Microelectronics Reliability 54 (2014) 2550–2554

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Study of free air ball formation in Ag–8Au–3Pd alloy wire bonding

Rui Guo [a], Liming Gao [a], Dali Mao [a], Ming Li [a,*], Xu Wang [b], Zhong Lv [b], Hope Chiu [b]

[a] State Key Laboratory of Metal Matrix Composites, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Packaging RnD and Advanced MFG Engineering, SanDisk Semiconductor (Shanghai) Co., Ltd, Shanghai 200241, China

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form 8 April 2014
Accepted 8 April 2014
Available online 28 May 2014

Keywords:
Ag–8Au–3Pd alloy wire
Electronic flame-off
Free air ball
Auger electron spectroscopy

ABSTRACT

An innovative Ag–8Au–3Pd alloy wire has been developed as an alternative to the traditional gold wire bonding. This paper focused on the free air ball (FAB) formation of 0.7 mil Ag–8Au–3Pd alloy wire, which was vital for the yield of the subsequent bonding process. During electric flame-off (EFO) process, the wire tail was melted by a high voltage spark, and then the FAB was shaped by the effects of surface tension and gravity. The EFO current was the key factor to influence the Ag–8Au–3Pd alloy FAB size and morphology due to the energy input via arc discharging. The defects including off-center and ripple appeared on the Ag–8Au–3Pd alloy FABs were discussed by cooling and solidification. It is suggested that low EFO current will effectively avoid FAB defects. The contaminants on the Ag–8Au–3Pd alloy FAB surface were analyzed by Auger electron spectroscopy (AES). Under the protection of the shielding gas, oxidation and sulfuration have been effectively prevented.

1. Introduction

Wire bonding is the most widely used interconnection technology in microelectronic packaging, due to its simple process and cost advantage. In the last decade, continually increased cost pressure began to limit the application of gold wire. As a result, an amount of research and development efforts have emerged in low cost wire bonding technology. Copper wire has attracted much attention of industry, due to its better material properties than gold wire [1–4]. However, the increased bonding force due to the inherent hardness of copper will result in about 30% higher stress to the aluminum pad [5], which will increase the possibility of silicon damage in thin die application. Moreover, oxidation tendency of copper wire will limit the stand-off stitch bonding (SSB) technology which is widely used in high density stacked die packaging. Silver also shows merit in cost saving, which has also been studied for more than two decades [6,7]. It possesses better electrical and thermal conductivities than copper and gold, which will contribute to higher signal speed and better heat dissipation. However, surface oxidation and sulfuration of the silver wire will cause reliability concern. Recently, an innovative Ag–8Au–3Pd alloy wire has been developed, which appears as a hopeful low-cost candidate [8]. Alloying with Au and Pd is able to enhance the reliability of silver wire [9]. Material properties of Ag–8Au–3Pd alloy are close to the gold, such as mechanical performance and thermal conductivity. Moreover, the mechanical properties of annealing-twinned Ag–8Au–3Pd alloy wire are better than ordinary grain structure [10]. And the intermetallic compound (IMC) formation of Ag–8Au–3Pd/Al bonding interface has been illustrated in detail [11]. Therefore, Ag–8Au–3Pd alloy wire could serve as an important alternative to gold wire in 3D interconnections and fine pitch bonding applications.

While the Ag–8Au–3Pd alloy wire appears as a hopeful low-cost candidate for gold wire, challenges of thermalsonic bonding have to be solved to meet requirements of application. This paper focused on the Ag–8Au–3Pd free air ball (FAB) formation, which will influence the subsequent bonding yield. During the electric flame-off (EFO) process, a high voltage spark discharges and melts the tail of the wire. The molten FAB is formed by the effects of surface tension and gravity. With consistent size and surface appearance, the FAB adheres to the aluminum pad under ultrasonic power and force.

The FAB size is attributed to the heat energy input during arc discharging, which is related to the EFO current and time. The EFO current and time are measurable energy inputs, and the FAB diameter is the output. The experiments were carried out to investigate the relationship between the EFO parameters and FAB size. It is convenient to avoid complex computations, which involves the phase transition during FAB melting and solidification.

The ripple and off-center are defects often observed on copper FABs when the inappropriate EFO parameters were used [12]. The FABs with imperfect sphericity and surface morphology will obviously affect the bonding yield. It is closely related to the

* Corresponding author. Tel.: +86 21 3420 2728; fax: +86 21 3420 2748.
E-mail address: mingli90@sjtu.edu.cn (M. Li).

http://dx.doi.org/10.1016/j.microrel.2014.04.005
0026-2714/

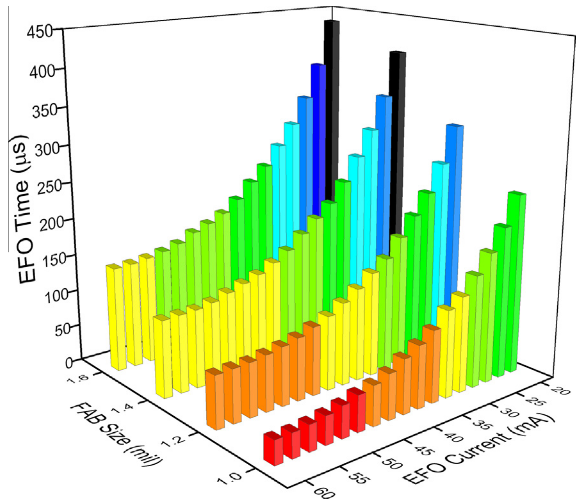

Fig. 1. Relationship between EFO current and time for different FAB sizes.

solidification process and microstructure evolution during FAB formation. In order to prevent these defects, the EFO parameters should be precisely chosen.

