A PORTABLE TV-HOLOGRAPHY (ESPI) SYSTEM FOR QNDE

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INTRODUCTION

Quantitative nondestructive evaluation of structures is achieved by this remote sensing technique which measures the deformation vector components of a surface in all 3 dimensions. Traditional techniques involve predominantly the application of strain gauges for the two in-plane deformation vector components. This technique unfortunately only reveals the in-plane deformation between two distinct points where the strain gauge is glued onto the surface. Interferometric techniques on the other hand are most common to measure the out-of-plane deformation component. Conventional film or thermoplastic holography is one of the most sensitive among those techniques measuring out-of-plane deformations in the micron and submicron range. One major disadvantage of this technique is the low time-resolution due to the fact that it involves the processing of photographic or thermoplastic film.

Measuring only the out-of-plane deformation is insufficient for an in-depth analysis of the deformation of a structure. The most suited technique must be able to measure all 3 components of the deformation vector without disturbing the structure. The 3D-TV-Holography presented here is based on electronic speckle pattern interferometry and can measure all 3 deformation vector components in real-time at video camera speed in the micron and submicron range. Besides static deformations the new, portable TV-holography system, SD800-ESPI-3D, can also perform real-time measurements of vibrational modes in the frequency range from 0.01 Hz to 1 MHz.

MEASURING PRINCIPLES

The basic TV-Holography technique has been developed back in the 1970's independently by 4 different groups [1-4]. Significant improvements in digital imaging techniques over the past 2 decades paved the way for the application of this technique for industrial and R&D applications. A more detailed description of the basic ESPI technique is found in [5-6].

The SD800 Electronic Speckle Pattern Interferometer combines two techniques, (1) the out-of-plane measurement and (2) the in-plane measurement. The system mainly consists of a 100mW laser diode in single-mode operation, a phaseshifter, a CCD camera and a computer/controller system.

Out-of-Plane Deformation Measurement

The out-of-plane deformation opto-mechanical setup of the SD800 is very similar to conventional holographic interferometry (Figure 1). The beam from the laser diode is split into the reference beam and the object beam illuminating the surface of the sample. The surface of the sample is imaged onto the CCD array and superimposed by the reference beam. The phaseshifter is used to apply a phase stepping technique to analyze the direction of the out-of-plane deformation by introducing a controlled phaseshift to the reference beam.

The advantage of the TV-holography setup is the fact that the CCD camera produces 25 holograms per second at an exposure time of 40 msec which makes it an excellent technique for objects with rapid changing deformations.

In-Plane Deformation Measurement

For in-plane deformation measurements the beam from the laser diode is split into the reference beam and the object beam both illuminating the surface of the sample (Figure 2).

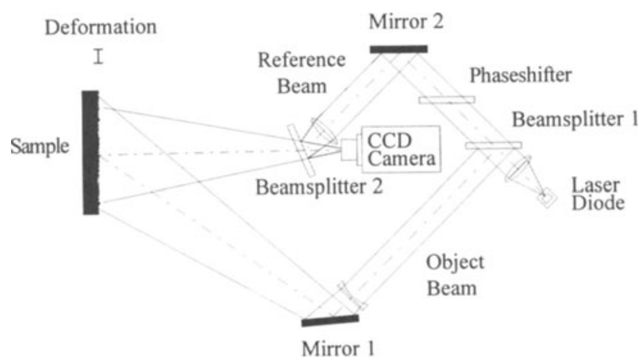

Figure 1. SD800 optical setup for out-of-plane deformation measurements.

