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Measurements of deformations and strains of a Si-epoxy-FR4 structure during thermal testing

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Abstract

Deformations and strains of a Si-epoxy-FR4 structure were evaluated during thermal testing using high sensitivity, real-time Moiré interferometry. The specimen studied was a sandwich structure consisting of a silicon chip, epoxy underfill and FR4 substrate. The deformations and strains of the FR4–underfill and silicon–underfill interfaces of the specimen under certain thermal loading were examined. The results show that the shear strain increases significantly along the interfaces, with the maximum shear strain occurring at the intersection of the specimen edge and the silicon–underfill interface. The shear strain at the silicon–underfill interface experienced a 2% increase after heated for two hours at 100 °C, but the shear strain at the FR4–underfill interface showed a 12% increase. This is an indication that the creep effect is more dominant in the FR4–underfill interface. The interfaces of the specimen experience partial strain recovery after one hour of the holding time at 20 °C.

Keywords: Moiré interferometry; Thermal testing; Deformation; Strain; Creep; Flip chip

1. Introduction

Single-crystal-silicon-based integrated circuits and microelectro-mechanical systems have brought enormous revolution to modern technologies [1,2]. There was an explosive growth in research and development efforts devoted to advance packaging technologies. The increasing demands for miniaturization, high electrical performance, high I/O pin count have led to significant advances in development of many simple processes for flip chip assemblies at low costs [3–7].

Currently, underfill is widely used to enhance the reliability of flip chip assemblies because it can reduce the mismatch effect of coefficients of thermal expansion (CTEs) between the silicon chip and the substrate. Improved reliability of solder bumped flip chips on FR4 substrate with perfect underfill has been confirmed by many researchers through thermal cycling tests, mechanical tests, shock and vibration tests and computational modeling [3,8–10]. However, underfill also creates new reliability concerns. Delamination along the chip-underfill and substrate-underfill interfaces is a major reliability issue in flip chip assemblies. Underfill defects in the form of voids and cracks are quite common due to manufacturing processes such as fluxing, cleaning, dispensing, and curing [11,12].

Finite element analysis has been used widely to estimate stresses and strains in electronics packaging structures. Almost any kind of electronic packages can be modeled, but simplifications and uncertainties are inevitable due to complex loading and boundary conditions [13–16]. Therefore, advanced experimental techniques are highly demanded to provide accurate solutions for deformation studies of electronics packages [17].

Validation of numerical models generated by the finite element method is achieved by experimental measurements of the same quantities. Experimental evaluations of stresses and strains usually provide realistic solutions because they are not affected by assumptions made for numerical models [18].

Thermally induced stresses and strains play an important role in controlling the structural reliability of flip-chip packages. As the demand for better performance continues to shrink bump pitches and sizes of flip-chip packages, experimental techniques with high sensitivity and resolution

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are required to measure local strains and stresses. Real time observation is often demanded to investigate the deformation trend and to understand failure mechanisms [19].

Optical Moiré interferometry has been used to analyze thermal deformations and strains of electronics packages [17,20,21]. Recently, the AFM (atomic force microscope) Moiré [22–24] and the scanning electron microscope (SEM) Moiré [25] methods have also been employed to measure thermal strains of electronics packages. However, reports on measurements of thermal deformations and strains of electronics packages during thermal testing using real-time Moiré interferometry are still scarce [26].

Deformations and strains of a simplified flip chip structure under thermal testing were examined using high sensitivity, real-time Moiré interferometry in this study. The specimen was a sandwich structure consisting of a silicon chip, epoxy underfill and FR4 substrate. The behavior of underfill-substrate and underfill-chip interfaces of the specimen under thermal loading was evaluated.

2. Real-time moiré interferometry

Moiré interferometry is an optical experimental method, providing non-contact measurements of displacements and strains [27–29]. A high reflection, symmetrical diffraction grating is reproduced on the specimen surface. The specimen grating deforms together with the specimen surface when loads are applied to the specimen. As shown in Fig. 1(a), two coherent laser beams illuminate the specimen grating obliquely from angles α and -α, creating interference and hence resulting in a virtual reference grating having a frequency f determined by Eq. (1) in the zone of their intersection.

$$f = (2/\lambda)\sin\alpha \tag{1}$$

where λ is the wavelength of the laser light source.

The deformed specimen and virtual reference gratings interact with each other to form a Moiré fringe pattern. As shown in Fig. 1(b), the Moiré pattern defining the U displacement field is formed by interaction of the x family of the specimen grating lines with the virtual reference grating. Similarly, the Moiré pattern defining the V displacement field is formed by interaction of the y family of the specimen grating lines with another virtual reference grating parallel to those lines, as shown in Fig. 1(c). U and V displacements in the x and y directions respectively can be calculated using the following two equations [28],

$$U = N_x/f \tag{2}$$

$$V = N_y/f \tag{3}$$

where, N_x and N_y are fringe orders in the U and V field patterns respectively. The normal strains, ε_x and ε_y, and the shear strain γ_{xy} can be determined by the following strain-displacement relationships.

$$\varepsilon_x = \frac{\partial U}{\partial x} = \frac{1}{f}\left(\frac{\partial N_x}{\partial x}\right) \tag{4}$$

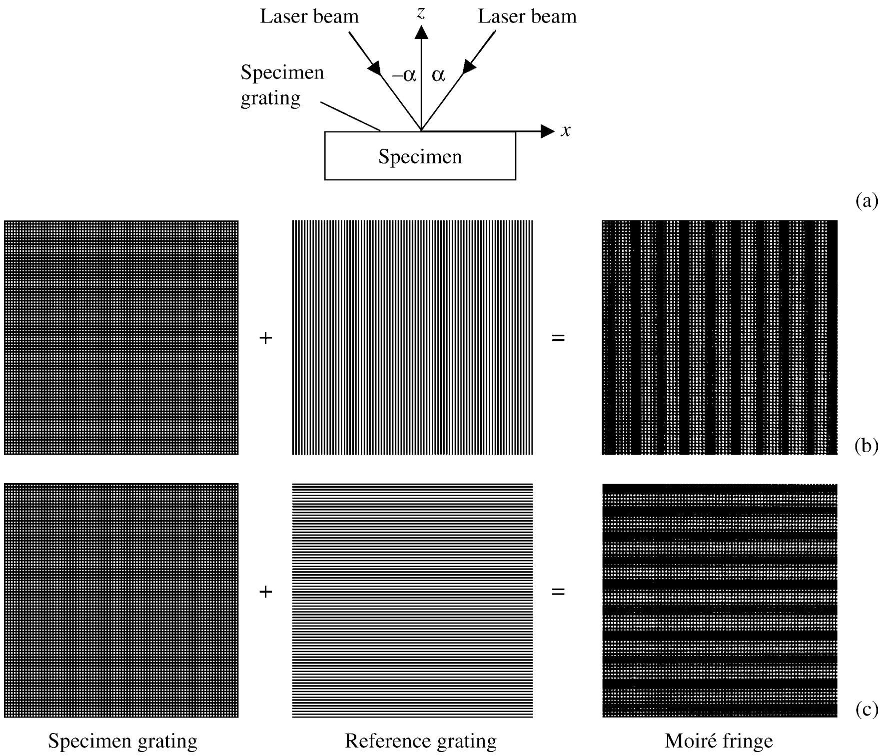

Fig. 1. Schematic diagrams showing how Moiré fringe patterns are formed and U and V fields are generated.