NONDESTRUCTIVE DAMAGE EVALUATION OF ELECTRO-MECHANICAL COMPONENTS USING A HYBRID, COMPUTATIONAL AND EXPERIMENTAL, APPROACH

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ABSTRACT

With the electronic industry being one of the most dynamic, in terms of new technologies, electronic packages have to be designed and optimized for new and ever more demanding applications in relatively short periods of time. This, in turn, indicates a need for effective quantitative testing methodologies. In this paper, a novel hybridized use of nondestructive, noninvasive, remote, full field of view, quantitative opto-electronic holography techniques with computational modeling is presented. The hybridization is illustrated with a representative application, which shows that the combined use of opto-electronic holography techniques and computational modeling provides an effective engineering tool for nondestructive study of electro-mechanical components.

INTRODUCTION

An electronic printed circuit board (PCB) is categorized as the second level of the electronic packaging hierarchy[1]. A PCB may contain a large number of electronic components (first level of electronic packaging) made of materials with different characteristics and properties and, therefore, each of the components behaving differently under specific loading conditions.

Under actual operating conditions the PCB as well as the individual electronic components, assembled on the PCB, are subjected to electromagnetic, electrical, thermal, and/or mechanical conditions of loading, which may generate failure of an electronic package. This failure can be due to any individual or a combination of the following mechanisms: fatigue, creep, stress relaxation, stress concentration, and/or bonding fractures[1,2]. Reliability of an electronic package depends on the correct functionality, under operating conditions, of the components at each one of the electronic packaging levels, starting from the first level. Therefore, due to the quantity of components assembled on an electronic package and the complexity of possible failure mechanisms, reliability assessment requires the application of effective quantitative methodologies. These quantitative methodologies comprise the computational and experimental techniques.

An effective study and characterization of electro-mechanical components should include the use of both computational and experimental methodologies. Computational investigations enable parametric studies and the determination of critical engineering conditions, while experimental investigations, especially optical, provide quantitative information on the actual response of the component of interest to the applied load condition[3,4].

In this paper, the functionality of a first level electronic packaging component, an electronic carbon resistor, is investigated using a hybrid, computational and experimental, approach.

EXPERIMENTAL INVESTIGATIONS

Figure 1 depicts a cross sectional view of a 3 ± 3 % ohm carbon resistor package of interest. In this resistor, the carbon/silica core is encapsulated in a silica shell package and two copper/lead leads are molded-in in order to provide connections to other components. The resistor has nominal dimensions of 3.48 mm for the diameter and 10 mm for the length.

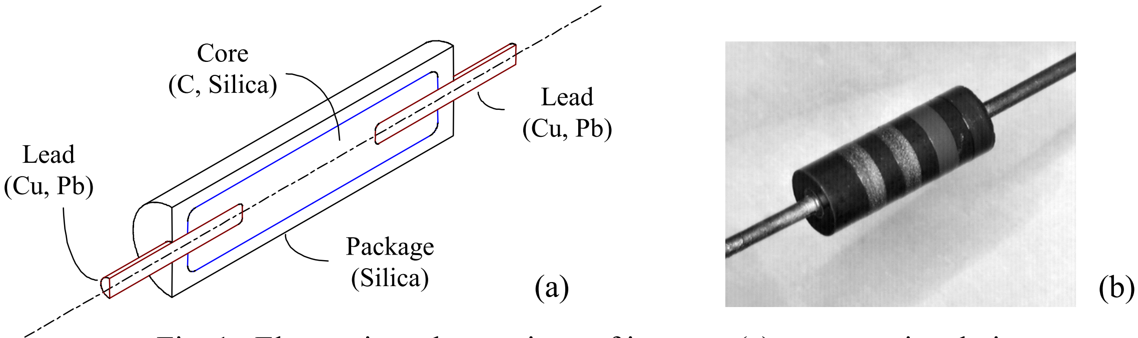


Fig. 1. Electronic carbon resistor of interest: (a) cross sectional view, and (b) actual package. The impedance of the resistor is 3 ± 3 % ohm.

The importance of testing the functionality of an electronic resistor is illustrated by comparing the electrical effects of two resistors in an electrical circuit: one in good operating condition and another in damaged condition. The damaged condition is produced by 15 sec overloading of the resistor. Figures 2 to 4 illustrate results of the testing procedures used to investigate the electrical effects of the resistor in an electronic circuit. Figure 2a depicts the measured frequency response (FR) of the circuit obtained with the resistor in good operating condition, and Fig. 2b the measured FR of the circuit obtained with the resistor in damaged condition. A periodic signal $V(t)$ of 2 V_{pp} and 1 kHz was used as an input to the circuit.