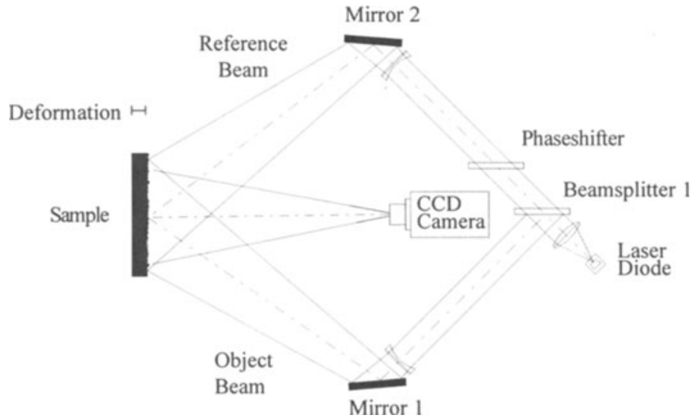

Figure 2. SD800 optical setup for in-plane deformation measurements.

This surface is imaged onto the CCD array. The phaseshifter is used again to apply a phase stepping technique to analyze the direction of the in-plane deformation by introducing a controlled phaseshift to the reference beam.

This setup is insensitive to out-of-plane deformations and highly immune to surface vibrations. The sensitivity is adjustable through a variation of the angle of incidence relative to the normal vector of the surface of the sample. An instrument of this kind mounted on building walls has been proven to measure successfully long-term in-plane deformations over several weeks against one single reference picture [7].

3D Deformation Measurements

To measure all 3 deformation vector components the SD800 combines the opto-mechanical setup for the out-of-plane deformation (Figure 1) with two in-plane setups (Figure 2) perpendicular to each other. A fast switching between each deformation component ensures a quasi-simultaneous quantitative 3D deformation analysis.

The measurement procedure requires the digital storage of a reference picture and subsequently the subtraction of the current speckle pattern in real-time. The result is a fringe pattern which shows in real-time the individual deformation component. The digital image processing software filters the optical noise of the speckle patterns. Using the built-in phaseshifter the software displays a quantitative 3-dimensional model for the out-of-plane deformation and a vector field for the 2 in-plane deformation components. An interactive cursor function relates any given point of the surface of the sample to any corresponding point at the deformation model.

DELAMINATION ANALYSIS OF PACKAGING OF INTEGRATED CIRCUITS

Delaminated areas between the silicon chip and the plastic packaging are commonly characterized by ultrasonic analysis, a destructive technique as it requires immersing the integrated circuit in water for impedance matching reasons. TV-holography provides an elegant nondestructive alternative with a remarkable geometrical resolution. The specimen is placed in a vacuum chamber and illuminated through a glass window by the SD800 ESPI system (Figure 3). The plastic packaging contains a gas volume which is expected to expand when a low vacuum of 22 mm Hg is applied. In case of delaminations the area will be larger than with samples without delaminations.

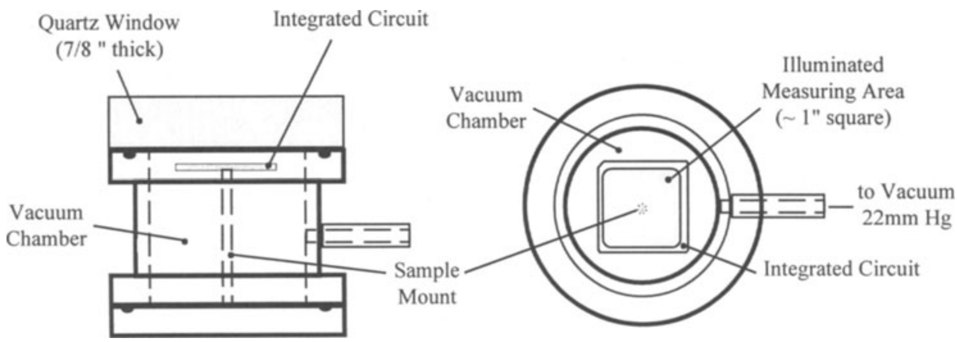

Figure 3. Vacuum setup for delamination measurements.

The samples have been subject to environmental treatments involving humidity and temperature changes. The relative overall deformation (Fig. 4) is around 0.25 microns. It is negative because the reference picture was taken under vacuum. The deformation therefore is relative to the expanded state of the sample. In case of a leak of the package the deformation would not be stable. The deformation changes over time would be expected to be a function of the size of the leak.

