Materials Science in Semiconductor Processing 31 (2015) 38–43

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

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

Study of solder jet bumping process using high-speed digital camera

Cheng-Han Wu, Weng-Sing Hwang *

Department of Materials Science and Engineering, National Cheng Kung University, No. 1, University Road, Tainan 701, Taiwan

ARTICLE INFO

Available online 29 November 2014

Keywords:
High-speed camera
Solder jet
Droplet bumping

ABSTRACT

With the development of solder jet technology in the electronic packaging industry, the bumping process of a molten metal droplet, which determines the shape of the solder bump and is crucial for the performance of the device, has attracted great interests. The solder bumping process of a single molten micro-droplet by a solder jet was recorded using a high-speed digital camera with a frame rate of 100,000 frames per second. It was found that the surface ripples on the solder bump was caused by the interaction of the fluid flow and the heat transfer/solidification processes in the bumping process of a micro-droplet. A droplet was observed to rebound on a copper pad coated with a layer of organic solderability preservatives, which was suspected to decrease the interfacial heat transfer coefficient between the droplet and the pad lower than a minimal value, 4.07×10^4 W/m^2 K, making the recoiling droplet rebound away.

1. Introduction

The bumping process of a molten metal droplet has attracted great interests due to its application in solder jet technology for the electronic packaging industry. A solder jet is a kind of ink-jet printing technology, which can produce small droplets through controlling the pressure variation of the fluid in the chamber. The main feature of the solder jet is using molten solder as the ink material. A solder jet can produce pico-liter solder droplets for the deposition of solder bumps. It provides a non-contact and direct forming process for micro-pattern fabrication, reducing the number of fabrication procedures, material waste, and fabrication time. The solder bump shape, which is crucial for the performance of a device, is determined by the solder bumping process. Solder jet bumping process described in this study is the bumping process of an ejected micro-droplet by solder jet as it hits the substrate. Simulations are commonly used for investigating the solder bumping process because unique facilities for high speed recording and microscopic observation are needed for observing the process on such a small scale and time period. Researchers [1–3] have discussed the effects of droplet impact velocity, size, and temperature on the solder bump shape and the bumping process using simulation. The evolution of the bumping process was simulated, and the observed surface ripples on the solder bump were related to the interaction between fluid dynamics and the solidification process. Haferl and Poulikakos [4] used simulation to observe the molten micro-droplet pile-up process. Wu et al. [5] and Bhardwaj and Attinger [6] examined the fluid dynamics of the bumping process using simulation without considering the solidification process. Tian et al. [7] simulated solder droplet impingements onto fluxed and non-fluxed substrates, and found that the droplet completely rebounded from the fluxed substrate. Wang et al. [8] and Attané et al. [9] calculated the variations of the spread factors in the bumping process for various interfacial heat transfer coefficients, viscosities, impact velocities,

* Corresponding author.
Tel.: +886 6 275 7575x62928; fax: +886 6 234 4393.
E-mail address: wshwang@mail.ncku.edu.tw (W.-S. Hwang).

http://dx.doi.org/10.1016/j.mssp.2014.10.038
1369-8001/

and equilibrium contact angles, and predicted the eventual size of the solder bump. For experimental observation, a technique called flash microscopy has been applied to record the evolution of the bumping process. Flash microscopy has been used to reconstruct the bumping evolution from multiple, reproducible events by patching together several frames taken at regular intervals [4]. The advantage is that a time resolution of 1 μs can be achieved. Research works [4,10–12] using flash microscopy have reported that the droplet changes shape in a period of microseconds to milliseconds, depending on the size of the impact droplet. Since the droplet in each frame is caused by different events, it takes time to record a series of shape variation of the bumping droplet; therefore, stable droplet formation and a steadily moving stage are strongly required to obtain a precise and distinct frame with flash microscopy. A high-speed camera has also been applied to record the evolution of the bumping process, with many frames taken of a single event. Its feature is that only a single event is required to record the process, and the operation is simple and time-saving. The recording speed is usually limited by the frame resolution. Researchers [6,7,13,14] have recorded the droplet bumping process using high-speed cameras with recording speeds of 1000–3000 frames per second (fps), which is suitable for the millimeter-long droplet. High-speed camera technique was also used for observing small-scale motion [15–18]. However, as droplets become smaller, the required time resolution needs to increase. For micrometer droplets, the frame rate required to observe the bumping process is more than 100,000 fps based on experience from flash microscopy. The present study used a high-speed digital camera (HSDC) to observe the bumping process of a metallic micro-droplet. It was used to record the process with a frame rate of 100,000 fps in a single event. As the frame rate is getting higher, the light exposing on each frame reduces. Additional light source is needed while using a HSDC at a high frame rate. In this study, two halogen lamps were applied as additional light sources. By using the HSDC, the ejected droplet was observed bumping on a target. The target was a copper pad with a diameter about 150 μm, which had been processed by immersing in a dilute solution of organic solderability preservatives (OSP), rinsing, and drying. The layer of OSP was used to protect the surface of the copper pad. It can be removed using Iso-Propyl Alcohol (IPA). The ejected droplets were observed to impact the copper pads with or without the OSP layer.