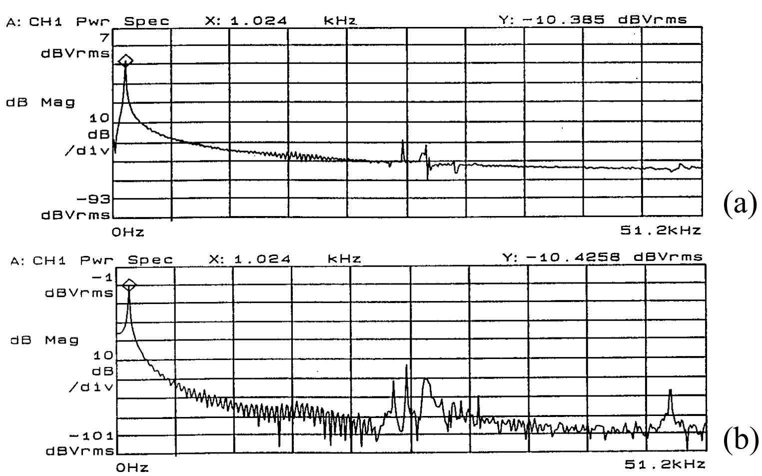


Fig. 2. Measured frequency responses of a testing circuit: (a) resistor in good operating condition and (b) resistor in damaged condition.

The undesirable noise observed in the FRs shown in Figs 2a and 2b, as compared to the FR of a pure 2 V_{pp}, 1 kHz signal, can be attributed to the effects of micro cracks developed in the core of the resistor as a result of imperfections in the manufacturing processes, Fig. 3, and as a result of damage caused by overloading, Fig. 4. Common testing procedures used to study and quantify the level of damage consist of sectioning the components of interest and applying failure analysis, fractography, and microscopy techniques. However, these procedures are time consuming and destructive in nature.

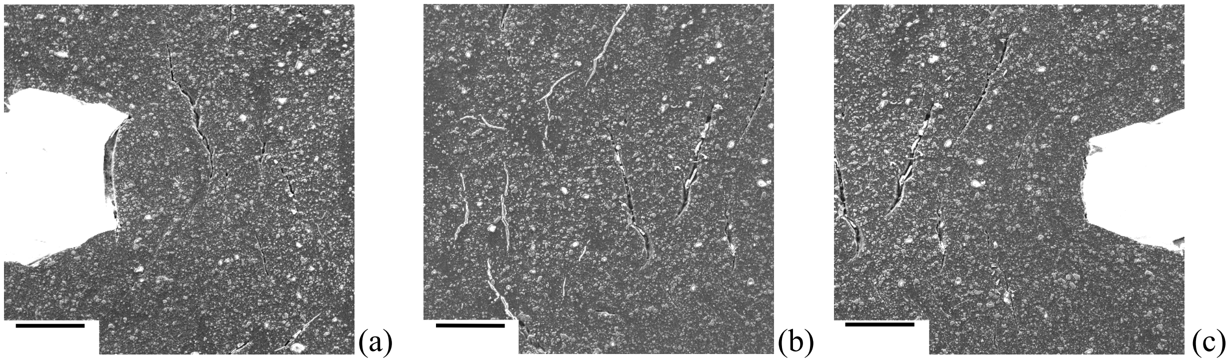


Fig. 3. New resistor in good operating condition: (a) micrograph near the left lead-core interface, (b) middle core, and (c) right lead-core interface. Small micro cracks developed as a result of imperfections in the manufacturing processes.

