2P2-10

Advanced Non-Destructive Material & Failure Characterization in Microelectronics using Ultrasound

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1. Introduction

According to Moore's law[1] the number of transistors on a microprocessor chip will double every two years – which generally means that the chip's performance will increase with decreasing chip size within the mentioned time span. Recently, the semiconductor industry released in accordance to Moore's law the More Moore strategy[2]. More than Moore (MtM) technologies refer to silicon based or silicon derived technologies that do scale with Moore's law but also take enhanced *e.g.* electrical, mechanical or bio functionilty[3] into account. However, the realization of MtM technologies[4], als means (a) an increased complexity, (b) increased chances and consequences of failures, (c) increased difficulties to meet quality, robustness and reliability requirements.

Therefore, in the field of microelectronics there is a special need for advanced non-destructive material and failure characterization methods beyond the state of the art. Those methods should also show the potential to characterize MtM devices at-line or in-line at wafer level. A particular driving technology with respect to MtM is represented by 3D integration[3]. Here, for instance through silicon vias (TSVs) represent a key technology. TSVs display critical components since they represent the electrical connections between various layers through the silicon substrate. TSVs can be achieved by etching holes into the silcon. The holes are then either fully filled or coated on the side-wall with a conducting material like copper or tungsten. The diameter of TSVs ranges from the lower μm range up to about 100 μm. TSVs with coated side-walls are also referred in literature as open or unfilled TSVs[5]. The defect detection of TSVs represents a demanding problem. State of the art detection methods[6] show various disadvantages with respect to non-destructive testing, statistics, complexity, at-line or in-line capabilities and cost effectiveness. Here, ultrasound based methods like scanning acoustic microscopy (SAM) may show high potential candidates to conquer this challenges[6].

Another key element in MtM microelectronic devices are multilayer thin/thick film structures. In such films residual stresses are one of the main challenges[7]. Those can cause damage, fatigue, delamination and cracking of the films causing a limitation of the service life time[8]. In this context, knowledge about the material properties *e.g.* elastic properties of the thin/thick film is crucial. However, since components are getting continuously smaller reliable characterization becomes problematic. In this context ultrasound based methods like laser induced ultrasound (LUS)[9] and the use of SAWs may bring new possibilities for quality management.

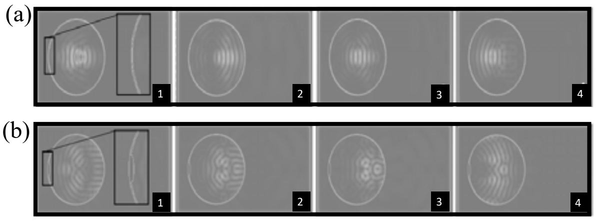

Fig.1 EFIT simulation showing the propagation of the SAW within the TSV for 4 time steps. (a) No failure, (b) a failure in the coating is present. Wave pattern changes give an indirect measure of the failure.

In this presentation, we discuss the use of advanced ultrasound methods in microelectronics for the non-destructive (1) characterization of failures in 3D integrated devices as well as (2) for material characterization of thin films used in modern MtM devices. In detail we detect artificially induced failures in open cylindrical shaped TSVs by using SAM with special acoustic lenses with a frequency of about 100 MHz. We show that this failures cannot be detected by conventional SAM approaches. This lenses give the possibility to generate surface acoustic waves (SAWs). To validate the results we use micro X-ray computed tomography (μXCT) and scanning electron microscopy (SEM). In order to understand the physics of the propagating acoustic waves we perform elastodynamic finite integration technique (EFIT) simulations[10]. For the characterization of the material properties in thin/thick films we also excite SAWs by using LUS and SAM. We show that the use of ultrasound in combination with the presented SAW approach is highly suitable to characterize MtM based technologies non-destructively and in a relaible fashion.

2. Methods

In SAM, a transducer is used, which piezoelectrically generates ultrasonic waves through a lens towards the sample of interest. Thereby the transducer is scanned in the x-y plane, keeping the z-position constant. In our analysis, we use a customized scanning acoustic microscope “SAM 400” from PVATePla which is utilized to detect failures below the surface within the TSVs. The “SAM 400” is operated in reflection mode. The sample is fully immersed in water to couple efficiently the ultrasound waves to the samples. For the measurements we use a 7 GHz ADC function card providing a time resolution of about 142 ps. For the excitation of the SAWs or Rayleigh waves we use a transducer showing an opening angle which is exceeding the critical Rayleigh angle, as well as de-focus the transducer with respect to the sample surface. The latter means that the distance of the transducer to sample surface is smaller than the focal length of the transducer.

Details for the LUS setup are described in[11]. The setup consists of two lasers. The pulsed laser is focused via a cylindrical lens on the sample surface to excite the Rayleigh waves. The pulse width depends on the laser which is in our case about 10 and 2 ns. The wavelength is 532 nm. For the detection we use a continuous wave laser and apply the beam deflection approach. For the simulation of the ultrasound sound field we use the elastodynamic finite integration technique. Here, the underlaying set of differential equations is given by the kinetics, kinematics and the material law. The velocities and stress field variables are discretized in a staggered manner on the spatial grid together with a leap-frog updating procedure in time[10].

3. Results

In this presentation we will present results with respect to the detection of failures in 3D integrated components based on SAW excitation and detection, using SAM. In addition we present results using LUS enabling the contactless determination of elastic material parameters, *e.g.* Young´s modulus and the Poisson ratio in thin/thick films. In Fig. 1 exemplarily the simulation of TSVs according to the experimental case is illustrated. SAWs can be excited on the sample surface and leak energy back to the lens and subsequently to the transducer. The detected SAWs provide information about failures with dimensions even below the lateral resolution which is usually given by the frequency of the transducer. In Table 1 exemplarily results of LUS measurements with respect to the determination of the Young´s modulus and Poisson ratio for a multilayer Si-Cu-Al-Cu stack system is shown.

LAYER	E [GPA] LUS	ν LUS	E [GPA]	ν
Cu Layer 1	132	0.35	110 - 130	0.33 - 0.36
Al Layer	70	0.33	70	0.33
Cu Layer 2	112	0.35	110 - 130	0.33 - 0.36

Tab. 1 Comparison of measured LUS results with literature values[11] for a Cu-Al-Cu multilayer system on top of a Si (100)-substrate.

4. Conclusion

The presented novel approach, which is based on the excitation and detection of SAWs allows the use of SAM for reliable and fast TSV failure inspection. In addition, we present an ultrasound-based method to characterize material parameters efficiently in a contactless manner for MtM structures on wafer level. Both show possibilities for process attendant characterization. Additional studies to measure also porous metallic layers are ongoing. Here, material parameters shall be linked to 3D microstructure properties.

5. References

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Acknowledgment

Special thanks to PVATePla for the support with the SAM system. This work has received funding from European Union's ENIAC Joint Undertaking, FP7 program P. No.: 621270 including national funding according to P. No.: 843740 (eRamp) as well as EU's Horizon 2020 research and innovation program under the Grant Agreement P. No.: 688225, (Metro43D) and the FFG project 853467.

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