EVALUATION OF MICROCRACKS IN MICROELECTRONIC COMPONENTS

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Abstract

Advanced applications of modern micro- and nanotechnologies more and more require improved very local stress and strain analysis of micro- and nanocomponents to meet the increasing requirements for reliability and lifetime. **D**igital **I**mage **C**orrelation tools **(DIC)** have become a very powerful means to reach this goal. The authors deal with special DIC-techniques the microDAC and nanoDAC deformation analysis (DAC – **D**eformation **A**nalysis by **C**orrelation Method) which enable to determine deformation fields in very small dimensions. The method is applied to describe the local deformation fields around microcracks in various applications. NanoDAC technique has been shown to become an important tool for measurements of local stress fields investigated by scanning probe microscopy (AFM, AFAM etc.). The method has been performed as well on bulk materials, thin films and on devices, i.e. microelectronic components, sensors, and MEMS/NEMS as well. Thus, modern fracture mechanics can be used in the immediate transition range between micro- and nanotechnology.

1. Introduction

Proceeding progress in miniaturization of electronic packages and the development of nanomaterials result in the need for experimental methods on the nanoscale. The evaluation of local strain fields at material interfaces, microcracks and defects is the key for the successful design of highly integrated systems and nanostructured materials. Furthermore, the quality of electronic systems and nanomaterials have to be guaranteed for end users. To fulfill this crack and fracture avoidance in the micro and submicron regions have become essential.

In most cases experimental procedures are complemented by simulations to assess, evaluate and then predict the mechanical integrity of the structure in question. As cracks and delaminations continue to be a worrying problem in the field of micro- and nano-electronics, it is vital to have a tool at hand to make conclusive statements about the reliability of components, which, following the roadmaps, show the tendency towards smaller features and structures down into the nano-region. Of special interest in the field of electronic packaging is the employment of micro- and nano-filled polymers and thin layers.

As far as material characterization is concerned recent research showed that deformation measurement on the nanoscale is the key for mechanical evaluation of micro- and nanomaterials. The application of SPM-based imaging techniques combined with digital image correlation (DIC) methods is a powerful method for the determination of displacement fields with the accuracy in the range of a few nanometers.

Two examples of this so-called nanoDAC method (nano-Deformation Analysis by Correlation) are given in the experimental part of this paper followed by the simulative approach. The aim is the development of a combined experimental and simulative procedure towards an improved nanomechanical material analysis. The final result of the approach are fracture parameters (e.g. K_{Ic}) and related field quantities in the immediate vicinity of very tine micro- and nanocracks.

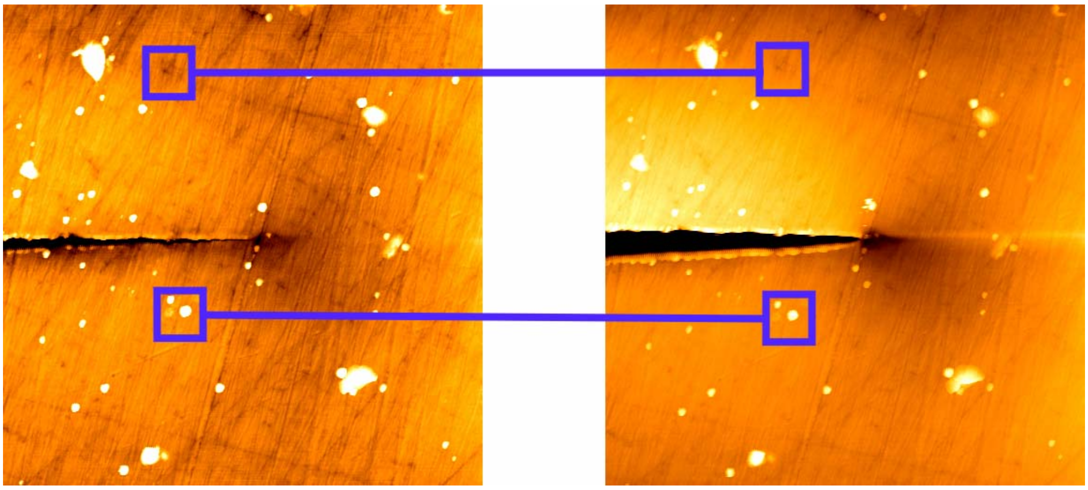

FIGURE 1. AFM topography image of a crack in a thermoset polymer material for different crack opening displacements in different load stages of the crack specimen.

2. Crack Tip Analysis by NanoDAC Method in AFM

The first example for a nanomechanical analysis is performed at a crack tip of a neat thermoset polymer. Therefore a compact tension (CT) specimen is loaded in-situ under the AFM. Topographic non-contact AFM scans are carried out before and after loading and digital image correlation is applied to the derived images. Figure 2 illustrates the evaluated crack tip opening field.

