A NEW METHOD FOR LOCAL STRAIN FIELD ANALYSIS NEAR CRACKS IN MICRO- AND NANOTECHNOLOGY APPLICATIONS

B. Michel[1)], D. Vogel[1)], N. Sabaté[2)], and D. Lieske[3)]

[1)] Fraunhofer Micro Materials Center Berlin and Chemnitz, Germany

bernd.michel@izm.fraunhofer.de

[2)] University of Barcelona, Spain

[3)] Infineon Technologies Dresden, Germany

ABSTRACT

The paper presents a new reliability approach based on local stress and deformation field analysis by means of so-called digital image correlation technique (DIC). NanoDAC and FIBDAC are special variants of this method using AFM and Focus Ion Beam (FIB) experiments, respectively, to provide the images before and after the deformation processes. NanoDAC and FIBDAC will be applied to study advanced packaging reliability, MEMS and sensor applications as well taking into account creep and fatigue phenomena and their interaction. Various kinds of flip chip, CSP, COB and other packaging technologies for sensors, chips and MEMS will be discussed based on the nanoDAC analysis of critical interconnection regions. Special attention will be given to interface cracking taking into account effects of humidity, vibration etc. The FIBDAC method is applied to determine internal stresses in the near-chip region.

Introduction

“Nanoreliability” is a new name to describe local effects arising from the nanoscale view for reliability analysis and life-time estimation. An advanced nanoreliability approach requires new tools for local stress and strain evaluation taking into account structural effects and physics of failure concepts combined with those continuum-based calculations which are suited to describe the essential procedures of the dominant failure mechanisms sufficiently well.

Strain fields are coupled with thermal effects, diffusion phenomena, vibrations and various kinds of local changes of structure (defects, defect interactions etc.). Most of these phenomena have been shown to be related with internal stresses. That’s why an advanced reliability analysis based on local deformation field characterization also requires an incorporation of local self stress analysis. By means of X-ray diffraction some information will be obtained, but very often this is not sufficient enough because local strains on a submicrometer scale have to be taken into account.

The authors developed a special FIBDAC technique which enables to get a lot of quantitative information on internal stresses using a stress release by drilling nano-holes and/or removing local materials using the FIB technology.

Stress and Strain Measurements in Very Small Regions

A new approach to the local measurement of residual stresses in micro- and nanostructures is described in the presentation. The presented technique takes advantage of the combined milling-maging features of a focused ion beam (FIB) equipment to scale down the well-known classical hole drilling method. This method consists of drilling a small hole into a solid containing inherent residual stresses and measuring the displacements/strains caused by the local stress release, that takes place around this hole. In the presented case, the displacements caused by the milling are determined by applying digital image correlation techniques (DIC) to high resolution micrographs taken before and after the milling process. The residual stress value is then obtained by comparing the measured displacements with the analytical solution of the ideal displacement fields. The feasibility of this approach and some generalization has been demonstrated on a micromachined silicon nitride membrane showing that this method has very high potential for practical applications in the field of MEMS, silicon chip interconnection technologies and related topics.

The authors call this new method FIBDAC. It received the 2005 Fraunhofer award for science and technology. Besides the FIBDAC method the authors also present another example using the DIC approach. It deals with fracture toughness evaluation by means of so-called nanoDAC technique, i.e. nanodeformation analysis around tiny cracks using atomic force microscopy.

