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Investigation on reliability of interconnects in 3D heterogeneous systems by ageing beam resonance method

G. Janczyk*, T. Bieniek, J. Wasowski, P. Grabiec

Instytut Technologii Elektronowej, ITE, Al. Lotnikow 32/46, 02-668 Warsaw, Poland

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ABSTRACT

This paper is the ongoing research report and discusses important aspects of new investigation method selected for interconnects reliability and ageing which has to be considered in nano-scale. The research is ongoing and applies to heterogeneous device structures like SiP, SoC where mechanical stress caused by thermal cycling, heat dissipation, assembly technique etc. distributes inside thin layers of metal interconnects.

1. Overall idea

Continuous development of IC fabrication technology is followed by advancements in device assembly and packaging. Reliability issues force the designers to take into consideration layout, material and properties of inner-device interconnects [1–3]. Clock distribution issues like signal integrity, clock skew and applied solutions like optimized clock tree and lack of interconnect reliability control lead researchers to focus on 3D integration-related specific issue of interconnect reliability and methods to make it predictable. Several research methods like destructive [4] and non-destructive ones [5] are focused on reliability of interconnects applicable to various types and parts of interconnects like interconnect strips, solder balls, vias, microbombs etc., various domains (DC [6], RF [5,7]), various materials (silicon nanowires, carbon nanotubes, Cu, Al, TiW, etc.). This paper intentionally follows [6] and discusses selected aspects of investigation technique on interconnects reliability and faces them with innovative Accelerated Thermo-Mechanical Ageing (ATMA) method [8] focused on interconnect ageing accelerated by natural, thermo-mechanical hazards present inside SiP's, SoC's and other 3D intergrated systems. ATMA method relies on an assumption that mechanical fatigue of interconnecting material stimulated by mechanical stress and assisted by thermal cycling of the AABS structure under test [6] reflects natural interconnect ageing in a real device. Novelty of the approach relies on natural ATMA mechanism of material defects generation, contrary to the methods reported in [4] where Cu–Al solder ball bond is exposed to an artificial mechanical hazard manually applied to solder ball part of the interconnect, or as reported in [7,9] where cracks are manually introduced to the surface of interconnect strip. Frequency domain was not a factor of primary importance for development of Accelerated Ageing Beam Structures (AABS) test samples. It can be investigated in a whole signal specter from DC to RF. The ATMA philosophy has been invented, implemented and developed up to the test structure by authors Team in ITE. This particular implementation of ageing experiment relies on series of MEMS silicon cantilever beams with deposited aluminum paths on top, excited by an external mechanical vibration system connected to the dedicated readout structure for DC measurements of resistance deviations. There is a set of structures without readout ASIC connected for the sake of future high frequency measurements. The deviation of resistance is temporarily related to the interconnect deformation and steady state change related to progress of the real ageing phenomenon.

2. Methodology

Specific AABS samples dedicated for accelerated ageing process (ATMA) with metal interconnects on the top of the beam which

* Corresponding author.
E-mail addresses: janczyk@ite.waw.pl (G. Janczyk), tbieniek@ite.waw.pl (T. Bieniek), jwasowski@ite.waw.pl (J. Wasowski), grabiec@ite.waw.pl (P. Grabiec).

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undergoes ageing investigation have been fabricated in ITE (Fig. 1). Resonant frequencies of the 1st harmonic vibration mode vary from single 0.5 kHz (long beams) up to 20 kHz (short beams). Predicted resonant modes have been successfully verified by experiment based on MEMS cantilever beam [6] developed in frame of e-BRAINS project [10]. AABS parameters have been calibrated. MEMS silicon cantilever beams length is 1–4 mm, width is 300–700 μm whereas thickness is 5–20 μm. Following the simulation results in some cases (long cantilever beam structures) it is even possible to reach plastic deformation of metallization material and led the metal interconnect into plastic deformation for particular mode of mechanical resonance excitation. Such a high level of material deformation causes material fatigue: deformation, cracks, dislocation etc. Overall distortion is assumed to reflect ageing of interconnect.

On the current stage of investigation the interconnecting layer is made from aluminum (typical material in CMOS/MEMS technologies for metallization, fully compatible with CMOS, in this particular case: thickness 1.2 μm, resistivity 2.82E − 9 Ωm, formed by standard vapor deposition). In general other metals than aluminum as well other materials and parameters like resistance, geometry, length, etc. are available for testing purposes. In order to strengthen results of metal degradation the AABS MEMS and make ageing results better detectable, the design has been optimized by application of specific interconnect layout with a dedicated multi-bend strip chaining in the beam root area (Fig. 2). It is expected that for the 1st vibration mode mechanical stress should reach highest levels in this area. It is expected that the applied measurement method (discussed below) should be sensitive enough to detect progress in interconnect degradation process. More data on MEMS-based cantilever beams used for ATMA methodology is available in [11].

