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ELECTROPLATING OF Cu IN TSV AND CHARACTERISTICS OF LOW ALPHA SOLDER BUMP

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ABSTRACT

Three-dimensional (3-D) packaging is a popular candidate to meet the demands of high density packaging and miniaturization of electronics. Especially, 3D packaging with TSV (through-Si-via) has advantages of shorter electric path and smaller bonding area. In TSV electrical conductive material is filled, and Cu-filling by electroplating is most popular one. Meanwhile, the soft error, the temporary malfunction of electronic devices caused by the effect of radiation, became a momentous issue in high density electronics packaging. Solder was found to be one of the major sources of radiation in electronic devices. In three-dimensional packaging, the solder bumps are very close to the active Si devices, where even the low energy alpha ray can induce soft error, which needs to choose the low alpha solder in packaging. For high density packaging, Cu electroplating to TSV and characteristics of low alpha solder bumps were investigated in this study. A straight via with a diameter of 60 µm and depth of 120 µm were drilled in a Si wafer by deep reactive ion etching (DRIE) process. Cu was filled to the via by electroplating where the current waveform of a periodic pulse reverse (PPR) was applied. The LC3 class of low alpha solder bump having a composition of Sn–1.0Ag–0.5Cu (SAC105) and a
diameter of 80 µm was formed by reflow on a UBM (under bump metallurgy) and on a Cu-filled TSV. For estimating the shear force of the low alpha solder bump, high speed shear tester (Dage 4000HS) was used, and for the fracture mode analysis, scanning electron microscopy (FE-SEM) was employed. As experimental results, Cu filled into TSV showed a typical bottom up filling. The shear force of low alpha SAC105 bump increased with increasing shear speed from 10 to 1,000 mm/s, which depends on kinds of bump pads. Brittle fracture tendency increased with increasing shear speed. The properties of low alpha SAC105 solder were comparable to those of normal solder.

Key words: TSV (through silicon via), electroplating, low alpha solder, high speed shear test

INTRODUCTION

Recent electronic devices and products become small, lightweight and high system performance. In order to meet these trends, the electronic devices need to be miniaturized and packaged in higher density. Three dimensional (3-D) packaging technology of Si-chip stacking is a promising candidate for the miniaturization and high density packaging [1-2]

In Si-chip stacking, Au wire bonding or TSV (throughsilicon via) technology can be used for the interconnection of the chips. The Au wire bonding needs for a long connection length and a larger bonding area. Meanwhile, the TSV technology is a strong candidate to replace wire bonding because of shorter connection length, less power
consumption and small bonding area. [3-5]

The 3-D Si chip stacking technology having TSV consists of several steps; via (TSV) formation, filling of a conductive material into TSV, wafer thinning, and chip stacking steps [6-7]. For filling conductive materials to TSV, Cu, W and Ag have been used, and among them Cu electroplating is popular one. In chip stacking with TSV process, Cu-filling needs high cost because of long filling time and defects like seam and void in Cu deposit produced during electroplating. To avoid these defects and to reduce filling time, various filling methods have been studied. For example, to optimize electroplating current forms, Pulse Current (PC), Pulse Reverse Current (PRC) method, Periodic Pulse Reverse (PPR) Current and 3 step PPR methods were applied. [8-10]. To find appropriate organic additives to optimize electroplating solution were also investigated [11-12]. In this study, PPR current method was employed for Cu electro-deposition into TSV.

Between stacked Si chips having Cu-filled TSVs can be connected for electrical path through bonding using Sn or solder bumps fabricated on the top surface of the Cu plugs.

Advantage of Sn bump is a uniform composition throughout the bumps and easy plating condition. However, it may cause a whisker or low strength compared to Sn-alloy bumps such as Sn–Cu, Sn–Ag and Sn–Ag–Cu [13-15]. In this study, Sn–1.0wt%Ag–0.5wt%Cu (SAC105) and Sn–3.5wt%Ag (SA3.5) were selected for bumping materials.

In high density packaging and high performance electronics, various reliability issues occur and soft error is one of them. Soft error is a temporary error in electronic devices and can cause a loss of data and may result in a system malfunction [16]. Thus, in order to avoid the soft error, a low alpha solder is needed. In solder several sources of alpha particle emitter are contained like ^{210}Pb, ^{214}Bi, ^{214}Po and so on. When an unstable isotope decays to a lower energy level, the alpha particles emit, and the particle has kinetic energy approximately from 4 to 9 MeV. In lead free solder, lead content is approximately 0.1%– 0.2%, and normal lead free solder produces several alpha particles counts per hour and per square centi-meters. In this study, low alpha solder which has alpha particle emission lower than 0.005 cph (LC3 grade) was selected as bump material. The research objective is to estimate metallurgical and mechanical properties of low alpha solder. Cu-filling property to TSV was also investigated.

EXPERIMENTAL

A Si wafer of <100> p-type having a thickness of 525 μm and diameter of 4 inch was used as a substrate. Via holes were drilled in the Si wafer by etching with deep reactive ion etching (DRIE) process. The resultant via hole size was 60 μm in diameter and 120 μm in depth.

SiO_2 of dielectric layer, Ti and Au of adhesion and seed layer, respectively, were deposited in the via walls as functional layers. The Si wafer was cut into chips sized of 5x5mm^2 and used as a cathode for Cu electroplating. A Pt plate with size of 10x10 mm^2 was selected as an anode.