As a low-cost bonding material, anti-oxidation performance is another concern about EFO process of Ag–8Au–3Pd alloy wire. Surface oxidation layer will break the surface tension of the FAB. It causes imperfect FAB shape, which results in poor ball bonding contact. Moreover, surface oxides on the surface makes the FAB harder, which will impede plastic deformation the FAB during bonding. In order to prevent oxidation and sulfuration, shielding gas of $N_2 + H_2$ was necessary. The nitrogen plays a role as the barrier to the oxygen, while the hydrogen is used as reducing agent.

2. Experimental procedure

The experiments were performed on 0.7 mil (17.5 μm) Ag–8Au–3Pd alloy wire manufactured by Wire Technology Co. Ltd., Taiwan. An automated KnS bonding machine was employed and equipped with copper kit. A shielding gas of 95% N_2 + 5% H_2 with a flow rate of 0.4 L/min is used to prevent the oxidation of the molten Ag–8Au–3Pd alloy during EFO process. The parameter of EFO gap was 25 mil. The Ag–8Au–3Pd alloy FABs were formed during EFO process, and then bonded on the Au fingers of the substrate. The variables as EFO current and time were used to control FAB size. The diameter and sphericity of FAB were measured by Hisomet II non-contact depth measuring microscope, and the surface morphology was observed by scanning electron microscope (SEM), FEI Sirion. For each group of EFO parameters, 376 FABs were generated. Evaluation criteria for FAB quality were shown as the following aspects:

(1) DA was defined as the max diameter in radial direction of the Ag–8Au–3Pd alloy wire. DB was defined as the max diameter in axial direction of the Ag–8Au–3Pd alloy wire. DB/DA was defined as the sphericity of FAB with the optimal ratio of 1. The appropriate DB/DA ratio ranged from 0.9 to 1.1. And the corresponding abnormal percentage was obtained.
(2) Surface morphology of the FAB was considered to be perfect, with no golf ball, concave-convex or ripple, etc.

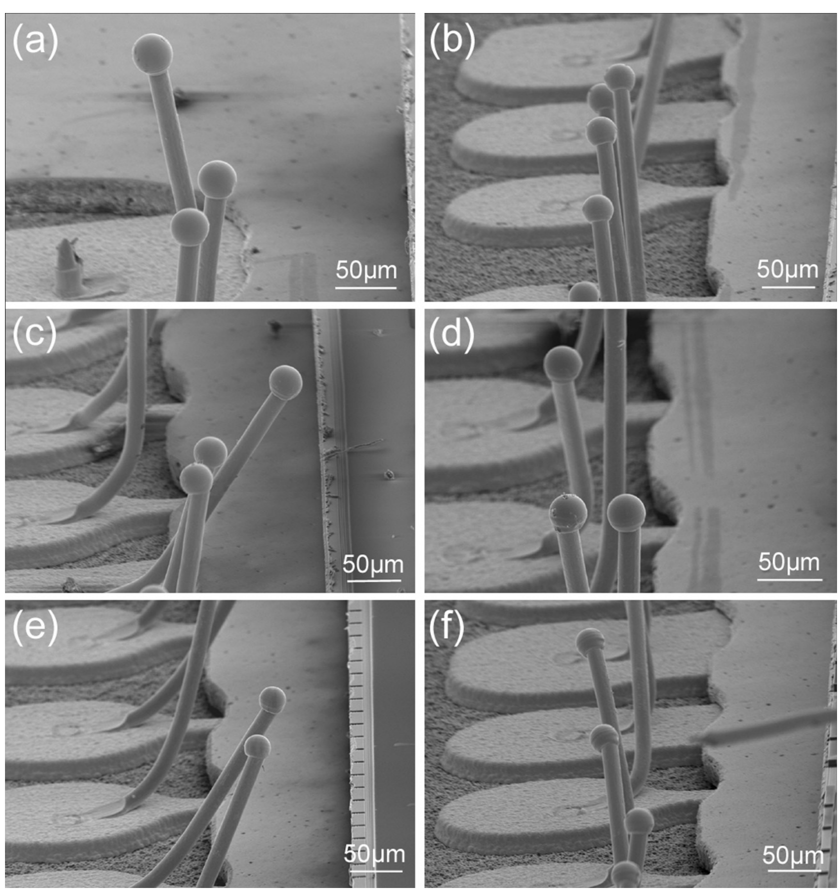

Fig. 2. Ag–8Au–3Pd alloy FAB topography at 1.2 mil under different EFO currents. (a) 20 mA; (b) 22 mA; (c) 30 mA; (d) 40 mA; (e) 50 mA and (f) 60 mA.