

Electric NDT Method to Estimate Wirebond Pull Force

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Abstract

The microelectronics industry strives to create fast and reliable methods to non-destructively estimate bond quality. We measure the electrical contact resistance (CR) to estimate the strength of ultrasonic wirebonds. A Kelvin-Cross Resistor determines the CR between the bond wire and the substrate. This value is used to estimate the contact area and thus the maximum pull force that the contact can withstand. The method is non-destructive, i.e. a measurement is done with no mechanical stress applied to the bond wire. The experiment verified the applicability of the proposed method. The results show that the probability that the bond, below the nondestructively measured 0.58 mOhm, fails to qualify the MIL-STD limit, 25 mN for 25 µm Al wire, is less than 1 ppm. We propose the method for US wirebond quality monitoring and pull force estimation.

Keywords: Contact resistance, non-destructive testing, wirebond

Introduction

Microelectronics production demands high yield and long term reliability, which can be achieved only by proper process control. Bonding thin metal wires from component terminals to circuitry is a major part of the microelectronics production. Currently, the wirebond quality is typically tested only after the bonding relying on statistical methods, such as destructive pull tests or optics [1], [2].

Electronic failures and failure analysis occur throughout a product's life cycle. These failures and their associated analyses become more costly as the product progresses into each successive phase of technology development and market maturation [3]. Therefore a reliable, fast and low cost test method to qualify the product as early in the production as possible can increase reliability and may increase overall net profit [3]. Of special interest in the ultrasonic wirebond testing are non-destructive (NDT) methods that test each individual bond.

Electrical conductivity and mechanical strength are two important properties of wirebonds. In this article, our aim is to non-destructively estimate the maximum pull force that a wirebond can withstand. We do this by means of contact resistance (CR) measurements.

Theory

According to Harthoorn [4] a wirebond's ultimate pull force and its bonded area are linearly related.

$$F_{ul} = t_{ul}A, \quad (1)$$

where t_{ul} is the ultimate tensile strength of the bonded material. The relation between the contact resistance (R) and the contact area (A) is

$$R = \rho_c / A, \quad (2)$$

where ρ_c is a specific contact resistance [5]. Equation 2 has limitations with regards to its accuracy due to assumptions that the potential is constant in the contacting layers and that the current density entering the contact window is uniform [5].

The relation between the maximum pull force that the bond withstands and the CR is obtained by combining eq. 1 and 2

$$F_{ul} = t_{ul} \rho_c / R. \quad (3)$$

Methods

The contact resistance can be measured, using a 4-wire test [6], Fig. 1.. A constant current is driven through I_1 and I_2 . The potential is measured between V_1 and V_2 . The only common part of the transmission lines of current and potential is in the bond contact volume shown by the arrow. The potential difference of V_1 and V_2 is created in that contact. A high impedance measurement setup was used to minimize the current between V_1 and V_2 . Consequently, the transmission lines cause a negligible potential drop.

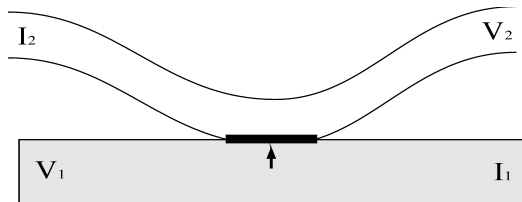


Fig. 1. CR- measurement of a single bond using the 4-wire test method.

Sixty-six measurements were carried out to measure the CR of the single bonds. Standard 25 μm Al(1%Si) wirebonding wire manufactured by SPM was used. Bonds were done to a gold substrate with a Delvotec 6400 wedgebonder that employed a 60 kHz frequency transducer. The contact resistance was measured with a HP4284A LCR-meter. To reduce the effects of noise, a long averaging time (96 s) was used. Destructive pull tests were carried out immediately after the CR measurements. To measure the CR of a single bond, the setup presented in Fig 2, was built. Stitch bonds were used, cfr. Fig. 2., to avoid stress to the center bond caused by wire tear off. Probe needles, identified by letters I and V, were in contact with three bonding pads during the CR-measurements. The wire was pulled between the first and the second bond (shown by the arrow in Fig. 2.). The wire is stitch bonded to three bonding pads. Four contact probes on the bonding pads are used to measure voltage (V) and current (I). The CR is measured for the bond attached to the center pad. The arrow shows the position for the pull hook of the destructive pull test.