The electrolyte for Cu filling to TSV consisted of Cu sulfate, H_2SO_4, HCl and additive. Stirring rate of the electrolyte during plating was 200 rpm (revolutions per minutes) at room temperature. Experimental equipment for electroplating was illustrated in Figure 1.

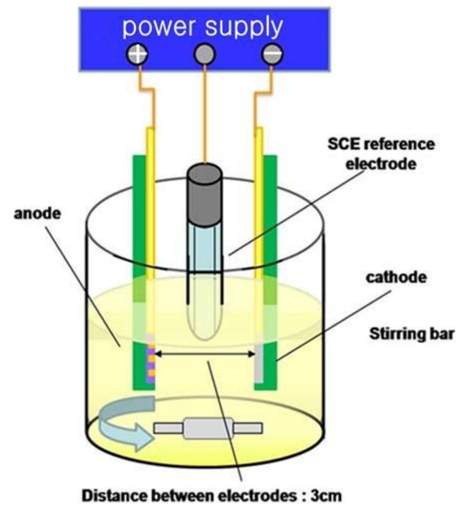

Figure 1. Experimental apparatus for electroplating PPR (Periodic pulse reverse) wave form was applied for electroplating of Cu to TSV which consists of cathodic term, anodic term and current-off term (see Fig.2). Through our previous study, the PPR current form was effective for Cu filling to TSV in relatively short time with less defects [17]

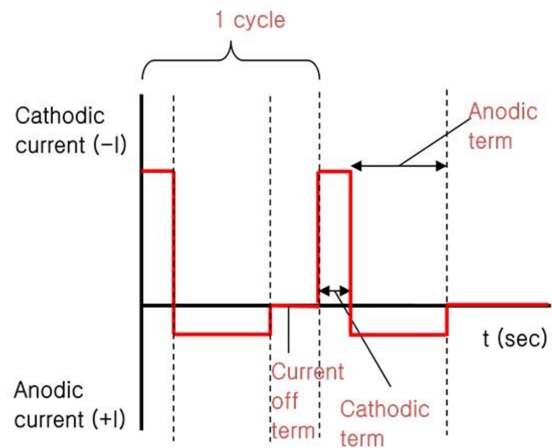

Figure 2. Applied current form for Cu filling to TSV.

The Cu filled chip was ground and polished until Cu surface in the top of the via hole was exposed. A low alpha solder having Sn-3.5Ag composition was electroplated with thickness of 15 μm on Cu-filled TSV as a bump. Since the bump size was thin to estimate the shear strength, solder ball of SAC105 having a diameter of 80μm was placed on the Cu-filled TSV. The bump was prepared by reflowing at 245℃ for 10 sec.

High speed shear test was performed for the low alphas SAC105 solder bump to evaluate the bonding force using Dage 4000-HS bond tester. Shearing speed was increased up to 3.0 m/s. The microstructure of the solder was

examined by a field emission scanning electron microscope (FE-SEM).

RESULTS

The TSVs were filled with copper by electroplating with PPR current wave form, where Cu electro-deposits during cathodic term, and over-deposit part like via entrance etches away during anodic term. High Cu ion concentration around the via entrance by etching mitigates during current-off term.

Cu filling into TSV showed a typical bottom up filling. The Cu-filling in the TSV didn't have serious defect like seam or void in the Cu deposition.

Low alpha solder of Sn-3.5Ag was electroplated on the Cu-filled TSV as shown in Figure 2. The height and width of the solder bump was 15 and 60 µm, respectively.

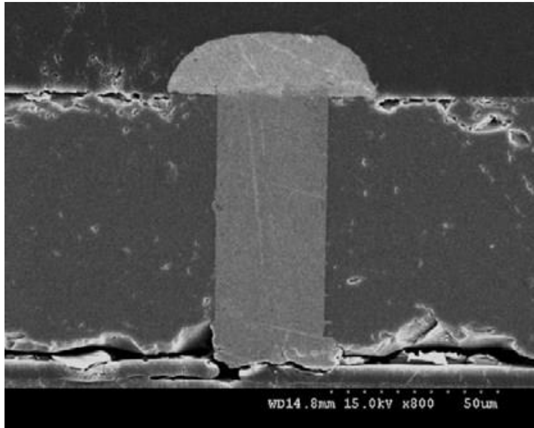

Figure 3. Cross section of low alpha solder of Sn-3.5Ag electroplated on the Cu-filled TSV.

Cu_6Sn_5 IMC having a scallop shape was produced between solder bump and Cu after reflow. Ag_3Sn IMC was found in the bulk SAC105 solder and the microstructure of low alpha solder showed similar to that of normal solder. The maximum shear strength of the SAC105 solder bump formed by 80 µm of diameter was approximately 360 mN.

Failure modes of 80 µm of diameter SAC105 low alpha solder after shear test were analyzed. Brittle fracture modes increased with increasing shear speed. This tendency is similar to that of normal solder like SAC305 solder on Cu with OSP (organic solder preservative) [18].

In the force–displacement curve after the shear test, the area under the curve indicates the shear energy or fracture energy. This shear energy is known to correlate much better to the failure mode than shear force. Shear energy of the low alpha solder ball decreased with increasing shearing speed, and the maximum shear energy is approximately 7 mJ in average.

SUMMARY

Cu was electroplated in TSV by PPR current wave form, and it showed a typical bottom up filling. The Cu-filling didn't show serious defects like void or seam. Low alpha solder bumps were produced on the Cu surface of TSV. Similarly to normal solder, Cu_6Sn_5 and Ag_3Sn IMCs were found in SAC105 solder. The high speed shear property was also evaluated.

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