X-Ray Diffraction Reticulography for the Non-Destructive Analysis of Deformation and Strain Fields for Silicon Indents and Packaged Integrated Circuits

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CMOS manufacturing of Integrated Circuits (ICs) is becoming ever more complex and expensive. In parallel, the requirement to minimise device failure is becoming more stringent. Future advances in modern nanoelectronics will depend more than ever on early diagnosis of defects and other manufacturing flaws. These might take the form of cracks/indents in silicon wafers - which might lead to wafer breakage - , or could be stress/strain, warpage, delamination or voiding inside the advanced packaging of ICs.

This study examined the use of x-ray reticulography for the non-destructive examination of indents on silicon wafers and of warpage in advanced packaged ICs. The reticulography concept was originally developed by Lang & Makepeace [1] and consists of the use of a fine meshed slit system to sample the diffraction of x-rays from a single crystal under test. In the experiments reported upon herein a range of Au TEM grids were used. Grids had either square openings of 100 um spaced at regular rectangular intervals of 20 um, or had long (~1mm), thin (100 um) rectangular openings. Grids were placed across a region of approx. 2.5 mm x 2.5 mm and the reticulography tests were used to analyse in real time a series of deliberately indented silicon wafers and commercially available ICs order to locate local on-chip defects or warpage (See Figure 1). However, crucially in these experiments, the grid is placed between the x-ray source and the sample in order to initially decompose the source beam into a series of micro-beams. This minimises the heat load onto the sample as the package components may otherwise be damaged by the ensuing heat load and since a white x-ray beam is used (DORIS Beamline F-1) we record the diffraction from numerous planes simultaneously on Geola VRP-M high resolution film (grain size ~ 35 nm).

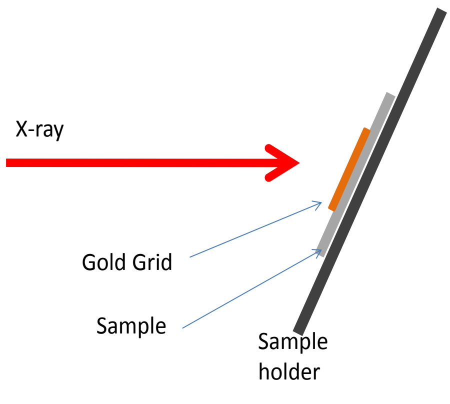
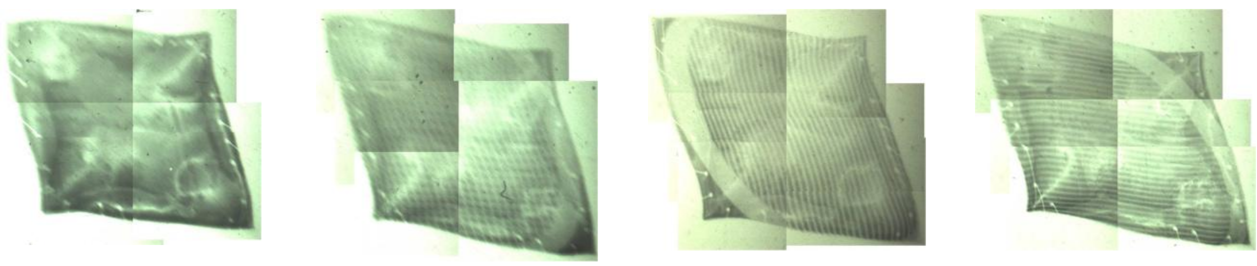


Figure 1: Schematic diagram illustrating the grid-sample-sample holder set-up.

We examined a commercially available 28-pin quad flat non-lead ultra-thin quad flat non-lead (UQFN) flash microcontroller (Manufacturer Part No. PIC16LF1827-I/MV) from Microchip as a means of demonstrating the potential for this technique to provide quick feedback towards process improvement and thus reduce major sources of die warpage. An example of a transmission mode reticulograph is shown below in Figure 2.



(a) 400 transmission topograph image of a commercially available UQFN packaged chip

(b) 400 transmission topograph of the same UQFN, with a patterned grid in front of the sample during measurements

(c) 400 transmission topograph of the same UQFN, with a vertical grid in front of the sample during measurements

(d) 400 transmission topograph of the same UQFN, with a horizontal grid in front of the sample during measurements

Figure 2: Transmission x-ray reticulography on a fully encapsulated Si chip inside a UQFN package. The x-rays impinging on the sample under test are diffracted onto the recording film. Deviations from the periodic regularity of the mesh pattern reflect localised crystal strain/misorientation in the silicon in the packaged chip, as evident in (b)-(d)

We also examined silicon wafers with indents created using a nano-indenter in an attempt to identify the type and magnitude of strain generated close to the indent. An example of a transmission mode reticulograph is shown below in Figure 2.

(a) 400 transmission topograph of a silicon wafer with four indentations

(b) 400 transmission topograph of a silicon wafer with four indentations, with a horizontal grid in front of the sample during measurements

Figure 3: Transmission x-ray reticulography on a Si wafer with indentations. The x-rays impinging on the sample under test are diffracted onto the recording film. Deviations from the periodic regularity of the mesh pattern would reflect localised crystal strain/misorientation in the silicon but are quite low in the case of indents examined here

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