IN-PLANE DEFORMATION ANALYSIS AROUND A CRACK TIP

The SD800 Electronic Speckle Pattern interferometer has been successfully applied in the determination of a mixed-mode stress intensity factor [8]. It was used to determine the displacements around the crack tip of Polymethylmethacrylate (PMMA) in Compact Tension Shear (CTS) configuration (Figure 5).

The observation area was 9 mm x 9 mm. The geometrical resolution of the displacement of this area is 900 - 1000 points. The corresponding fringe patterns for different loading angles for the in-plane deformation components X and Y are shown in Fig. 6 & 7. Around 300 of these data points inside a 3 mm radius around the crack-tip have been used to determine the stress-intensity-factors K_I and K_{II} (Figure 8).

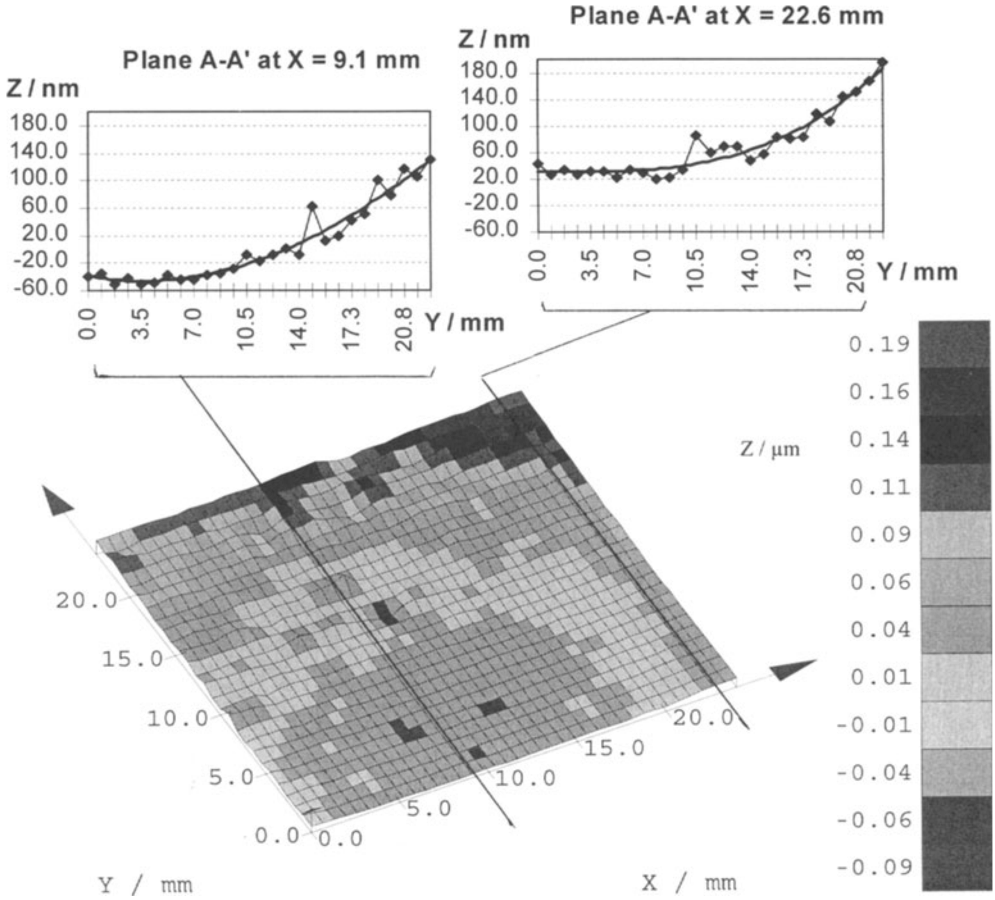

Figure 4. Delamination of a package of an integrated circuit (Out-of-plane deformation relative to deformation under vacuum).

