Microelectronics Reliability 55 (2015) 602–607

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Development of a fast method for optimization of Au ball bond process

J. Gomes *, M. Mayer, B. Lin

Department of Mechanical and Mechatronics Engineering, University of Waterloo, 200 University Ave. W., Waterloo, ON N2L3G1, Canada

ARTICLE INFO

Article history:
Received 17 October 2014
Received in revised form 17 December 2014
Accepted 18 December 2014
Available online 20 January 2015

Keywords:
Wire bonding
Process optimization
Fast method
Bond geometry
Gold ball bond

ABSTRACT

An accelerated optimization method is developed to minimize required time and resources, and demonstrated for a 25 μm diameter Au ball bonding process. After a preparation phase to pre-set many parameters based on literature values, the values for more significant process parameters, impact force (IF) and EFO time (t_{EFO}) for a given target bond geometry are optimized in a second phase, utilizing a 3^2 full factorial experiment and the response surface method (RSM). The target bond strength of 120 ± 2 MPa is achieved in a third phase by optimizing the ultrasonic energy (US) parameter using an iterative method. For an example process with a target geometry of 58 μm for the bonded ball diameter measured at the capillary imprint (BDC) and 16 μm for the height of the bonded ball (BH), the optimized process parameters (phases 2 & 3) can be found in less than 4 h. The values for IF and t_{EFO} are found to be 424 mN and 0.474 ms, respectively. The bond is strengthened with incrementing US until additional ball deformation occurs. The bond strength achieved is >120 MPa with 48.6% US. Other bonding parameters include EFO current (I_{EFO}) = 50 mA, temperature (T) = 158 °C, bond time (Bt) = 20 ms, and bond force (BF) = 185 mN.

1. Introduction

Wire bonding is the most widely used method for making interconnection in semi-conductor packaging with more than 80% of integrated circuits (ICs) using thermosonic wire bonding [1]. Gold (Au) has been the dominant bonding wire material since the beginning of wire bonding. However, the high price of Au has been pushing the wire bonding industry to look for alternative bonding wire materials. Copper (Cu) [2–6] silver (Ag) [7], and alloyed wires [8] have emerged as potential replacement to Au in recent years. With each new wire material, the bonding process is required to be re-qualified. In general, several process setup tasks are required before any mass production with new bonding wire can be started. The wire bondability is established by proper selection of equipment, materials, and process. Bond reliability is assured by accelerated aging tests. One of the demanding process setup tasks is ball bond optimization.

Six basic parameters of a typical ball bonding process can be used to determine basic profiles of electric flame-off (EFO) current, bond force, and ultrasonic energy, as shown in Fig. 1. These parameters include current amplitude and duration of the EFO spark (I_{EFO} and t_{EFO}, respectively) for free air ball (FAB) formation, impact force (IF) for FAB deformation, and bond force (BF), ultrasonic energy (US), and bond time (Bt) for bond formation. When the IF is substantially higher that the BF (double load profile), most of the ball deformation happens during impact in contrast to low IF process with deformation during ultrasonic bonding (US deformation) [9]. The process of bonding balls with mainly impact deformation is found to reduce cratering (a defect related to bonding stress) [9].

Optimization methods can include simple trial and error, full factorial design of experiment (DOE), response surface methodology (RSM), and numerical finite element analysis (FEA) [2–4,10–15]. For example, a sequence of tests is carried out in [2] to optimize ball bond quality, starting with variable selection using an analysis of variance (ANOVA), followed by screening experiments, a fractional factorial DOE to find the detailed ranking of the process factors, and finally a central composite type DOE combined with the response surface method to find process windows for the main factors. Such a stepwise approach has excellent results but requires substantial effort, and the adjustment of the geometry of the bonded balls was not described in [2].

More recent attempts to optimize the wire bonding process parameters are reported in [5,6]. In [5], an experimental design and grey relational analysis (GRA) is used to identify the relationship between process parameters and responses first, and then parameters are optimized using a fuzzy inference system and Taguchi method. The method provides superior optimization performance, however, it is a complex method requiring detail understanding of the process steps and the method did not focus on optimizing the bonded ball diameter. GRA is also used in [6] where an integrated neural network and genetic algorithm method is

* Corresponding author.
E-mail address: jjgomes@uwaterloo.ca (J. Gomes).

http://dx.doi.org/10.1016/j.microrel.2014.12.013

applied to achieve optimized parameters. Optimized parameters are then verified experimentally using RSM and excellent results are achieved. The method, however, is long and complex, and requires substantial amount of time and statistical understanding.

A method for a quicker verification of the bondability would be helpful when new types of wires are investigated. This study aims at applying existing process knowledge and models to develop a new method consisting of full factorial experiment, response surface method, and iteration resulting in faster ball bond optimization. This paper reports the details of a method that aims at making wire bonding studies more efficient, e.g. when process parameters need to be adjusted for different temperatures, wires, and substrates, or when machine-to-machine variations need to be identified. To completely setup a wire bonding process, many tasks are carried out with existing methods. The method presented here aims to be added to the existing methods for quicker and more accurate adjustment of ball bond geometry and strength.