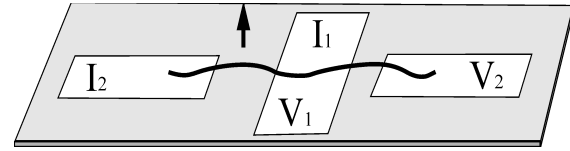


Fig. 2. Scheme for the center bond CR-measurement.

Measurements

Sixty-six NDT measurements were done to measure the CR-method's capability to estimate the maximum sustainable bond pull force, cfr Fig. 2. The process parameter 'bond force' (BF) was varied between 4 - 14 (machine units) to create variation in the CR-output, whereas the other bond parameters were held constant (Ultrasonic power (USP) 28 (machine unit), ultrasonic time (UST) 100 ms). To estimate the variations caused by the bonding process and the measurements 26 out of 66 measurements were made with fixed process parameters (BF 8, USP 28, UST 100).

The maximum sustainable pull force was determined by the computer controlled pull hook and electrical scale (Precisa 1620C) measuring forces. The precision of the scale was 0.01gf. The geometry of the loop was estimated visually by the microscope and by the bonding process loop parameters. The maximum sustained pull force was calculated as

$$F_{ul} = F / (2 \sin \theta), \quad (4)$$

where F is the scale reading and θ is the angle between the bond pad and wire [7].

Since the main interest of the measurements was to show the capability of the CR-method to estimate the maximum sustainable pull force, the bonding parameters were chosen to produce more lifted bonds than heel brakes. In case of the heel brake the pull force value reflects the wire strength and only a minimum limit of the contact strength can be estimated, whereas in case of the lifted bond, the PF-value reflects the contact strength.

Results

The 66 data pairs of maximum sustainable pull force and CR are presented in Fig. 4. Two bond breaking modes, lifted and heel brake, are presented.

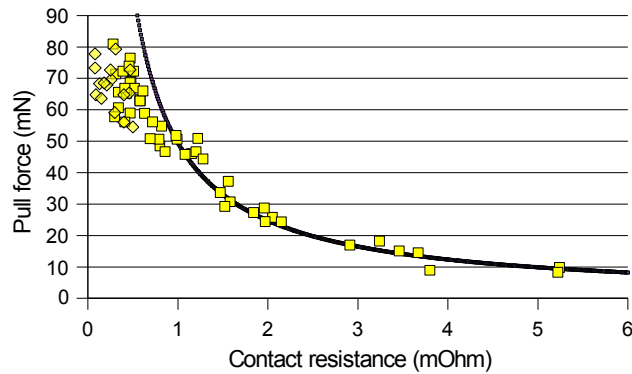


Fig. 4. Contact resistance as a function of maximum sustainable pull force. Two breaking modes, lifted (square) and heel brake (diamond), were observed. According to the eq. (3), ‘lifted’ data points should lie along the black line when ρ_c is constant (in the figure $\rho_c = 0.59 \Omega\mu\text{m}^2$ and $t_{ul} = 85 \text{ MPa}$). However, for low CR values, the measured values diverge from the prediction.

The results of the constant process parameter test are presented in table 1. The number of measurements were 26, including 7 heel brake and 19 lifted bonds in the pull test.

Table 1. Constant process parameter test results (n=26)

Pull force	Contact resistance
66±8 mN	0.42±0.16 mOhm

An average $\pm$ one standard deviation. 26 measurements with constant process parameters (BF 8, USP 28, UST 100).

Conclusions

As shown in Fig. 4. the CR-method can be used to nondestructively estimate the maximum sustainable wirebond pull force. In table 1. the pull force values (66±8) mN exceed five times the standard deviation of the MIL-STD qualification limit 25 mN for 25 μm Al wire, whereas the upper

limit for the contact resistance with one standard deviation is 0.58 mOhm. With this result the probability that the bond, below the nondestructively measured 0.58 mOhm, fails in MIL-STD test is less than 1 ppm. In wirebond mass production the limits for acceptable CR and pull force will be set according to the demands of the yield and quality of the product, but the above estimation shows that the CR-method can be used to measure wirebond quality.

The discrepancy between data (lifted bonds in fig. 4.) and the shape of the theoretical estimation curve is assumed to be caused by the limitation of the CR model presented in eq. 2.. The model and its validity are discussed in more detail in [5], [6] and [8].

In practice the presented CR measurement can nondestructively estimate individual maximum sustainable bond pull forces. The main limitations of the presented measurement setup are its long measurement time (96s) and the need for manually controlled probe needles. Next we therefore intend to improve the system so that each wirebond quality can be measured in real-time during the bonding process. Further on we propose that CR-development could be used to actively control the bonding process. To do so requires the rapid feedback control of the bonding parameters.

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