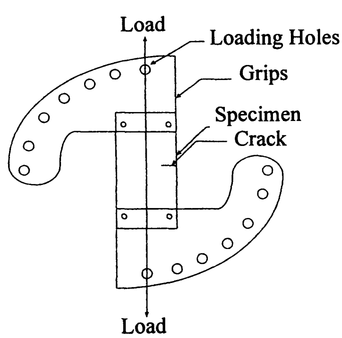

Figure 5. Schematic diagram of the CTS configuration [8].

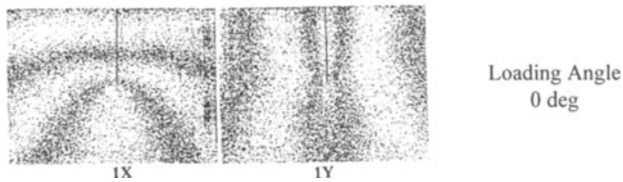

Figure 6. Fringe pattern caused by the X and Y in-plane deformation around the crack tip at a loading angle of 0 deg [8].

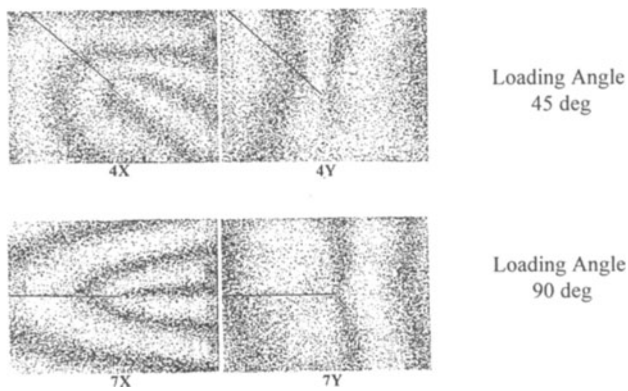

Figure 7. Fringe pattern caused by the X and Y in-plane deformation around the crack tip at loading angles of 45 and 90 deg [8].

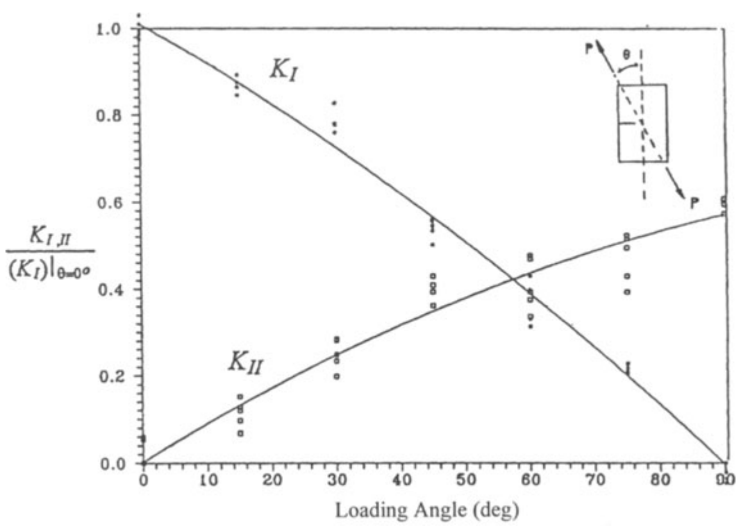

Figure 8. Variation of the stress intensity factor with the loading angle [8].

CONCLUSIONS

Quantitative analysis of all 3 vector components of a deformation of an entire surface in real-time has been demonstrated successfully. The SD800 electronic speckle pattern interferometer can perform this analysis quasi-simultaneously in the time domain of seconds and - depending on the stability of the setup - days relative to a reference speckle pattern of the surface. The experimental results correspond to the theoretical models of the exspected deformations. The application of the SD800 to the analysis of delaminations in packaging of semiconductors has been shown to be an excellent alternative to ultrasonic techniques. It has been demonstrated that this technique provides a flexible quantitative and qualitative non-destructive analysis for various industrial and R&D applications.

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