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SOME ASPECTS ON FREE AIR BALL (FAB) FORMATION OF COPPER WIRE BONDING

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ABSTRACT

Wire bonding is one of the popular interconnection methods in semiconductor device packaging. The most important technique in wire bonding process is the formation of Free Air Ball (FAB). The FAB form by Electric Flame Off (EFO) with diameter ranging from 1.5 to 2.5 times of the wire diameter. Copper wire ball bonding has been developed as an alternative method for gold wire ball bonding because of economic advantages, strong resistance to sweeping, superior electrical and mechanical performance. Copper wires normally being used in some low end ICs packages. Copper wire oxidizes readily at relatively low temperatures. During the formation of FAB, the copper wire must be enclosed in an inert gas environment in order to prevent oxidization of the FAB. This paper investigates the FAB formation for 50.8 µm (2 mil) copper wires due to various EFO parameters which are EFO current and firing time. It is found that the higher EFO current was needed to form copper FAB. The effect of firing time and FAB formation will briefly discuss in this paper. FAB would get symmetrical shapes and perfect surface in setting of high EFO current with low EFO time and in low EFO current with high EFO time.

INTRODUCTION

Wire bonding technique is the most widely technology in the microelectronic industry as a definition of interconnecting IC chip and substrate. Wire bonding cycle started with electrical breakdown of the air gap between the wire and wand followed by the discharge which heated and melted the tail of wire. Surface tension causes the melted part roll up into a ball and the ball would then be pressed to formed first bond. Gold wire bonding has been introduced about 1950's, rapidly develops and fits well the industrial requirements. Beside, in the IC manufacturing environment, copper wire ball bonding has gained considerable attention due to cost per unit length less than gold, technical advantages which are better electrical conductivity, slower intermetallic growth results in lower electrical resistant and increased reliability. The wire ball bonder uses an electric flame off (EFO) unit connecting with high voltage to create a free air ball (FAB). During operation, the EFO gap was breached by a high current to create a high voltage spark that melt the tail of the metal wire in a glow discharge to form a spherical ball. Copper wire must be sealed

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in an environment without oxygen and be enclosed in an inert gas environment to prevent the oxidization of the FAB during FAB formation. Figure 1 shows the schematic illustration of the EFO setup of copper wire ball bonding.

Furthermore, forming gas (95%N_2 and 5%H_2) was used to prevent copper oxidation and to prevent oxygen from dissolving into the copper during melting. The FAB can be shaped by using the EFO parameter setting, mainly from EFO current level and its corresponding firing time. Various researchers had investigated the phenomena of the FAB formation. The melting and solidification of the thin wires FAB experimentally and numerically were investigated (Cohen et al, 1995). The heat affected zone length can be decreased by higher current and shorter EFO time (Qin et al, 1997). Some studies indicated that EFO current and time are the most significant factors on the FAB formation. However these studies only focused on the gold wire ball bonding (Chen et al. 2000). Qnuki et al. (1990) had deduced that copper wire FAB formed at above 175 ºC in inert environment is softer than that at a room temperature. It was able to predict copper wire FAB to provide consistent FAB size by using their method. Many authors conceived that the forming gas with 95% N_2 and 5% H_2 was rather suitable than 100% N_2 and other types of forming gas for copper FAB formation. For the stable bonding of copper wire, it is very important to characterize the FAB ball size and surface appearance with various EFO parameters during EFO process. In this study, the copper FAB sizes under different EFO parameters were investigated.

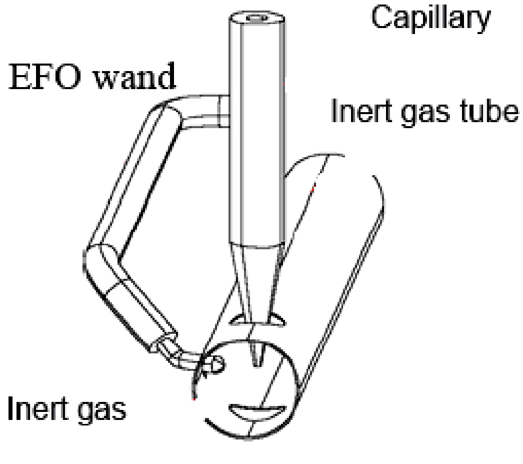

Figure 1: Schematic illustration of the EFO setup of copper wire ball bonding [1].

EXPERIMENTAL PROCEDURE

The modelling of the FAB was employed using the following procedures: First, numerous tests were run on an automatic ball bonder with various diameters of copper wire in which current and time were varied and the resulting ball size was measured. A cherry pit bonding was used to ensure that the FAB obtained consisted

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of only spherical balls. A special bond program was used to obtain sticks of FAB which using the cherry pit bond features of K&S wire bonder. For every data, 30 FABs were generated. These FAB sizes were then inspected using optical measuring microscope and Scanning Electron Microscope (SEM) for their sphericities. The parameters investigated were as shown in Table 1.

In wire ball bonding, after the wedge bond was formed, the wire clamped and held the wire and then tore it from the weakest section of the wedge bond. Then a wire tail with some deformation would be formed at the end of the wire. Besides, higher energy would be applied to shape the copper ball bond and wedge bond due to the higher mechanical properties and stiffness. The deformation of the copper wire tail would be more serious comparing to gold wire. Short tail would cause the EFO open and tilted tail trend to form a tilted FAB during EFO process. So the wedge bonding parameters and capillary structure many also have some effects on the FAB formation.