2. Experimental

The bonding experiments are carried out on an ESEC 3100 automatic wire bonder (Besi, Cham, Switzerland). The capillary used is a commercial ceramic bottleneck capillary having a hole diameter of 35 µm and a chamfer diameter of 51 µm. The wire used is a 25 µm diameter 4 N (99.99%) Au wire. Test chips used for the bonding process optimization are mounted on ceramic sidebrazed DIP substrates (Fig. 2). The aluminum (Al) metalized bonding pads contain 0.5% Cu dopant (Fig. 3). A total of 68 bond pads are used on each test chip. Bond sample size is typically five for the average and standard deviation values. The wedge bonds are made on the substrate terminals which are metalized with Au. All bonds are made at a nominal heater plate temperature of 175 °C. The actual temperature on bond pads is ≈158 °C.

The ball bond quality is measured based on bond geometry and shear strength (SS), and following JEDEC JESD22-B116A standard [16]. Dimensions measured include bonded ball diameter at capillary imprint (BDC) and bonded ball height (BH) as shown in Fig. 4. Values for shear force (SF) of ball bonds are measured in gram-force (gf) with a shear tester (1 gf = 9.81 mN). Bonds are shear

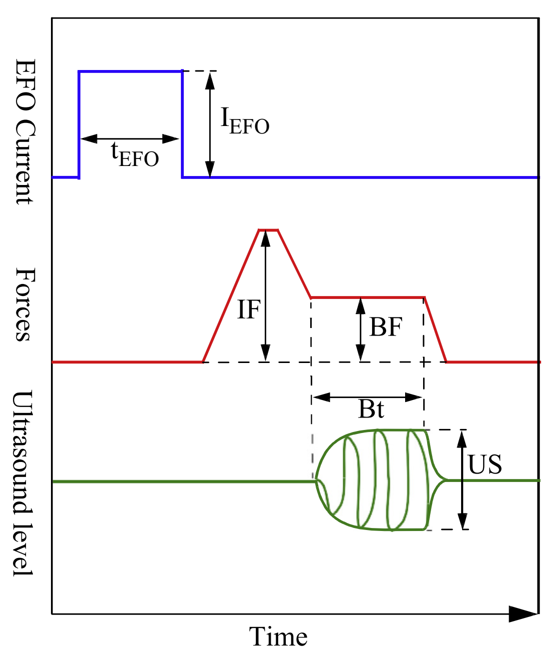

Fig. 1. Profiles of basic parameters for ball bond process.

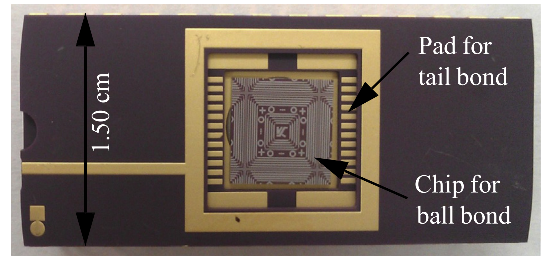

Fig. 2. Picture of test chip mounted on substrate.

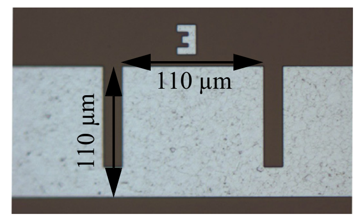

Fig. 3. Micrograph of ball bond pad (with dimensions) used for optimization.

tested in the direction perpendicular to the previously applied ultrasonic energy and towards the wedge bond [17]. Values for SS are calculated by dividing SF by an estimate of the cross-section area of the bond which is calculated from the BDC. Eq. (1) is used to normalize the shear test values so that the bond strengths can be compared from one ball size to another [1]. In this study, SS, SF, and BDC are measured in MPa, gf, and µm, respectively.

$$SS = \frac{SF}{\pi \times (BDC/2)^2} \quad (1)$$

FAB diameters are measured in the x and y directions using optical micrograph as shown in Fig. 5, and the average of the Δx and Δy measurements is taken as the FAB diameter. Similar to the FAB measurement, the BDC is measured twice in orthogonal directions and the average is taken as shown in Fig. 6a. BH is measured from the change required to focus on the bottom and top of the ball bond (Fig. 6a and b).

Effective stress on the ball bond during bond formation can be quantified by dividing the BF value with the cross-sectional area of the bond which is measured by BDC. For the purpose of this study, Eq. (2) is developed to calculate that normal bond stress, σ_N, induced by the BF. In this study, σ_N, BF, and BDC are measured in MPa, mN, and µm, respectively.

$$\sigma_N = \frac{BF}{\pi \times (BDC/2)^2} \quad (2)$$

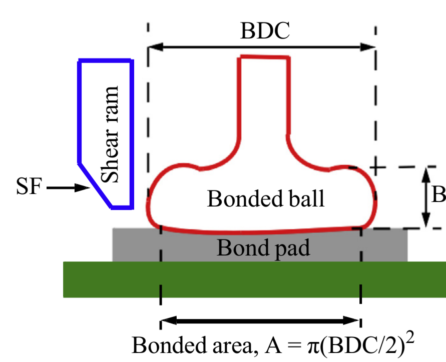

Fig. 4. Schematic defining dimensional parameters of ball bond.