Thin film stresses distribution in thin film/substrate systems at elevated temperatures, which results from the thermal mismatch strain between the film and substrate, usually decides the reliability and safety of such structures in microelectronic devices. The reflection mode of digital gradient sensing (DGS) method, a real-time full-field optical technique, is applicable to measure deformations of reflective surface topographies. In this paper, the reflection mode DGS method was developed for measuring topographies and thin film stresses of thin film/substrate systems at elevated temperatures. The air convection at elevated temperatures, which is a serious problem for optical techniques, is calibrated and compensated. The principles for surface topography measurements by the reflection-mode DGS method at elevated temperatures and the governing equations for removing the air convection effects are introduced in detail. The proposed method is applied to successfully measure the full-field topography and deformation of a NiTi thin film on a silicon substrate at elevated temperatures. The evolution of thin film stresses obtained by the extended Stoney’s formula implies the “non-uniform” effect featured by the experimental results.

**Keywords:** digital image processing, thin films, temperature.

**INTRODUCTION**

Stresses in a thin film/substrate system can be obtained through the deformation of a surface topography via mechanics theory, which can be used to study the mechanical performance of the system (Feng X., 2006). There are two methods for measuring deformations of surface topographies: contact and non-contact measurements. Contact-type deformation measurement methods, such as scanning probe microscopy, obtain the specimen surface topography deformation directly. However, it is time-consuming to perform a full-field measurement and is not convenient for real-time monitoring at elevated temperatures.

Non-contact type deformation measuring methods obtain the deformation information via optical measurement technologies due to their convenience and stability. Optical technology based on Twyman-Green interferometry is widely used for the measurement of specimen surface profiles (S. Chatterjee, 2011). Rosakis et al. used a coherent gradient sensing method (CGS) to measure the reflective surface curvature by shear interferometry (A. J. Rosakis, 1998). A Moiré-based method was used for large surface deformation measurement through the distortion of projection stripes by the geometric relationship with the specimen surface profile (M. Finot, 1997). However, all optical measuring methods encounter the challenge of overcoming convection of the air in an atmospheric environment at elevated temperatures. There have been some techniques developed to overcome the air convection, for instance, the long-wave infrared interferometric techniques. However, these are not widely used because...
they require specific optical elements (I. Alexeenko, 2013). The above optical techniques are based on interferometry or grating projection, and they require monochromatic light or grid patterns. Because the experimental setup for these methods is complex, they are not suitable measurement techniques in an environment with convection. Moreover, with the development of computer technology, digital image processing, and photographic techniques, a digital image correlation method (DIC) has been developed for deformation measurements. It is widely used in engineering fields because it uses a simple experimental setup (Zhang D., 1999). However, for deformation measurement at elevated temperatures in atmospheric environments, this DIC method is still vulnerable to air disturbances.

RESULTS AND CONCLUSIONS

One experiment was performed to verify the fitting precision of the speckle image displacement resulted from air convection by the polynomial fitting as shown in Fig. 1.

![Fig. 1 - Fitting precision verification of speckle image displacement resulted from air convection](image)

The reflection mode DGS method was developed to measure surface topography deformations at elevated temperatures, and used to remove the effects of air convection. For the thin film/substrate system, the full-field film stresses subjected to varied temperatures can be obtained from the surface topography deformation by the extension of Stoney’s formula.

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