Self-Contained Built-In-Self-Test/Repair Transceivers for Interconnects in 3DICs

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Abstract—In this paper, we propose self-contained built-in-self-test/repair (BIST/R) solutions to improve the reliability of the direct face-to-face copper thermo-compression bonding. A dual-mode transceiver is presented to operate either as an ohmic mode when the bonding has low resistance or as a capacitive coupling mode when the bonding is faulty showing high resistance.

Keywords—3DIC; capacitive coupling; interconnect reliability

I. INTRODUCTION

Three dimensional (3D) integration technology has been considered as a solution to complex system integration making heterogeneous integration viable. There are a number of compelling technologies enabling the 3D integration. State-of-the-art copper-to-copper thermo-compression bonding technology is employed by Tezzaron for wafer-to-wafer stacking [1]. Fig. 1(a) illustrates the examples of F2F and F2B bonded 3DICs. With the alignment inaccuracy of less than 1 μm in the wafer level bonding, fine-pitch bonding for high level of interconnects density can be achieved. According to Tezzaron, only over 50% of the interconnects in stacked CMOS image sensors are utilized for electrical; whereas, the rests are for mechanical support. An example of the failed copper fusion interface due to insufficient pressure is shown in Fig. 1(b) [2]. Its bonding interface has only a few contact points and thus, the resistance of the bonding interfaces increases significantly affecting the signal integrity. Although the entirely separated pads exhibit strong coupling effect due to their closed proximity, the receiver designed for ohmic contact will not be able to recover the signal due to the undefined DC level at the receiver input. To address this issue, we propose a dual mode receiver with the capability of built-in-self-test/repair (BIST/R). A resistance sensor embedded in the proposed receiver monitors the bonding interface condition autonomously and reconfigures the receiver to work as either ohmic contact mode or capacitive coupling mode. The transceivers are self-contained and not requiring any other peripheral scanners and complex control circuitry.

II. PROPOSED DUAL-MODE TRANSCEIVER

Fig. 2(a) presents the model of copper thermal fusion interface at the near failure condition [3]. Two rough surfaces of both TX and RX pads are modelled as one perfectly smooth pad (RX) and equivalent rough pad (TX). The gap between two pads is (h) which is the distance from RX pad to mean surface of TX pad. Considering the worst case scenario, only a single contact point presents whose asperity diameter is given as 2a. Due to the small constriction shown in Fig. 2(a), the electrons travel in ballistic motion and thus, the constriction effective resistance is R12 whose equation is given in Fig. 2(b). The value of R12 deviates from the ohmic resistance when the constriction radius is less than the electron mean path of the conductor. R12 become higher than its ohmic resistance when the contact radius is less than its electron mean path. In the R12 equation, K is the Knudsen ratio and (K) is a function decreasing from 1 to 0.694 as K increase from 0 to ∞.

Figure 1. (a) Cross-section of 3D integrated chip from Tezzaron, (b) cross-section of copper thermal fusion pad with varying pressure.

Figure 2. (a) modeling of F2F stacked copper direct bonded pad at near failure condition, and (b) an electrical model of (a).

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The design of the dual-mode transceiver is based on the capacitive coupling transceiver [4] shown in Fig. 3. At the receiver side, the input and the output of I1 are connected through a pass-gate resistor to detect the data transition at RX and pulses are produced at the I1 output. These are amplified by I2 to achieve full swing digital signal. To make it work in ohmic contact, the pass-gate should be disabled. To address this issue, in the proposed dual-mode transceiver, a resistance
sensor is introduced to enable and disable the pass-gate in accordance with the interface resistance (Fig. 4). During the start-up, the node P from L2 is reset to GND and TX will be reset either to GND or VDD depending on the system configuration. At that point, the pass-gate is enabled and the weakly biased RX node is pulled up to VDD (when TX is 1) or down to GND (when TX is 0) by the stronger driver when the copper interface presents low resistance. During the sensing period (when EN = 1), S1 and S2 fight each other to overwrite P and N. When RX is connected to GND, S2 wins S1 and P is pulled up to VDD disabling the pass-gate. When the interface resistance is high, the RX node will be weakly biased around VDD/2. In this case, both S1 and S2 are not strong enough to overwrite the initial value in L2, which sets the transceiver in ohmic mode. The proposed resistance sensor exhibits a hysteretic window for F2F stacked copper thermo-compression pad.

The proposed resistance sensor exhibits a hysteretic window between V_L and V_H. Target values for V_L and V_H are 200 mV and 1 V, respectively when VDD is 1.2V. The resistance value (R12) at the trigger point is found to be 3 kΩ when 1 kΩ drive is used (Fig. 5(a)). The sigma of V_L and V_H is ~30 mV obtained from 1000 points Monte Carlo simulation and that subsequently varies the trigger R12 values from 1 kΩ to 5.6 kΩ. However, this trigger point variation within 1-5.6 kΩ is acceptable because it has little or no impact on the signal integrity. The parametric simulation of the dual-mode transceiver is carried out with a 5 µm × 5 µm thermally compressed pad model whose gap (h) and the asperity radius (a) are swept from 10n to 100n and from 1nm to 0.001nm, respectively. The chosen pad dimension is to achieve enough coupling when h is at 100 nm. The respective C_C values at h = 10 nm, 25 nm, 50 nm and 100 nm are 22 fF, 9.2 fF, 4.7 fF and 2.2 fF. These values are extracted by a FEM simulator using air as a medium in the gap. According to the simulation, the jitter performance of both ohmic mode and capacitive coupling mode are relatively similar across all the parametric points (Fig. 5(b)). The maximum propagation delay different across all the points is just 35ps (Fig. 5(c)). The power consumption of the transceiver is peaked at the capacitive coupling mode when h is 10nm, where C_C is the largest (Fig. 5(d)). The larger C_C value is, the higher the power consumption is as more charges are coupled to RX node. Note that the resistance sensor is only activated once during the system start-up and it won’t incur any additional power during normal operation.

III. CONCLUSION

This paper presents a solution to test and repair faulty F2F copper compression bonding. A dual mode transceiver is proposed. Due to receiver’s ability to adapt the signal recover mode assisted by the resistance sensor, it is self-contained and doesn’t require any control circuit for fault scanning.

REFERENCES