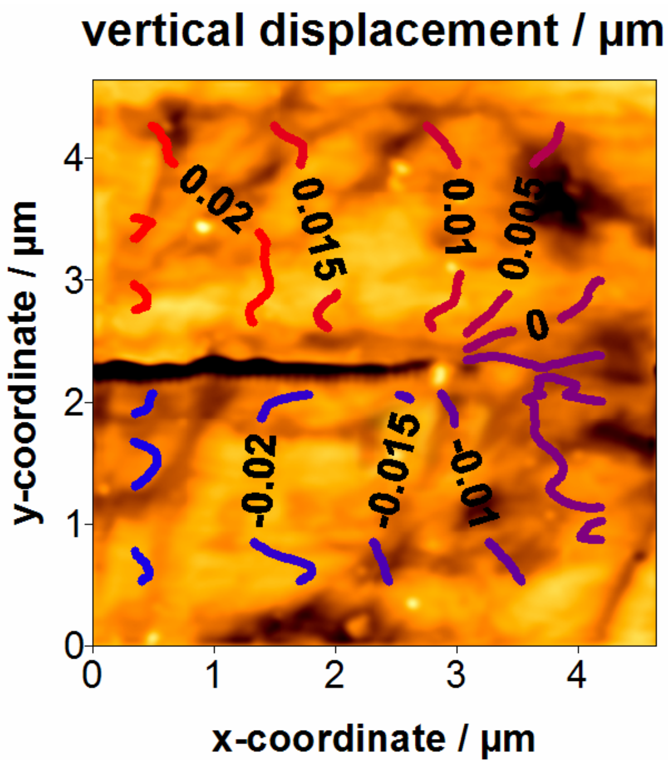

FIGURE 2. AFM topography image with overlaid displacement results in the (vertical) y-direction (crack opening), u_y.

The derived crack tip field is an inevitable data source for fracture mechanical analysis of the materials so that concepts such as crack opening displacement (COD) or J-integral are applicable.

The presented displacement measurement at a polymer material emphasize the analysis of all kinds of composite materials. Especially the interface between micro- or nanoparticles and the polymer matrix will be of interest for the design of new materials.

A straightforward approach for crack evaluation in the AFM is the technique of crack opening displacement (COD) determination. In order to extract the mode I stress intensity factor K_I crack opening displacements, u_y^u and u_y^l, are measured along both the upper and lower crack boundaries.

If determined by linear elastic fracture mechanics they must equal to

$$u_y^{u,l} = \pm \frac{K_I}{2\mu}\sqrt{\frac{\chi}{2\pi}}(\kappa+1) \qquad \chi \le 0 \qquad (1)$$

$$u_y^u = u_y^l = 0 \qquad \chi > 0 \qquad (2)$$

where μ is the shear modulus and κ is a function of Poisson's ratio, ν; $\kappa = (3 - 4\nu)$ for plane strain and $\kappa = (3 - \nu)/(1 + \nu)$ for plane stress. Taking the square of the difference of upper and lower displacements, we obtain a linear function of the χ-coordinate or 0, depending on the position relative to the crack tip:

$$\left(\frac{u_y^u - u_y^l}{2}\right)^2 = \quad C\chi \qquad \chi \le 0 \qquad (3)$$

$$0 \qquad \chi > 0 \qquad (4)$$

The expression of Eqn. 3 does not change if specimen rotation due to inaccurate loading is included into the considerations. In this case, equal rotational terms on both sides of the crack boundary are subtracted from each other. For the equation above, the crack tip is set at location $\chi = 0$. The crack tip location on the real specimen can be found at the interception of a linear fit of the curve $C\chi$ with the χ-axis. The slope C allows to estimate the stress intensity factor K_I, which is a measure of the crack tip load. It is given by:

$$K_I = \frac{E}{1+\upsilon}\frac{1}{\kappa+1}\sqrt{2\pi C} \qquad (5)$$

where E is the Young's modulus.

The discussed analysis is applied to the displacement field measurements presented in Figure 3. From (5) the K_I can be obtained immediately from the experimental data via equation (3).

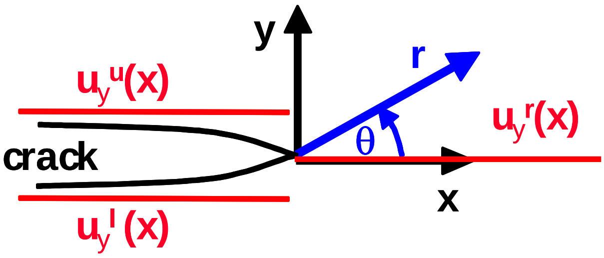

FIGURE 3. Crack opening displacement, mode I crack opening.