Table 1: Range of experimental parameters investigated.

Parameters	Range Investigated
Copper wire diameter	50.8µm
Type of cover gas	Forming gas ($5\%H_2 + 95\%N_2$)
Cover gas flow rate	1.4 scfh
EFO gap setting	30
EFO current (mA)	90, 100, 110, 120, 130
EFO firing time (µs)	1200 - 2400

Generally, the dimension of the FAB affected by all parameters investigated in Table 1. The main focus of this paper is on modelling the FAB, therefore this will be the main stream of discussion. Only parameters of EFO current and firing time were used to generate the characteristics curves for various diameters copper wire FAB.

RESULT AND DISCUSSION

Figure 2 shows the FAB size under different EFO current and firing time. The EFO current range was from 100mA to 130mA. The size of FAB ball became large with the increase of the EFO current. As in previous studies by Chen, Jonathan, et al, 2000 the EFO current was one of the most significant factors in the ball formation. The formation of a FAB from the EFO box can be regarded as a system having both energies input and output. The input for the FAB is from the EFO box and the controlling parameters on the EFO systems are constant current and firing time.

A plasma discharge is then generated from the spark gap and a heat flux is generated as the plasma stuck the tail of the wire. This heat flux then formed the energy input to melt the wire from its tail. Surface tension causes the melted part to roll up into a

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ball. Eventually, the measurable output is the size of FAB. It is reasonable to assume that FAB is a function of constant current output and EFO firing time and this can be written as (Hang et al, 2005)

$$\mathrm{FAB(D)} = f\,(\mathrm{I}^2,\mathrm{t}) \qquad (1)$$

where FAB(D), the diameter of FAB ball represents the energy input. Referring to Figure 2, example from relation of EFO current and time for 2.0 mil copper wire FAB, it is reasonable to assume that with the energy output represented by the same FAB size, the energy input by various current characteristics curves are the same. From figure 3,as what the energy level to produce a FAB size of 3.5mil are the same as what, energy level of (100mA+2000µs) is the same as (130mA+1400µs), (120mA+1600µs) and (110mA+1725µs).

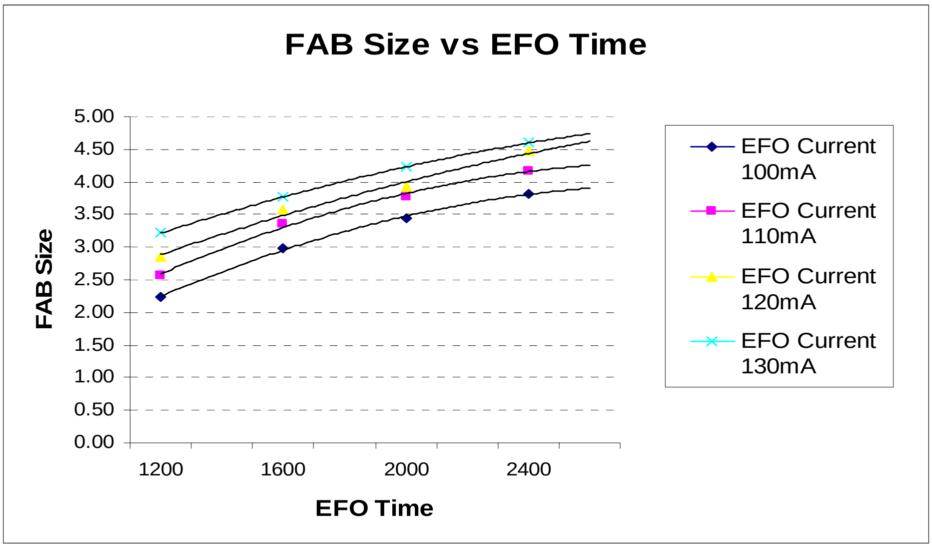

Figure 2: Relations of FAB size for EFO current and time for 50.8 µm (2.0 mil) copper wire.

Hence, it is necessary to transform various characteristic curves into a common characteristic curves so that the energy output can be read-off as a common energy input which comprises of various characteristics curve. First examined the EFO-FAB as a system that consists of energy output and input to carry out this transformation process. The input variables were EFO current and EFO firing time while the measurable output is FAB size. Within the system, the ideal energy input is (Hang et al, 2005)

$$E_{in} = R \times I^2 \times t \qquad (2)$$

Where E_{in} is energy input by the system, and R is the resistance of the system at the gap, I is the EFO current and t is the EFO fire time. The resistance of the system at the gap is negligible once the breakdown voltage occurs and can be regarded as a

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constant. Therefore both energy input and output can then be correlated by a common characteristics curve described by the equation. The fitted equation took the form of the natural logarithm, hence by plotting the x-axis using the natural logarithm scale. The characteristics curve is able to describe the efficiency of the EFO-FAB system. By these means, the study of the effects of EFO current and EFO firing time on FAB size can be carried out.

CONCLUSIONS

In this paper, the used method is capable to predict the diameter of the copper wire FAB. It is observed that the energy input is capable describe the energy efficiency of the EFO-FAB system. A general equation is developed to describe the behaviour of FAB size with wire diameter of 50.8μm using gas (5%H_2 + 95%N_2) as a cover gas. More energy is needed to form FAB during EFO process due to the thermal properties of copper. FAB can obtained symmetrical shapes with perfect surface by setting a high EFO current with low EFO time and in low EFO current with high EFO time.

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