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Electro-mechanical studies of micro-tube insertion into Al–Cu pads for 10 μm pitch interconnection technology and 3D applications

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ABSTRACT

Various interconnection technologies such as reflow soldering, thermo-compression, Direct Bond Interconnect (DBI), Solid Liquid Inter Diffusion (SLID) and insertion are under intense investigation in order to accommodate the latest revision of the International Technology Roadmap for Semiconductors (ITRS). The room-temperature insertion technology has been proposed and developed using micro-tubes as inserts to address most of the industrial bonding issues.

In the present work, we experimentally study the electrical and mechanical behavior of a single golden micro-tube and its insertion into Al–0.5Cu pads. A modified nano indenter coupled with an electrical measurement device were used in order to determine the insertion mechanisms and mechanical behavior during large plastic deformation of the gold and Al–Cu. Furthermore, finite element (FE) simulations are added to complete the analysis. The numerical load and displacement results are compared with experiments and complemented with a geometrical cross section examination.

1. Introduction

In order to address industrial requirements and 3D integration issues, a lot of research is focused on the main bonding technologies such as reflow soldering, thermo-compression, Direct Bond Interconnect (DBI), Solid Liquid Inter Diffusion (SLID) and insertion [1,2]. Over the last few years, shortcomings caused by planarity, parallelism and roughness defects have been investigated and mitigated. Additionally, bonding parameters such as high process loads, temperature and low hybridization speeds are also critical. However, by decreasing the interconnection pitch, the size of components, and increasing the number of stacked dies, all of these issues have to be revisited. That is why the room temperature micro-tube insertion technology is a good candidate to address all of these industrial difficulties [3].

This proposed insertion technology uses hard golden micro-tubes to penetrate into a ductile material, in order to establish a reliable electromechanical contact. As illustrated in Fig. 1 and presented at the Electronic Components and Technology Conference (ECTC) [4], this technique can easily address 10 μm interconnection pitch and 3D integration stacking. Micro-tube height can be tailored to compensate for roughness, non planarity and parallelism, and their small cross section area allows reducing the insertion bonding load. In addition, the micro-tube insertion process does not require any flux since breaking the pad oxide layer. As it is a room temperature process, all the differential thermal expansion issues are avoided. However, in order to meet industrial requirements it is mandatory to achieve electromechanical characterization of the micro-tube and of its insertion behavior into Al–0.5Cu pads. The main objective of this work is to fully

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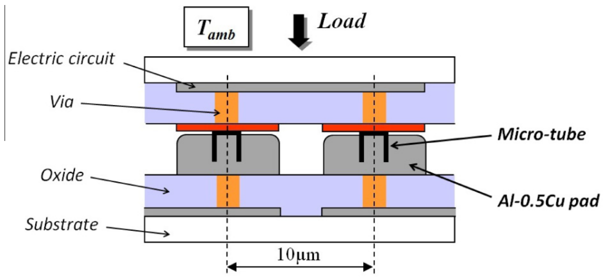

Fig. 1. Schematic drawing of the insertion flip-chip technique.

understand the micro-tube insertion behavior in order to determine the best assembly parameters and help to design future interconnection geometries.

In the present paper, we first focus on the compression behavior of a single golden micro-tube, then on mechanics of its insertion into Al–0.5Cu pads. This alloy is one of the most common materials used in microelectronic applications. For that purpose, we use a nanoindenter to accurately measure the load required to strain a single micro-tube and to analyze its insertion behavior. An electrical measurement device is added to characterize the evolution of the electrical contact as a function of the insertion time. In parallel, a finite element (FE) analysis is carried out to analyze experimental results and to quantify the stress/strain distribution in the different components.