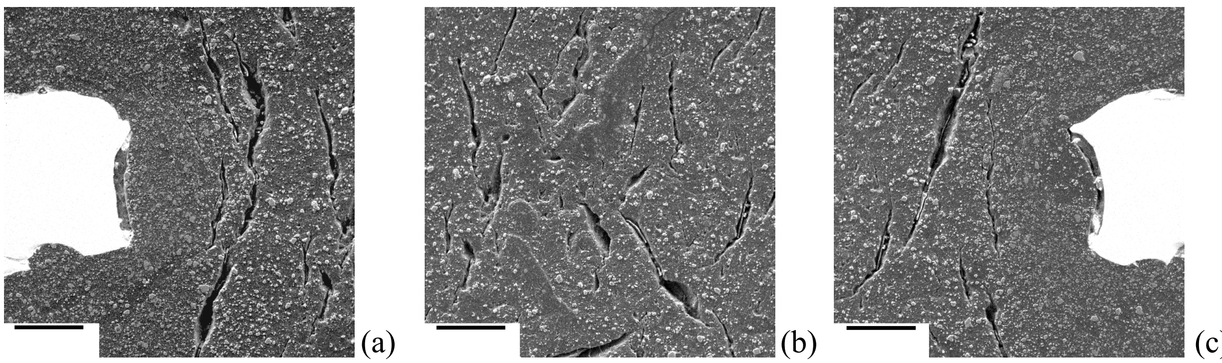


Fig. 4. Used resistor in damaged condition: (a) micrograph near the left lead-core interface, (b) middle core, and (c) right lead-core interface. Large micro cracks developed as a result of overloading.

For certain applications, the nondestructive testing (NDT) of electronic packages may be needed, especially for applications requiring noninvasive, full field of view, and real-time testing the behavior of a specific object subjected to actual operating conditions. This type of NDT can be accomplished by application of optical techniques and, in particular, speckle phase correlation techniques in the form of opto-electronic holography (OEH). Figure 5 depicts a typical fiber optic based OEH system used for NDT and shape measurement investigations[4]. This system is based on a single-illumination and single-observation geometry. This setup occupies a minimum space and can be readily arranged to obtain different experimental configurations characterized by the fringe-locus function Ω, described as

$$\Omega = (\boldsymbol{K}_2 - \boldsymbol{K}_1) \cdot \boldsymbol{L} = \boldsymbol{K} \cdot \boldsymbol{L} , \qquad (1)$$

where $\boldsymbol{K}_1$ and $\boldsymbol{K}_2$ are the vectors of illumination and observation, respectively, $\boldsymbol{K} = \boldsymbol{K}_2 - \boldsymbol{K}_1$ is the sensitivity vector, and $\boldsymbol{L}$ is the displacement vector[5]. Figure 6 depict typical interferograms corresponding to the real-time investigations of resistors. Resistors were tested with an OEH setup characterized by a vector $\boldsymbol{K}$ sensitive to the out-of-plane component of deformation, and loaded with a 2 V_{pp} at 1 kHz signal[4]. The larger number of interference fringes observed in Fig. 6c than in Fig. 6b clearly indicates that the resistors behave significantly different under the same loading conditions, therefore, illustrating the applicability of the OEH technique for health monitoring, in real-time, of electronic packages. Quantitative characterization of structural deformations due to thermal fields induced by electric loads can be obtained with OEH techniques[4]. Figure 7 shows typical results corresponding to the fringe analysis of interferograms associated with Fig. 6b.

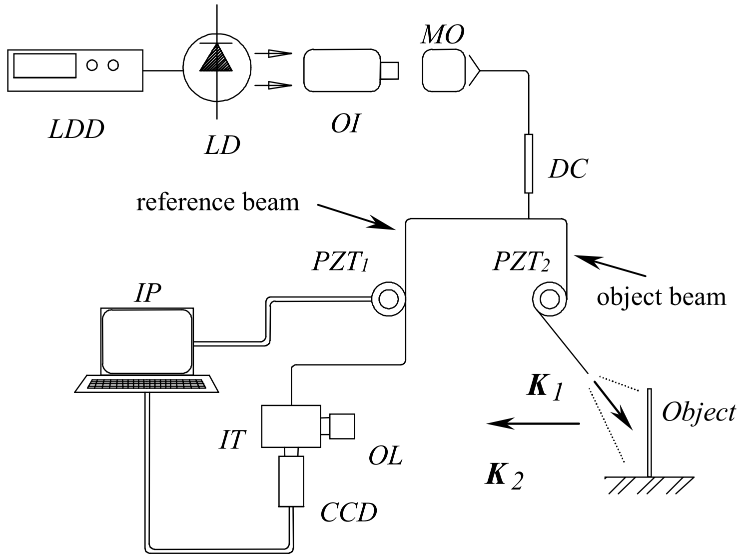
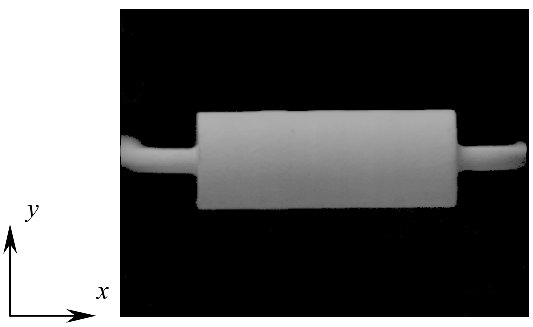
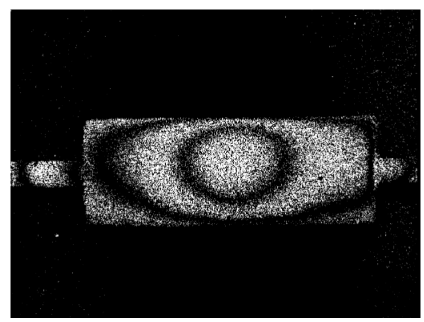


