Original Research Article

Wire Length Formulation Using Wire Density, Volume and Weight for Hand Calculation and Verification of Wire Usage

ABSTRACT

Wire Bonding process uses precious materials such as gold, silver, and copper wires to create a connection from the die to the strip and completing the circuitry of a semiconductor unit. Wire consumption is identified by length that is consumed per unit and higher consumption leads to high cost of the product. Upon unit processing, the standard wire consumption per unit is 0.036 equivalent to 27.8K units per 1000 meters spool but only produced 26.9K units. The study focuses on validation of the possible cause of lacking 800 units equivalent to 32 meters of wire length. Using the gold wire density, volume, and weight of the wire, wire length is formulated that can be used for hand calculation and verification of actual wire length. Methodology used for validation resulted that the actual unit consumption for wire length is at 0.037 meters which lacks 0.001 meters per unit, and this is equivalent to approximately 800 units per 1000-meter spool. In parallel, supply is compliant with the 1000 meters of wire per spool. Through the results collected, it was concluded that the standard is not sufficient to be the reference for the actual wire consumption resulting to the impression of high wire consumption. It was recommended for the alignment of the standards with the actual validation using the methodology stated on the study and hand calculation using wire length formula.

Keywords: Wire Length, Wire, Density, Weight, Cylinder Volume, Wire Usage

1. INTRODUCTION

Wire Bonding is the process of connecting the die to the strip leads which establish connection from die function to the board upon board mounting. Figure 1 shows the wire and how it connects the die and the leads of the strip.

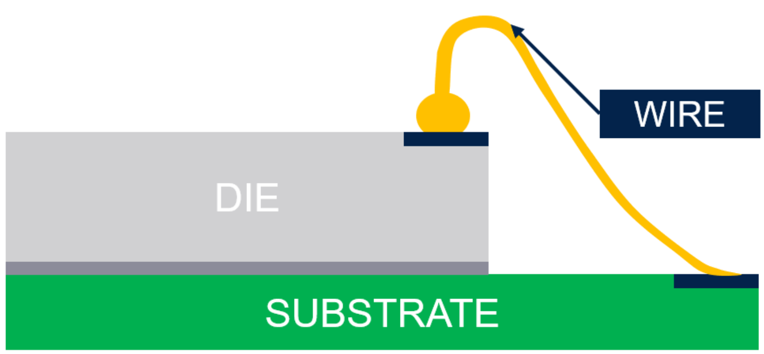

Fig. 1. Wire Bonding Connection

Wires used for wire bonding process varies with different material with different diameters, depending on the application and design of the devices being made. Different wire materials including gold, silver, and copper have different material properties including density and weight. On Table 1, densities of materials are different with precious materials used on wire bonding.

Table 1. Density of Precious Metals used for Wire Bonding

Density	Precious Metals (g/cm3)
Gold	19.32
Silver	10.49
Copper	8.96

Aside from the technical properties of the wires, wire length per spool is identified to be critical on the business side. With the length of wire, numbers of units can be calculated which is considered for unit cost of the product. Actual wire usage and the verification of the wire spool length from supplier was not verified upon usage, instead there is a calculated standards that came from the design of the unit.

During the processing of units with 40 gold wires, cost spent on the wire is very high compared to the output expected from the standards. The standard resulted to have 0.036 meters of wire per unit which will produce at least 27.8K units per 1000 meters spool. However, total units produced per wire spool is only 26.9K units at average which lacks approximately 900 units that is equivalent to 32 meters of wire per spool.

The study is pushed through to verify the cause of high consumption of wires at manufacturing. In this study, the authors will validate wire length per spool from the compliance of wire supply, the wire overconsumption at manufacturing, and challenge the accuracy of the declared standards.

2. METHODOLOGY

There is no hand calculation to validate the length of the gold wire used on the manufacturing area. Incoming quality checking refers only with the compliance of the supplier with the submitted certificates along with the wires. Through the gold's density in grams per cubic meter (g/m3), wire diameter in meters (m), and actual weight of the spool in grams (g), wire length can be formulated and derived and used for hand calculation method.

To validate the wire length considering the needed information from the formula, the first step was to get the actual weight of wires together with the spool. The next step is to install the weighed wire and spool on the machine as wires were delivered on the manufacturing line in a spool and ready to be installed.

Actual wire usage from the weighted spool is monitored and controlled from installation until spool was emptied. Stray wire bin was free from any wires prior weighted spool installation so all the wires to be collected are only coming from the same spool. Machine unit records were reset prior using the spool and all units processed were recorded as part of the actual validation.

Once the spool is emptied, the spool and collected stray wires were weighted separately. Weight of the spool will be deducted from the initial wire and spool weight to get the wire weight only. Stray wires will be added on the result of the wire only weight as it is part of the wire spool.

