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THE MODEL OF THE MECHANICAL SIMULATIONS USING A PAD STRUCTURES

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Abstract: This process is performed probing the ICs with suitable tips on a flat metal surface (PAD). Mechanical simulation feasibility of process is here presented. In most advanced technologies, in order to optimize the area consumption, Pad Over Active (POA) structures (see Figure 1) have been introduced. Active circuitry is therefore designed below the probing area with potential stress-induced problems. The behavior of probes has been simulated with a two dimensional modeling. Good agreement between mechanical simulations and experimental data has been detected evaluating probe mark and probe force. Finally, the stress on several three dimensional POA structures has been simulated to evaluate critical points.

1. INTRODUCTION

Electrical wafer sort process is performed to evaluate ICs functionality before assembling in package and installing in final application [1]. In Smart Power products current level higher than 1A per needle can be required and therefore a good electrical contact between tip and pad surface is needed. The wafer is raised up on a chuck to start contacting the probes: such condition is considered the reference status (zero level). To allow a good electrical contact, an additional overdrive of about 75-100µm is then applied.

Testing can be performed several times:

• at different temperatures;
• in order to verify failures.

The technology progresses are leading to a continuous scaling of lithographic dimensions in order to realize smaller integrated circuits. POA structures are therefore becoming more and more important in advanced technologies in order to optimize the area consumption of modern ICs.

The bonding processes have both to be compatible with these advanced pad structure. Below the last layer several metal lines at different potential are present to connect active circuitry. In all the considered structures, the basic assumption that the two uppermost metal layers are shorted together has been applied. In this case the top inter-metal dielectric (IMD3 in Figure 1) can be considered as a sacrificial layer and any crack in this region is not causing any electrical failure.

This condition has been implemented to realize robust architectures and not to impact the IC quality.

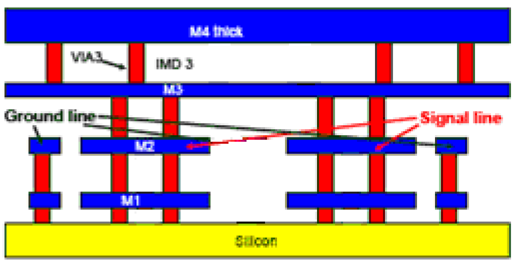

Figure 1. Pad Over Active structure section

During the process the probes induce local bending deformation and tensile stress in IMD, causing cracks when the stress is higher than the breaking point. In order to have electrical failures the following conditions must be fullfilled:

• presence of a crack in lower IMD layers

• metal extrusion in the crack causing short-circuit between two metals at different potential.

Metal extrusions usually appear after wire bonding and during the final application life time. To simulate an accelerated life time, ageing reliability tests (storage at high temperature and thermal cycles) are performed. The behavior of probes has been simulated with a two dimensional modeling. Dimensional POA structures has been simulated to evaluate critical points.

This simulation approach allows:

• to evaluate different EWS equipments behavior;

• to optimize POA layout.

2. METHODS

a) 2 – D model

The first methods analysis has been performed on a 2- D structure (see Figure 2) to verify the correct reproduction of contact effects between probe and pad.

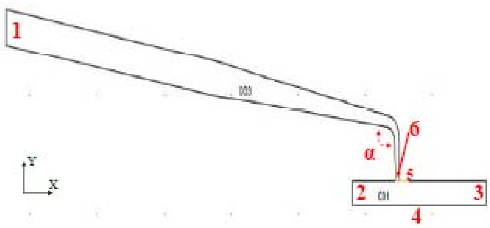

Figure 2. 2-D simulated structure

The probe layout has been imported from AUTOCAD tool, the pad has been reproduced taking into account only the top metal level. All the physical properties of the material which compose probe (WRh) and pad (Al) have been given from supplier. Probe-tip displacement in X - direction and contact force in both X and Y - directions are the three parameters taken into account to correlate simulations and measured data.

The portion of the pad where the tip shifts on during the probing process is the damaged region. Its total length is given by the tip surface plus the probe-tip displacement in X – direction.