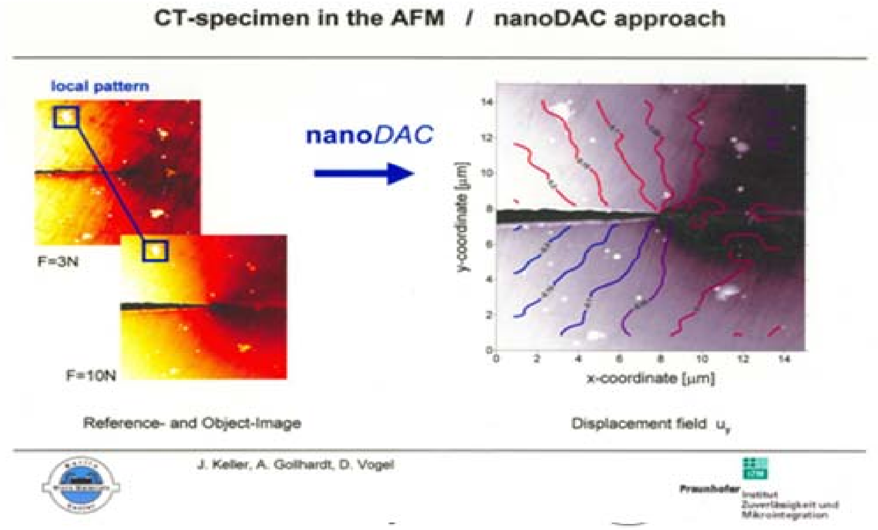

Fig. 1: Strain Field Around a Crack Tip Measured Within an AFM

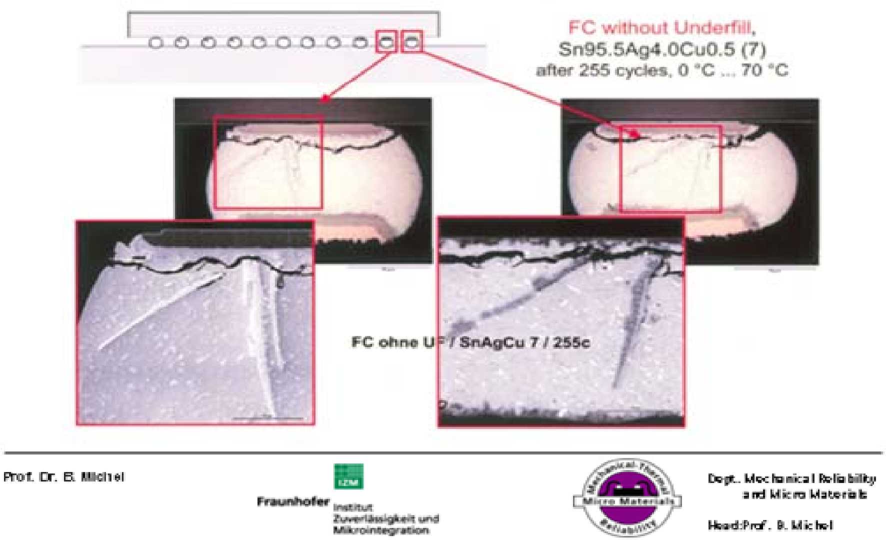

Fig. 2: Cracks in a Micro Solder Bump of an Electronic Package

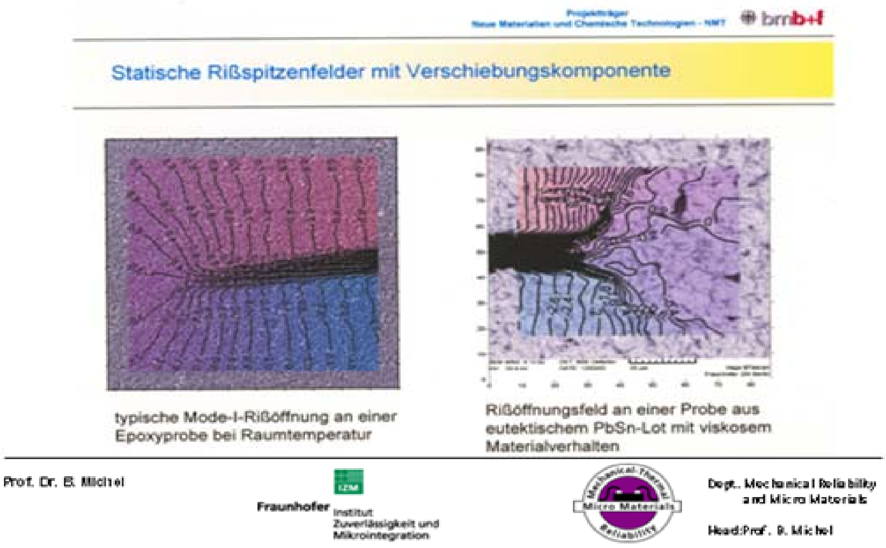

Fig. 3: Crack Opening Displacement Field Around a Nano Crack

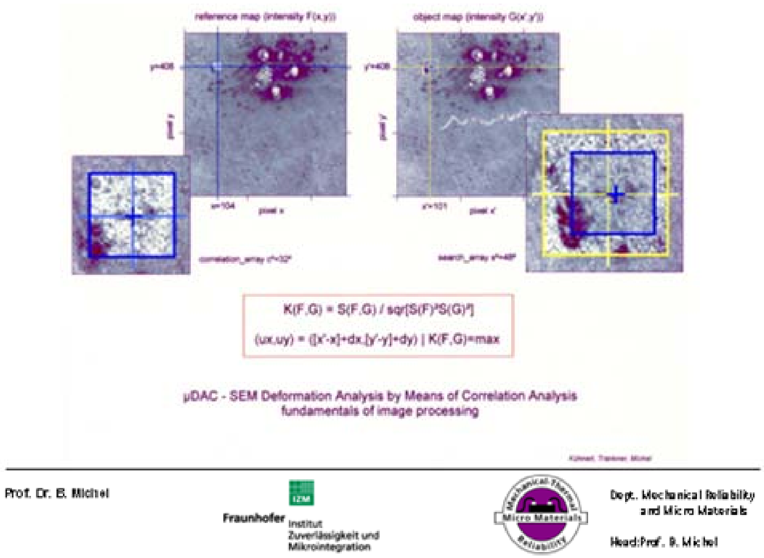

Fig. 4: Principle of Digital Image Correlation Technique

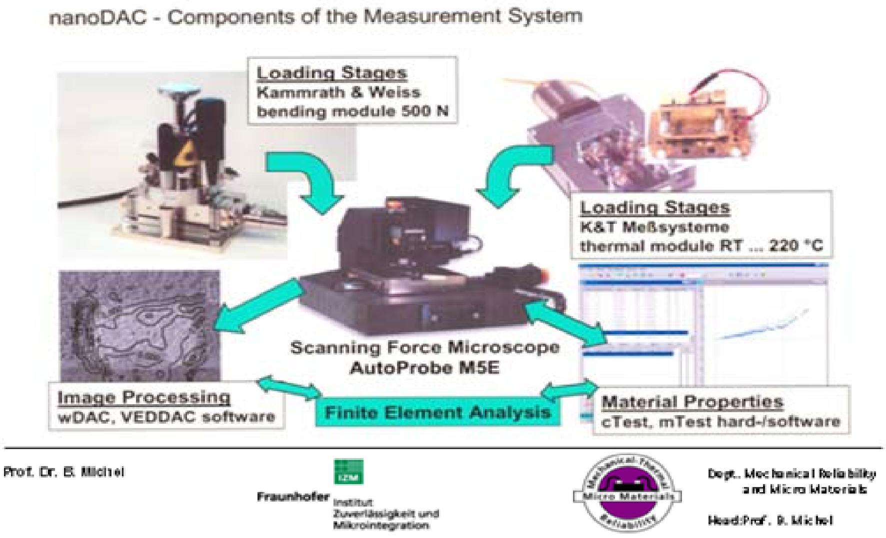

Fig. 5: NanoDAC Experiments by AFM Technique

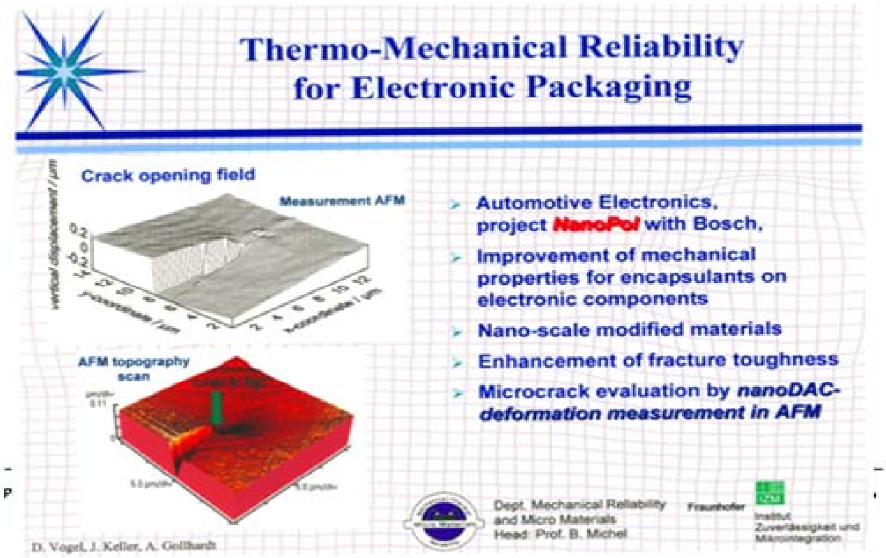

Fig. 6: Crack Diagnostics by AFM Measurements

NanoDAC is a special microDAC technique of digital image correlation approach where local deformation fields near crack tips before and after mechanical or thermal loading (or any other kind of deformation procedure) are compared applying digital image correlation methods (grey value distribution functions are compared) providing these images by means of local SPM techniques (e.g. AFM, AFAM etc.). The methods enable to derive local stress intensity factors and more general fracture quantities as well for micro- and nanostructures (e.g. MEMS, NEMS, MOEMS etc.).

