, *Non-destructive X-ray diffraction measurement of warpage in silicon die in integrated circuit packages*, J Appl Cryst., **50**, 547–554.
B. K. Tanner, R. K. Vijayaraghavan, B. Roarty, A. N. Danilewsky & P. J. McNally, 2019, *In-Operando X-ray Diffraction Imaging of Thermal Strains in Packaged Silicon Devices*, Microelectronics Reliability, **99**, 232-238.