Fig. 5. Single-illumination and single-observation geometry of fiber optic based OEH system: *LDD*, laser diode driver; *LD*, laser diode; *OI*, optical isolator; *MO*, microscope objective; *DC*, fiber optic directional coupler; PZT_1 and PZT_2, piezoelectric fiber optic modulators; *IP*, image processing computer; *IT*, interferometer; *OL*, objective lens; *CCD*, camera; and *Object*, the object under investigation.



(a)


(b)

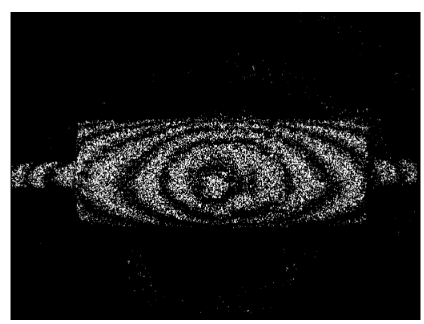

(c)

Fig. 6. Real-time NDT investigation of electronic resistors using OEH: (a) as observed on the OEH video display, (b) interferogram of a resistor in good operating condition, and (c) interferogram of a resistor in damaged condition. Experimental setup was sensitive to the out-of-plane component of deformation. Resistors were loaded with a 2 V_{pp} at 1 kHz signal.

COMPUTATIONAL-EXPERIMENTAL MODELING

An electrical resistor is introduced into an electronic circuit in order to provide a specific voltage difference. This voltage difference induces heat in the resistor and, therefore, temperature changes that produce mechanical strains and thus mechanical stresses, which may produce undesirable mechanical failure. The behavior of the resistor can be analyzed by considering electromagnetic, thermal, and mechanical stress-strain effects[4]. An initial investigation consists of studying a linear and steady-state loading condition. Therefore, computationally, it is necessary to solve the electric potential equation

$$\nabla \cdot (\bar{\kappa} \nabla V) = 0 \quad , \tag{2}$$

where $\bar{\kappa}$ is the electrical conductivity of the material, and V is the spatially varying electrical potential. Solution of Eq. 2 allows evaluation of heat generated, $Q = \bar{\kappa} \, |\nabla V|^2$, and determination of spatially dependent temperature field T by solving the thermal equilibrium equation

$$\nabla(\tilde{k} \nabla T) + Q = 0 \quad , \tag{3}$$

in which $\tilde{k}$ is the thermal conductivity of the material. Solution of Eq. 3 can be applied to the strain-displacement elasticity equations and to the solution of the stress-strain equilibrium equation

$$\sigma = E(\varepsilon + \alpha \Delta T) \quad , \tag{4}$$

where σ is the thermo-mechanical stress tensor, E is the modulus of elasticity of the material, ε is the mechanical strain tensor, α is the coefficient of thermal expansion of the material, and ΔT is the temperature difference between the temperature obtained by solving Eq. 3 and an ambient temperature T_o. Solutions of Eqs 2 to 4 can be obtained by finite element method (FEM) modeling[4]. Figure 8 shows the half cross sectional FEM solution for the radial deformation induced by a 2 V load indicating a maximum predicted radial deformation of 1.22 µm. Symmetry was assumed and boundary conditions similar to operating conditions of a resistor were used. Material properties were obtained from published data. By comparing experimental and computational results for the radial deformation, Figs 7b and 8b, differences between measured and predicted results are realized, which indicate that any further computational investigations would yield erroneous results.