The authors have applied the nanoDAC technique for the study of nanoparticle encapsulated microelectronic devices, for nanocarbon tube local deformation and reliability analysis and very broad variety of very different applications in automotive sensors and MEMS applications.

Summary and Outlook

MicroDAC, nanoDAC and FIBDAC techniques are very strong methods for reliability analysis of small components (“microreliability”, “nanoreliability”) based on advanced methods of digital image correlation combined with reliability concepts taking into account local stress and strain analysis. Fatigue, creep, vibrations, temperature, electrical and magnetic effects and their interactions can also be taken into account. First attempts will be presented in the paper generalizing classical fracture concepts.

References

1. Vogel, D., Sabaté, N., Wunderle, B., Keller, J., Michel, B., Reichl, H., „Nanoreliability for Mechanically Loaded Devices“, Int. Congress of Nanotechnology 2005 (ICN 2005), San Francisco, USA, Nov. 1-4, 2005.
2. Michel, B., Keller, J., “NanoDAC – a New Technique for Micro- and Nanomechanical Reliability Analysis of Lead-free Solder Interconnects”, Int. Conf. on Lead-Free Soldering, Toronto, Canada, May 24-26, 2005.
3. Michel, B., “Testing at Micro- and Nanoscale”, EuroSIME, European Conf. on Thermal, Mechanical and Multiphysics Simulation and Experiments in Microelectronics, Berlin, April 18-20, 2005.
4. Auersperg, J., Vogel, D., Michel, B., „Crack and delamination risk evaluation of thin silicon based microelectronic devices“, 11th Int. Conf. on Fracture (ICF 11), Torino, Italy, March 20-25, 2005.
5. Michel, B., “Experimental Mechanics on the Way from Micro to Nano”, Experimental Technique, vol. 29 (2005) **2**, 3-5.
6. Michel, B., “Reliability Research on the Way from Micro to Nano”, in: Proc. 1st Int. Conf. on Multi-Material Manufacture (4M), eds. W. Menz and S. Dimov, Elsevier Publ. Oxford, 2005, 43-45.
7. Michel, B., Keller, J., „Nanodeformation Analysis near Small Cracks by Means of nanoDAC Technique“, in: G. Wilkening and L. Koenders (eds.): “Nanoscale Callibration Standard and Methods”, Wiley VCH, Weinheim, 2005, 481-489.
8. Michel, B., „Microreliability, Nanoreliability – Reliability Issues for MEMS”, in H. Knobloch and Y. Kaminorz (eds.): “MicroNano Integration”, Springer Verlag, Heidelberg, Berlin, New York, 2003, 269-275.
9. Dudek, R., Döring, R., Michel, B., „Reliability Prediction of Area Array Solder Joints“, Transactions of ASME, Journal of Electronic Packaging, vol. 125, Dec. 2003, 562-568.
10. Michel, B., Wittler, O., „Cracks in Micro- and Nanoelectronics“, proc. ECF 16, Alexandroupolis, Greece, July 3-7, 2006, in print.
11. Michel, B., „Nanoreliability – Lifetime Estimation for Nanotechnology Applications Based on NanoDAC and FIBDAC Techniques”, 4th Int. Symp. Nanofair 2005, Dresden, Nov. 29-30, 2005.
12. Walter, H., Dudek, R., Michel, B., „Fracture and Fatigue Behaviour of MEMS Related Micro Materials“, 11th Int. Conf. on Fracture (ICF 11), Torino, Italy, March 20-25, 2005.
13. Michel, B., „MicroDAC and NanoDAC – New Experimental Testing Techniques for High Temperature Deformation and Reliability Analysis in Small Regions“, High Temperature Electronics Conf. (HITEN), Paris, France, Sept. 4-9, 2005.