2. Experimental method

2.1. Apparatus

In order to acquire images of an impacting molten solder micro-droplet, the equipment shown in Fig. 1 was used. Fig. 1(a) shows a solder jet apparatus for molten metal. It includes four blocks, namely heating, pneumatic, printing and monitoring systems. The heating system can heat the solder reservoir and piezoelectric print-head up to 230 °C to ensure that the solder is completely melted. The pneumatic system provided nitrogen gas (N_2) to create back pressure in the solder reservoir and a shroud flow around the nozzle exit to prevent the molten metal from oxidizing. The printing system (MJ-SF-04-50, MicroFab Technologies) can apply a voltage pulse waveform to the piezoelectric print-head to produce a droplet. The droplet shape was observed using the monitoring system, which included a CCD camera and an LED flash that was triggered after a set time delay after the voltage pulse was applied in each period. This solder jet was used to eject molten metallic micro-droplets toward a copper pad.

Fig. 1(b) shows the high-speed recording system. The HSDC (Memrecam GX-3, NAC Image Technology) was used to record images at a high frequency (up to 198,000 fps). Two halogen lamps faced the target. Lamp 1, which was used as the background light, faced the camera directly through the target, and lamp 2 was located on the same side as the camera to provide reflected light from the target to the lens to improve the droplet contour. The control system was used to adjust parameters such as frame rate, resolution, and shutter. After recording, images were selected and exported to the desired file type.

2.2. Materials

A commercial lead-free solder, Sn-3.0 wt%–Ag-0.5 wt%–Cu (SAC305), was used as the ink material. Its liquidus temperature is 217 °C and its solidus temperature is 211 °C. Its surface tension and viscosity are 493 mN m^{-1} and 2 mPa s, respectively. The target was a copper pad (diameter: ~150 μm) covered with a layer of OSP. The OSP layer can be removed using IPA before the solder jet printing process in order to improve the contact between the molten solder droplet and the copper pad.

2.3. Process conditions

In the solder jet printing process, a stable single droplet was expected. The operating temperature was set at 230 °C. The back pressure was 2.5 kPa and the shroud flow was 1 L min^{-1}. A bipolar waveform was applied to the piezoelectric print-head [19]. The time steps t_{rise}, t_{dwell}, t_{fall}, t_{echo}, and $t_{finalrise}$ were 150, 5, 30, 5, and 150 μs and the voltages V_{origin}, V_1, and V_2 were −10, −5, and −30 V, respectively. Under this condition, droplets can be observed stably produced through the monitoring system. Therefore, these droplets can bump on the substrate consistently. The diameter of a single ejected droplet was about 50 μm, and the flying speed was 1.0 m/s. The distance between the nozzle and the copper pad was about 750 μm.

To record the impact process, the control system was used to set the frame rate of the HSDC to 100,000 fps (10 μs per frame). With increasing frame rate, the corresponding frame size decreases. For the selected frame rate, the allowed resolution for observing the process from droplet formation to droplet rebounding was 36 × 144 pixels, and that for observing the droplet bumping process was 56 × 64 pixels. The resolution was not high, but it was enough to clearly observe the shape variation of the bumping droplet. A proper shutter speed can improve luminous flux and prevent motion blur. The shutter speed was set to about 8 μs.