Using the formula, wire length will be calculated using the wire actual weight, the smallest measured wire diameter from supplier certificate, and the gold density. Result of wire length will be compared with the supplier's declaration of wire length on their certificate. The result of the calculated length will be divided with the standard for result of ideal units produced. On the other hand, the actual number of units recorded from the spool will also be divided on wire length to verify the actual wire consumption. The results between the standard and the actual consumptions will be compared.

Once all the validations were done, the source of high wire consumption will be known together with the recommended actions for the solution.

3. RESULTS AND DISCUSSIONS

3.1. Wire Length Formulation and Derivation

Gold has the density of 19.3 g/cm3 thus it was the same density with the wires that are used for bonding of units. Wire is typically a long cylinder which has a radius, volume, and length. Weight of the wire with the spool can be measured through the weighing scale. With the given wire properties, wire length formula can be derived by using the volume, density, and weight of the wire.

Figure 2 shows the density formula for gold, where density is equivalent to mass over the volume of the wire. Mass is the weight under grams (g) and volume is on cubic meters (m3).

$$\text{(Density) } \rho = \frac{m \text{ (mass)}}{V \text{ (Volume)}}$$

Fig. 2. Density Formula

Mass is the actual weight of the wire from the weighing scale and display is already in grams. Volume to be used is the volume of the cylinder which was shown on Figure 3.

$$\text{(Volume) } V = \pi r^2 h$$

π — (pi 3.1416)
r — (Wire Radius)
h — (Wire Length)

Fig. 3. Cylinder Volume Formula

Considering the formulas with regards to the wire properties, the resulting formula for density is shown on Figure 4.

$$\text{(Density) } \rho = \frac{m \text{ (mass)}}{\pi r^2 h \text{ (Volume)}}$$

Fig. 4. Resulting Formula for Density

Figure 5 shows the derivation of Length from the formula shown on Figure 4. Length is equal to the mass divided by the area of circle multiplied by the density.

$$\textbf{Length (L)} = \frac{m}{\pi r^2 \rho}$$

Fig. 5. Wire Length Formula

With the data on hand available to supply and substitute values into the formula, wire length can be validated and computed through hand calculation.

3.2. Compliance of Wire Length on the Spool

Using the wire length formula, the length of the spool can be validated through the hand calculation. On this study, the wire under validation has a diameter of 15 micrometers with the wire length of 1000 meters per spool.

Actual weight of the wire is 3.23 grams. Length needed is in meters, thus gold density to be use is 19 300 000 g/m3. Actual diameter of the wire is 14.6 micrometers. Actual measurements resulted to the length of 999.38 meters which is close to the 1000 meters commitment by the supplier.

$$Length = \frac{m}{\pi r^2 \rho} \qquad Length = 999.38\ meters$$

$$Length = \frac{3.23g}{\pi(0.0000073m)^2\ (19300000g/m^3)}$$

Fig. 6. Sample Computation for 15um Wire

Through the hand calculation of wire length from actual data gathered for weight and radius, the result of the validation shows that the supply of wire per spool is acceptable and passing the specification. No observed lack of wire length from the raw material of gold wire.

3.3. Meters per Unit Consumption

Unit produced on the machine was closely monitored during the data gathering where the total number of units produced for 1000-meter spool is at 26.9K units only instead of the expected 27.8K units. Since it was validated that the spool is compliant with the 1000 meters length, it was divided into the actual units produced. Shown on Figure 7 is the computation of the wire consumption per unit.

$$\textit{Meters per Unit} = \frac{\textit{Calculated Length}}{\textit{Actual Unit Processed}} = \frac{999.38\ m}{26899\ units}$$

$$\textit{Meters per Unit} = 0.037\ m/unit$$

Fig. 7. Actual Wire Consumption Per Unit

Using the results of validation, it was found out that 0.037 meters of wire length were consumed per unit. Comparing with the standard of 0.036 meters per unit, the standard lack of 0.001 meters per unit than the actual which is equivalent to 32 meters per spool. These 32 meters of wire length is equivalent to process at least 800 units more. The 32 meters of wire length per spool is the source of the overspending at wire as the standard and the actual consumption is not aligned.

According to the results of validations, the standard wire length has been challenged to be aligned with the actual wire consumption using the stated methodology.

4. CONCLUSION AND RECOMMENDATIONS

Given with the data and results of the wire length validation, it is concluded that based on the actual wire consumption, the reference standard is insufficient by 0.001 meters per unit which is equivalent to on about 800 units per spool of wire. Result of the validation shows that the machine consumes 0.001 meters of wire more than the declared reference standard meter per unit. The difference induces the lack of units from the standard expected unit calculation which leads to conclude the source of high wire consumption impression.

Certificate of wire is compliant with the actual calculations that has approximately 1000 meters per spool using the lowest diameter referred to the certificate. As per the results of evaluation upon reference to the supplier's certificate, it is concluded that the standard consumption of wire is insufficient with the actual wire usage per unit.

Regarding the conclusion, it is recommended to revisit and update the reference standards to be aligned on the actual manufacturing consumption.

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