To correctly reproduce the EWS process, the following constraints (referring to Figure 2) have been imposed:

• edge 1 fixed because the probe is anchored to an epoxy ring;

• edges 2 and 3 fixed in X direction;

• edge 4 is lifted of the imposed overdrive;

• edges 5 and 6 are the contact surfaces.

Elastic – plastic materials have been considered to take into account the plastic deformation of the pad surface. A very fine mesh has been generated in the contact region to be able to describe the aluminum erosion. Temperature has been fixed to 30°C.

b) 3 – D model

A more detailed analysis has been performed on 3-D structures and focused to analyze the most stressed regions in different POA structures. Via, tungsten plug into an IMD to connect two metal levels (see Figure 1), can be placed in several matrix types.

Three structures have been built with:

- via 3 at pitch 2µm;
- via 3 at pitch 6µm;
- no via 3 under the region.

To simulate a complete structure too many computational resources are needed and therefore a simplification strategy has been adopted using appropriate constraints: a representative subset of the pad layout has been therefore considered (see Figure 3). The considered subset is a significant region of the pad (~20 x 6µm2) containing all layers which is repeated several times in X and Y directions. It can be considered the single element of a matrix. Von Mises stress is the parameter taken into account to evaluate the most stressed regions.

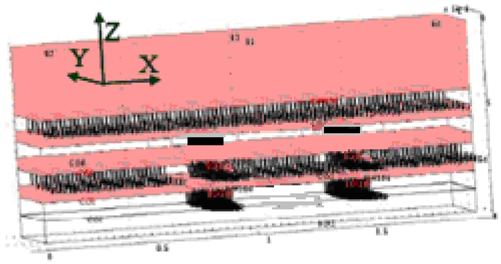

Figure 3. Example of a 3-D simulated structure

Referring to Figure 3 all lateral surfaces have been fixed in X and Y directions to reproduce the adjacent parts; the bottom surface has been fixed in every direction; on the top surface has been applied a pressure in Z and X direction coming from 2-D simulations or from technical data of probe supplier.

Elastic – plastic materials have been considered to take into account the plastic deformation of the pad surface. Temperature has been fixed to 50°C. In order to verify the simulation results, the main considered parameters, probe-tip displacement and contact forces as previously reported, have been measured with suitable equipments

One of the most important targets for the process is to limit the induced damage to a narrow surface, since a wide damaged area does not allow a reliable bonding process [2][3]. The process has been performed on one wafer applying an overdrive of 90 µm, considering a probe-card realized with the same needles as described and simulated Probe mark length has been measured using an optical profilometer

This equipment allows reproducing a 3-D image of the pad surface and to measure the scrub in any direction. An example of such analysis is reported in Figure 4.

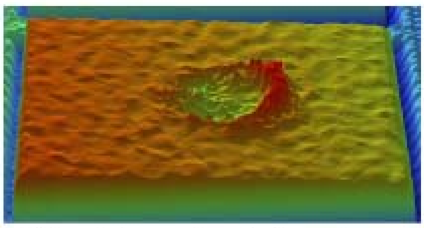

Figure 4. 3 – D pad image (optical profilometer)

Every probe card is built to guarantee a specific contact force, usually defined respect to the applied overdrive (g/mil). To better know the vertical and horizontal components of this force a dedicated setup has been used (see Figure 5). The equipment is made by a mechanical support, where is placed the wafer, which is lifted by an electric motor. Two force transducers, one for the vertical force and one for the horizontal force, are connected to the support. The probe card is fixed laterally. The setup is managed by a personal computer giving the input for the electric motor and reading output from transducers. Overdrive and rising speed can be given as input variables.

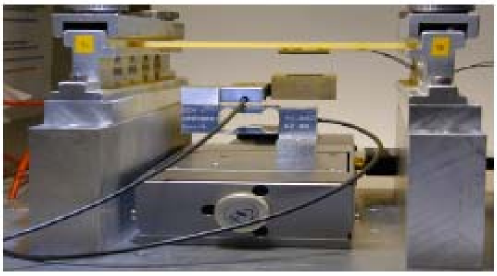

Figure 5. Contact force measure system

EXPERIMENTAL RESULTS

In this section first simulated 2 – D probe marks and contact forces in X and Y directions will presented and compared to experimental measurements.