Interconnect degradation stimulated during accelerated ageing will be evaluated on the basis of measurements on interconnect resistance. To achieve sufficient measurement stability, accuracy and real-time observation of ageing phenomena and progress of interconnect degradation dedicated an indirect measurement technique has been elaborated, implemented and will be applied

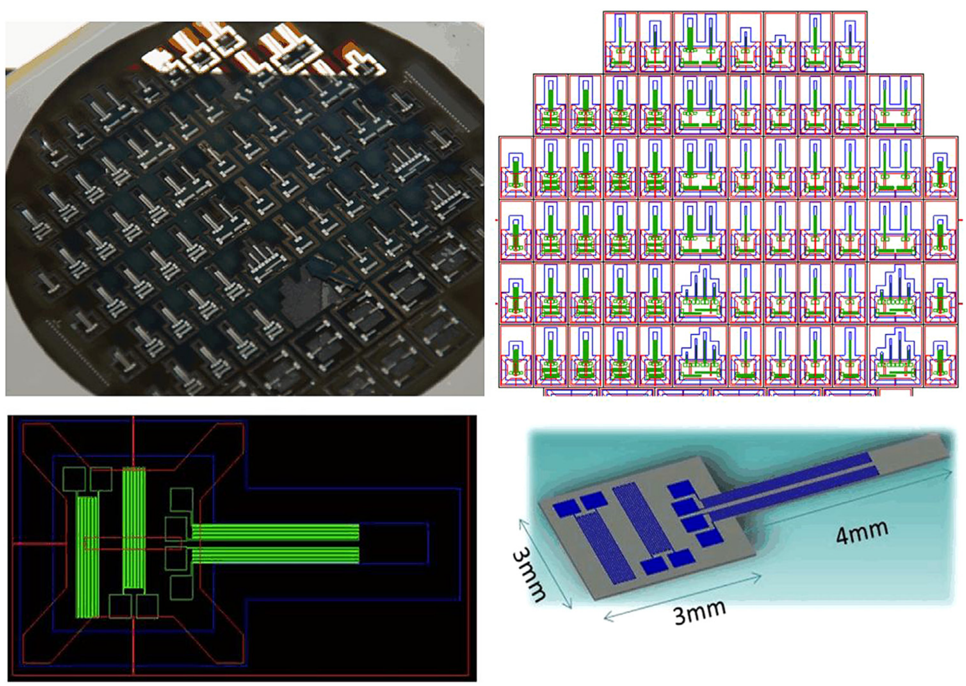

Fig. 1. Real test structures developed (top left) in ITE for experimental verification of CoventorWare design (top right) modeling. Figure on bottom-left side represents mask set of cantilever and 3D MEMS visualization by CoventorWare (bottom-right).

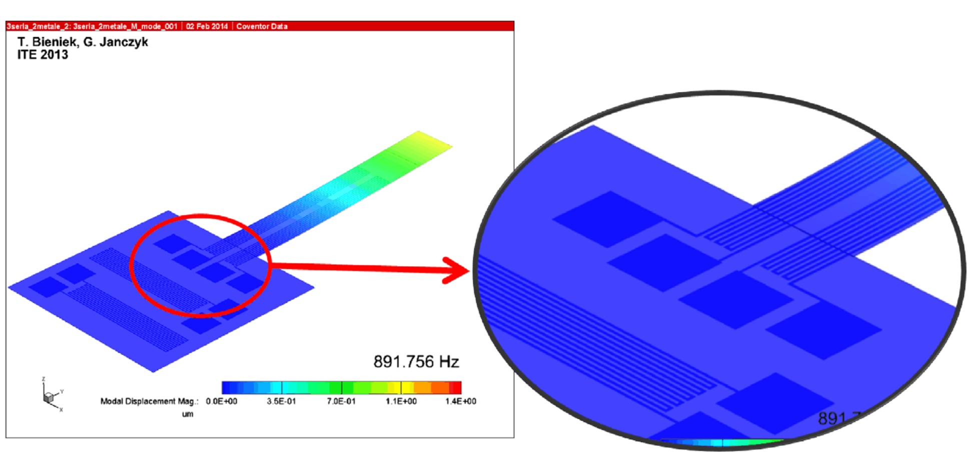

Fig. 2. First harmonic resonance mode (left) with multi-bend interconnect strip (right).