A similar procedure has been developed to derive critical values K_{Ic} (fracture toughness). The authors are going to generalize the method for more general fracture concepts. Generalized integral concepts e.g. C*, βT, $\hat{J}$ etc. can be used to get more realistic results taking into account the exact material behaviour. Another kind of applications of microDAC and nanoDAC methods is to study the thermomechanical behaviour of various microcomponents, microsensors, MEMS, NEMS etc. In the following example nanoDAC deformation analysis has been carried out at the membrane of a gas sensor.

3. Application of DIC to Micromachined Gas Sensor

Figure 4 shows a topographic AFM scan of a Pt-layer on top of a SiO_2 membrane where the platinum represents the heater of the gas sensor. Delaminations at the edge of the Pt-layer are caused by mismatch of material properties (CTEs; Pt: 9 ppm K^{-1} SiO_2: 0.65 ppm K^{-1}) in the presence of thermal loading up to 450 °C.

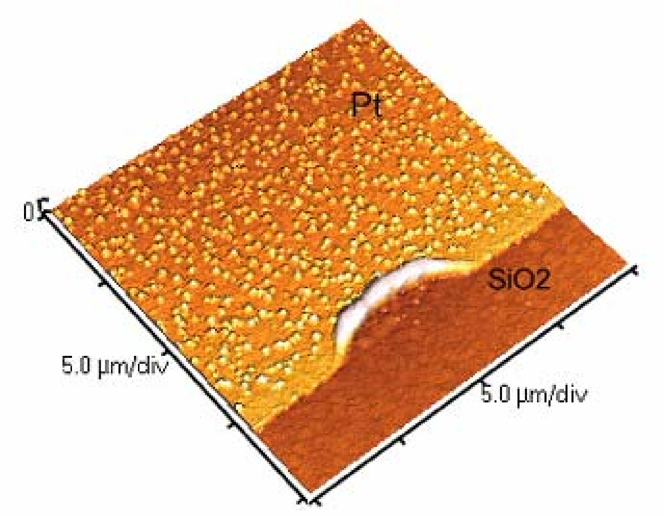

FIGURE 4. Micromachined gas sensor. AFM topography scan of membrane layers. Pt-electrode destruction at edge layer.

The question whether these delaminations are caused by large scale deformation during thermal loading is answered by nanoDAC analysis. In-situ non-contact AFM scans in top of the gas sensor membrane are carried out at room temperature and at 100 °C. The derived topography images of these load states are compared by digital image correlation and in-plane displacement fields are determined.

The Pt-layer reveals an inherent expansion towards the edge of the layer. Therefore, heating cycles of up to 450 °C as carried out at the membrane of Figure 1 may cause large scale deformation leading to delaminations or catastrophic failure in form of membrane cracking.

With in-situ AFM measurements on this microsystem the capability of the nanoDAC approach is demonstrated. Measuring of material deformation resulting from mismatch of material properties are detectable in nanoscale resolution.

By means of Digital Image Correlation method (DIC) based on AFM images the nanoDAC techniques enables to determine the local displacement fields and from these it is possible to derive stresses and strains as well.

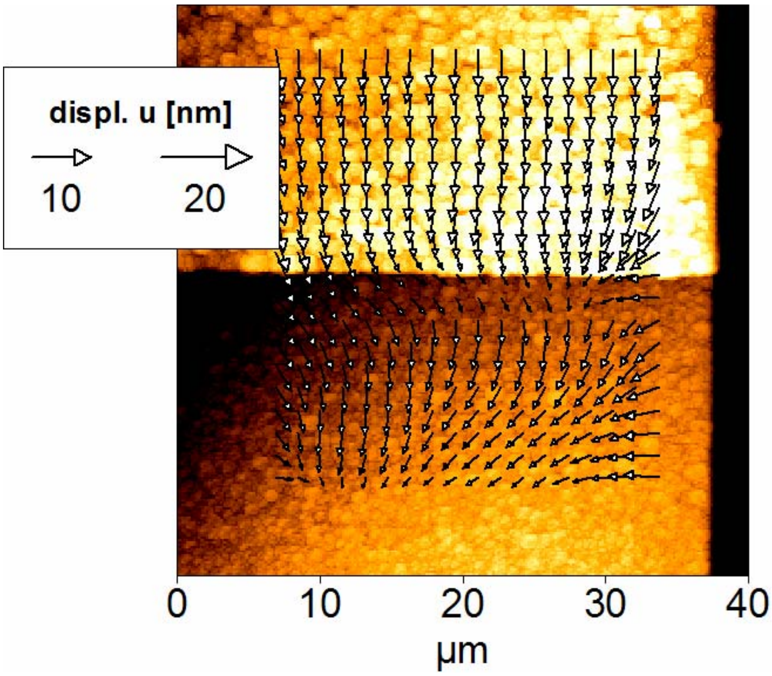

FIGURE 5. Displacement fields determined by nanoDAC technique from AFM image.

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