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Comparison of Phase Shifting Techniques for Measuring In-Plane Residual Stress in Thin, Flat Silicon Wafers

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This paper reports on a comparison of the six- and ten-step phase shifting methods in digital transmission photoelasticity and the application of these methods to obtain the residual stresses in thin (200 μm), flat crystalline silicon wafers (156 mm square). The ten-step phase shifting technique is judged to be superior with reduced noise in the isoclinics and a resulting higher accuracy when dealing with the near-zero retardation prevalent in residual stress measurements of silicon wafers.

Key words: Residual stress, silicon wafers, photovoltaics, NIR polariscope, phase shifting

INTRODUCTION

Residual stresses are a major concern affecting the processing and performance of electronic devices made on silicon wafers.[1–4] Residual stress in silicon wafers results from temperature gradients in crystal growth, precipitates and other point and line defects, and cracks due to mechanical processing and thickness. Many techniques are currently available to measure these residual stresses, including moiré interferometry, x-ray diffraction, transmission electron microscopy, micro-Raman spectroscopy, and digital photoelasticity.[5–8] Of these options, transmission photoelasticity is preferred due to its sensitivity in stress, simplicity, noncontact nature, and cost.[6] This optical technique is whole field and provides the information of principal stress difference (isochromatics) and principal stress direction (isoclinics) in the form of fringe contours. Brito et al. used the six-step phase shifting technique to measure the residual stress in edge-defined film fed growth (EFG) ribbons,[9,10] and measured stress as a function of applied stress in combination with residual stress, from which they extrapolated the residual stress. Vidya Ganapati et al.[11] used infrared birefringence imaging (IBI) to quantify macroscopic and microscopic internal stresses in multicrystalline silicon solar cell materials. They used the gray-field polariscope developed by Horn et al.[12] to find the maximum shear stress of the thin silicon wafers.

Digital transmission photoelasticity is increasing in popularity as a residual stress measurement tool as digital cameras, computers, and image processing techniques all continue to improve. The availability of high-resolution digital cameras allows for spatial resolution of only a few microns per pixel. Increased spatial resolution is beneficial due to the mechanics of the process, which measures the photoelastic parameters of both isochromatics and isoclinics at every pixel in the model domain. Various techniques of digital photoelasticity have been made available in the literature, and can be divided into three classifications: phase shifting, polarization stepping, and the Fourier-transform approach.[13] These methods may also be categorized based on the optical setup utilized, and on the algorithms, which are typically based on a plane, circular, or mixed polariscope. Over the years the phase shifting technique has been recommended for parameter evaluation for reasons of accuracy and stress sensitivity, and the low number of images necessary for analysis (typically six to ten). When using phase stepping, the quality of the resulting photoelastic parameters depends on various factors including wavelength mismatch, inherent error in the optical elements, and optical misalignments.

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