Then 3 – D simulations of three different pads layout probed with three different probes will be compared to measurement results.

2 – D simulation results

2 – D simulation of a tungsten-rhenium probe with an applied overdrive of 90 μm to the pad shows the typical deformation of a probe (see Figure 5 and 6). The angle α (see Figure 2) is initially set to have a planar contact between tip and pad surfaces then, during the probing process, it increases reducing the region of the tip surface which contacts the pad. Initial structures

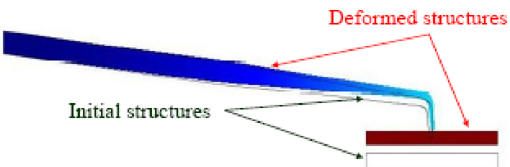

Figure 5. 2 – D structure total displacement

For this reason Figure 7 shows that the simulated probe-tip displacement in X direction is not constant along the tip surface (35 μm). As previously reported, the total damaged region is given by tip contact face plus the probe-tip displacement in X – direction (~25.47 μm). The length of the total simulated damaged surface is about 68 μm.

They has been performed on one wafer and probe mark length has been measured (see Figure 8): the obtained value of 35.6 μm is in good agreement with the simulated one.

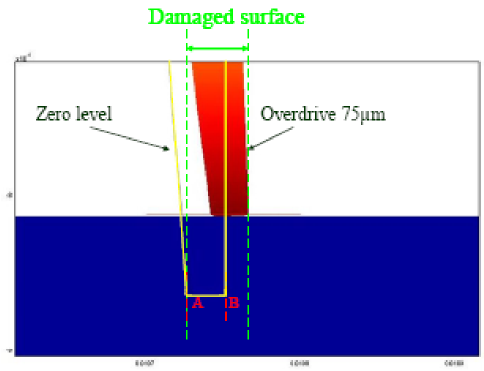

Figure 6. X-displacement of 2D structure simulation

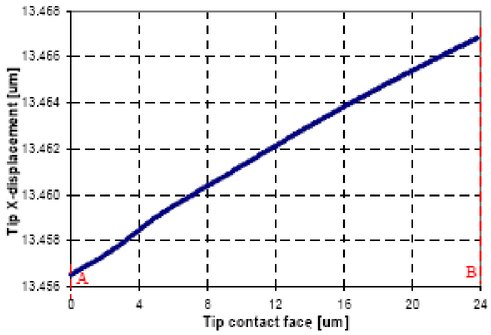

Figure 7. Tip displacement in X direction

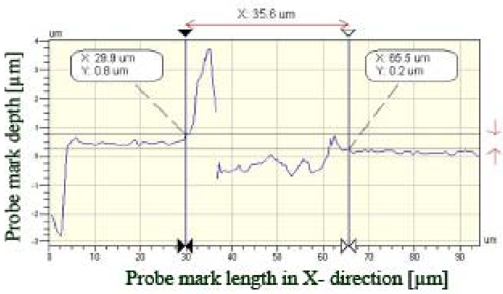

Figure 8. Measured length and depth of the damaged surface of a probed wafer

The simulated vertical and horizontal contact forces are reported, in function of the applied overdrive, in Figure 9 and 10 compared to the measured ones.

The vertical force is 10 times the horizontal force. In both cases a reasonable agreement can be observed, the discrepancies will be discussed in paragraph 4.