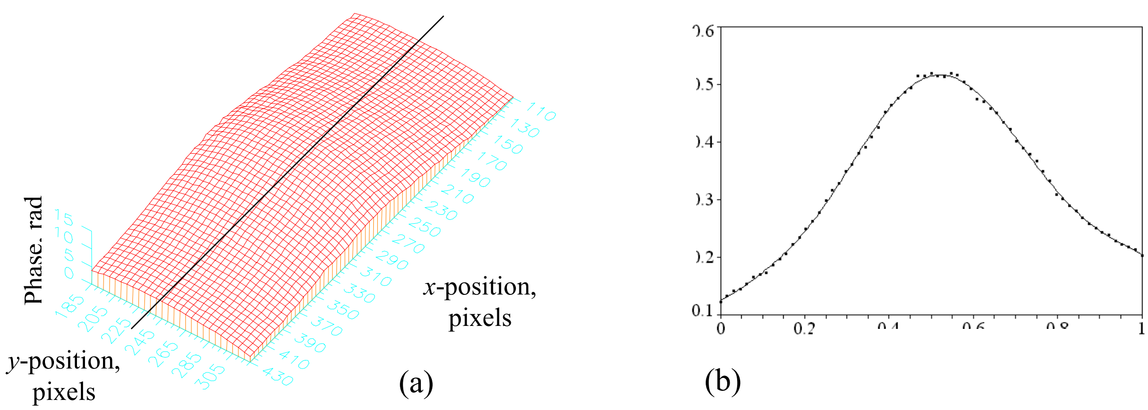


Fig. 7. Measured radial deformation U_r: (a) out-of-plane spatial phase distribution of the resistor based on quantitative OEH investigations, and (b) radial deformation along the line shown in (a), indicating maximum radial deformation of 0.52 µm obtained with an accuracy better than 0.010 µm.

The differences, which need to be resolved, can be attributed, from the computational side, to improper selection of modeling parameters, and from the experimental side, to an inadequate experimental setup and/or an improper quantitative interpretation of interferograms. Optimization algorithms that minimize the differences between experimental and computational results can be applied[4], which include simulation of interference fringes based on computational results. Figure 9 shows predicted fringe patterns before and after experimental-computational modeling. The predicted patterns should be compared to measured interference patterns, Fig. 6b, to realize improvements in the results.

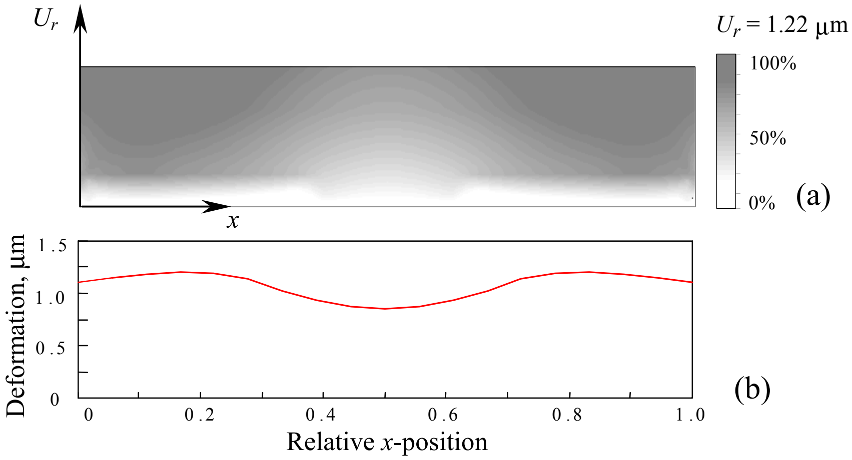


Fig. 8. Half cross sectional FEM predicted radial deformation U_r: (a) radial cross sectional field distribution and (b) deformation along a longitudinal external surface of the resistor.

Fig. 9. Predicted fringe patterns: (a) before and (b) after computational-experimental modeling. Comparisons with measurements, Fig. 6b, indicate improvements in the results.

CONCLUSIONS

A hybrid computational-experimental approach for nondestructive testing of electro-mechanical components has been presented and illustrated with a representative application. This application clearly demonstrates that neither only computational nor only experimental techniques should be applied to solve an engineering problem, because applying only one of the techniques can provide erroneous information. Using this hybrid approach, displacements and strains are determined with accuracies better than 0.01 μm and 0.000,05 %, respectively, and provide indispensable data for testing and development of reliable electronic packages.

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