2. Materials and methods

In this study, we worked with 2.8 µm high micro-tubes coated with a 240 nm thick gold layer. This gold layer is grown by e-beam evaporation and exhibits a grain size ranging from 50 nm to 250 nm. Some previous micro diffraction experiments performed on gold thin film [5] have shown significant texture which is often encountered in the case of face-centered cubic (fcc) materials. The hard frame of the micro-tube is made of titanium and tungsten alloys. As presented in Fig. 2, micro-tube samples have been prepared using Focused Ion Beam (FIB) in order to study the initial micro-tube structure. According to literature, all structural data are used to choose mechanical properties implemented in simulations.

First, the compressive micro-tube behavior was studied by a compressive test performed with a spherical diamond indenter of 50 µm radius (Fig. 4). Making use of the nanoindenter accuracy in load and displacement, the diamond tip is first aligned above the micro-tube, and used to compress it [6]. Thanks to this set up, the load required to strain the micro-tube is measured as a function of displacement. As illustrated in Fig. 3, the micro-tube diameter was equal to 2 µm in order to reduce radial stresses and strains. During all these experiments, the displacement rate was equal to 10 nm/s and the resulting load was measured.

Then, a 4 µm in diameter micro-tube was used as an indenter tip in order to study its insertion behavior (Fig. 5). In this case, a single micro-tube sample is glued on a dedicated holder in order

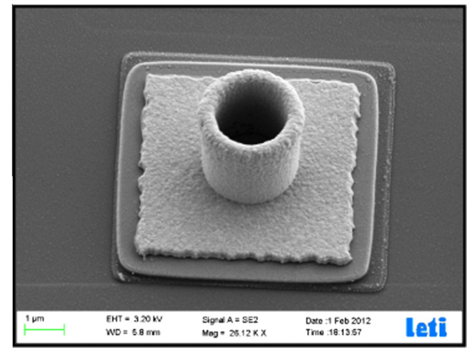

Fig. 3. 2 µm diameter micro-tube.

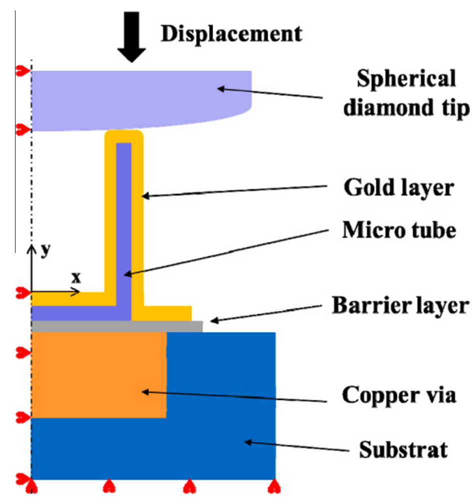

Fig. 4. Schematic axisymmetric model of the compressive test.

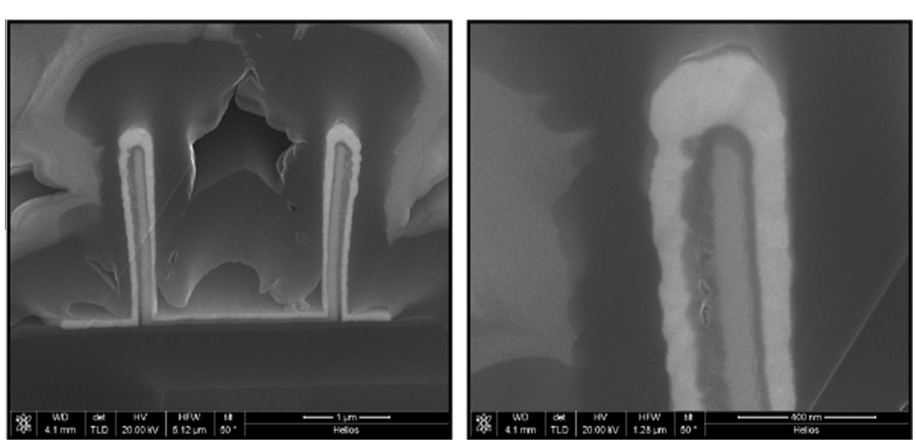

Fig. 2. FIB prepared cross section of a micro-tube.