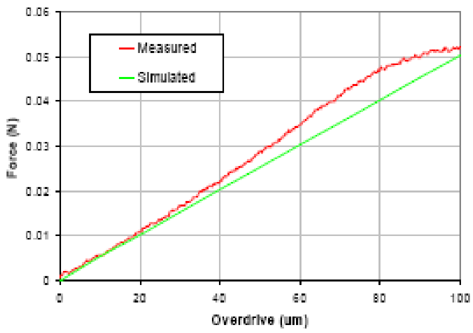

Figure 9. Vertical force: simulated vs. measured

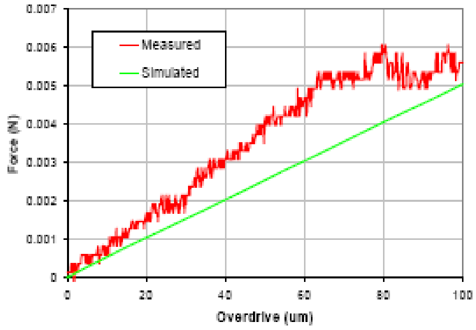

Figure 10. Horizontal force: simulated vs. measured

3 – D simulation results

3 – D simulations of three different POA structures show critical points and different stress peaks. The stress has been considered along a linear horizontal axis placed at midheight of the top IMD. The peaks reported in Figure 11 are located at the interfaces oxide/tungsten (when vias are present) and in these regions there are the most stressed ones.

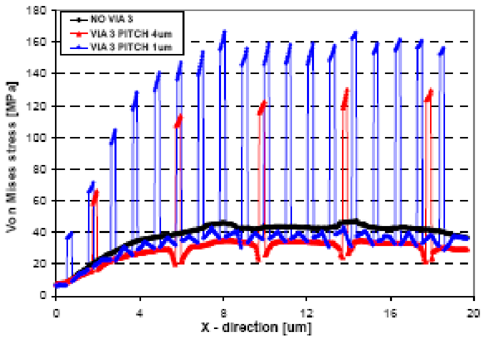

Figure 11. Von Mises stress in last IMD of POA structures

As a confirmation of such simulation result, a SEM image of a crack is shown in Figure 12.

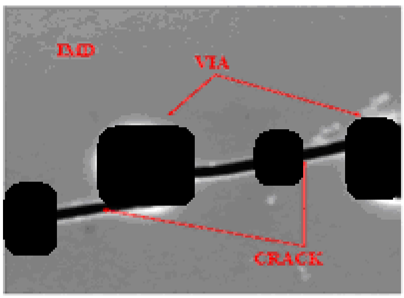

Figure 12. SEM image of an IMD crack

Moreover the least stresses architecture (no top via) has been simulated to evaluate the impact of several probe cards with different contact force:

- 1.8g / mil (WRh – probe card)
- 2g / mil (CuBe – probe card)
- 2.8g / mil (W – probe card).

The data are reported in Figure 13 and can benoticed that increasing the probe card force of 55%, the maximum Von Mises stress increases of 39%.

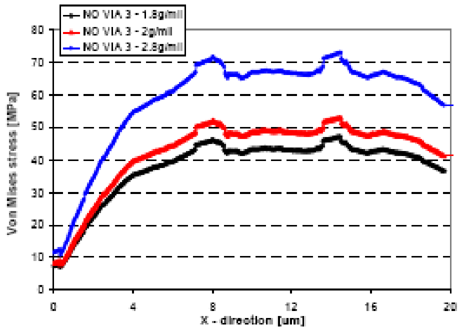

Figure 13. Von Mises stress in last IMD induced by different probe cards

4. DISCUSSION

2 – D simulations results of EWS process using a WRh probe card show a good agreement with all measured data. The probe behavior and the main process parameter have been well reproduced. The simulated damaged area shows a good agreement with the physical measurement.

The simulated contact forces show a good agreement taking into account the initial and the final values but some few discrepancies in the intermediate region are noticed, which could be explained as follows. The wafer is lifted up by the equipment with a given speed which, after the initial contact with the probe, decreases to stop at the right overdrive. The effects due to acceleration/deceleration are not considered in the static simulation of this work.

To correlate 3 – D simulations with physical measurements is more difficult because of the complexity to measure the stress inside a structure. Only the final effects can be noticed. However the most relatively stressed regions have been detected and it allowed us to understand that increasing via pitch there is a wider region where the local maximum can decay: in this way there are not only less high stressed regions but also lower peaks. All results can be considered to provide guidelines for a more robust POA structure design.

5. CONCLUSIONS

2 – D modeling process has been developed with good agreement between simulated and measured data. Applying stress to 3-D modeling of POA structures, some critical points have been detected. These simulation activity will be useful to the aim of testing the electronic devices without inducing any structural mechanical problems to POA structures which provide a significant die size saving.

6. REFERENCES

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