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Heat and mass transfer effects of laser soldering on growth behavior of interfacial intermetallic compounds in Sn/Cu and Sn-3.5Ag0.5/Cu joints

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ABSTRACT

The magnitudes of input power and scan speed of laser heat source can affect the morphology and size of interfacial Cu_6Sn_5 intermetallic compound (IMC) formed or grown in Sn/Cu and Sn-3.5Ag-0.5Cu/Cu (SAC/Cu) joints. Experimentally, it has been observed that greater power and smaller scan speed can create temperature field of higher magnitude, thereby enhancing the interfacial reaction. The occurrence of conglomerated, prismatic (faceted) and scalloped IMC morphologies in the specimens corresponding to designated laser processing parameters, has been explained with the help of Jackson parameter. The heat and mass transfer phenomena during laser soldering, is modeled using finite element analysis. Enthalpy method is applied in the FEM based computational model to describe the phase change based heat transfer at the melting regime of the solder. With an attainment of transient temperature profiles at several scan speeds through the numerical analysis, the values of interfacial reaction temperature at solder/substrate interface and diffusion phenomenon based mass transfer of Cu into solder are then utilized to explain the experimental results of IMC size. In comparison to pure Sn solder, SAC solder type is characterized with the formation of thicker IMC at laser power of 50 W and scan speeds below 180 mm/min.

1. Introduction

In the microelectronic and solar photovoltaic (PV) panel manufacturing industries, the growing popularity of lead-free solders can be attributed to their environmental and human-health related benefits. Soldering provides electrical, thermal and mechanical continuities in the electronic devices and assemblies. Being the integral components of electronic devices and circuits, solder joints influence the strength and reliability of the printed circuit board (PCB). The packaging and chip technologies are rapidly evolving towards miniaturization. Owing to this trend of downsizing, the density of components in PCB is increasing in a very significant manner. In a highly dense PCB, the vicinity of solder joints will be characterized by the presence of thermally sensitive components and thus it has been a challenging task during a conventional reflow procedure to form solder joints without causing harming to these components. Laser processing techniques for MEMS and microelectronic packaging have a huge potential to overcome many of the difficulties associated with traditional packaging technologies and they can thus offer an attractive alternative methodology for small-scale integration of components and devices [1]. Laser processing can also be employed on the Cu substrate material to modify the surface microstructure and thus improve the wettability of Pb-free solders [2]. Laser soldering, in which laser beam is utilized as heat source to melt the solder, is an alternative method to produce solder joints [3,4]. In this soldering technique, the laser beam is focused to a diameter appropriate to joint geometry [5,6], and is then applied to the joints individually or by scanning continuously, depending upon the materials and design criteria. [3]. The salient features of laser soldering which make it an advantageous procedure over conventional reflow soldering in electronic packaging and solar pv modules manufacturing sectors are (i) contactless method, (ii) localized application of energy, (iii) low thermal stress, (iv) fine grain size and better fatigue properties of solder, and (v) reduction in the rate of intermetallic compound (IMC) formation [7–11]. The contactless soldering characteristic of laser processing enables its potential applications in joining of fragile components [12].

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Due to their inherent benefit in precision soldering, laser based devices have found several applications in production of solder joints in electronic devices and solar cells assembly. The practical and industrial applications of laser soldering at the present and for the future, have been mentioned in [2,9,13-22].

Several experimental studies have demonstrated that the applied cooling rate during soldering has an important role on the resulting microstructure of alloy, intermetallic compounds (IMCs) particles distribution and their morphology [23–27]. Subsequently, the corresponding properties (e.g. mechanical, corrosion, thermal conductivity, resistivity) will be considerably affected. In case of laser soldering, characterized by Gaussian heat distribution as well as shorter heat application and removal durations; it is very imporant to describe the temperature evolution with space and time in the material during the laser processing. Any experimental or computational work done to quantify the transient temperature variation in laser soldered specimens can be utilized in the prediction or visualization of exact heating or cooling phenomena at several geometrical locations of the specimens.

Though the presence of intermetallic compounds (IMCs) at interface of solder and substrate is considered necessary during soldering to guarantee the joint formation [9], their excessive growth at the interface needs to be prevented owing to brittle characteristics of the IMCs [28]. As laser soldering results in smaller sized IMCs, a study or research related with IMC thickness during laser soldering can contribute to the overall reliability of solder joints. In this work, laser soldering is performed at Sn/Cu and Sn-3.5Ag-0.5Cu/Cu solder joints for input powers of 30, 40 and 50 W and varying scan speed. The transient temperature profile for the heat input and subsequent removal during laser soldering is modeled via finite element method (FEM). The diffusion of Cu into the solder from the bottom substrate is also analyzed via the finite element analysis. The intermetallic compounds, formed at the solder-substrate interface are characterized with scanning electron microscope. For the size and morphology characterization, Cu_6Sn_5 is considered as the IMC within the scope of present study.

2. Materials and methods

The materials for study of interfacial intermetallic compounds during laser soldering were pure Sn (99.99% purity), Sn-3.5Ag-0.5Cu (SAC) solder and polycrystalline Cu substrate. Just before the experiment, the Cu foil was pickled by ultrasonically vibrating in 5%HCl for 10 s to remove the oxides. The experimental setup for soldering process is shown in Fig. 1. Lead-free SAC solder sheet of dimensions 4 mm × 2 mm × 0.2 mm was placed over Cu sheet of dimensions 5 mm × 5 mm × 0.1 mm and the system was subjected to laser soldering. Fiber laser was used for the laser soldering procedure and its processing parameters are given in Table 1. The laser beam was aligned perpendicular to the top surface of the solder specimens as shown in Fig. 1. With the net motion of laser heat source from left to right with a variable scan speed (v_s), the incident laser beam spot traversed from the top surface of the solder. Upon the incidence of laser beam, the solder material was heated, then, melted and upon its removal it cooled to form solder joints with the Cu substrate. Interfacial reaction can occur significantly within the joint during the soldering procedure to result in the formation of intermetallic compounds (IMCs) only when the temperature of the interface reaches beyond the melting point of the solder type. Unless otherwise stated, Cu_6Sn_5 is considered as the IMC within the scope of this study. Notably, the laser output power is set up at three magnitudes, namely (i) 30, (ii) 40, (iii) 50 W and the value of v_s is varied ranging from 10 to 240 mm/min. The present study focuses on the effect of laser soldering on intermetallic compounds' size and morphology for two solder types: Sn and SAC; thus considering the corresponding effects on solder bulk properties as a topic of future study.

Table 1
Experimental parameters for laser soldering procedure.

Parameters	Value
Laser type	SP-50C Fiber Laser
Wavelength (nm)	1528–1565
Pulse frequency (Hz)	5000
Laser power (P_w)	30, 40, 50 W
Focal beam diameter (mm)	0.025
Pulse width (ms)	0.2
Scan speed (mm/s)	Variable v_s

For the morphology observation of top-view of IMC, the experimental solder joints were etched in the 10%HNO_3 solution and mounted in epoxy. SiC sandpapers of several roughness values followed by synthetic diamond polishing paste were used to polish these specimens. In order to view the cross-section morphology of samples, they were etched in a solution containing 93%C_2H_5OH-5%HNO_3 -2%HCl solution. Scanning Electron Microscope [Zeiss Supra 55(VP)] was used to observe the IMC morphology for top-view and cross-section samples.

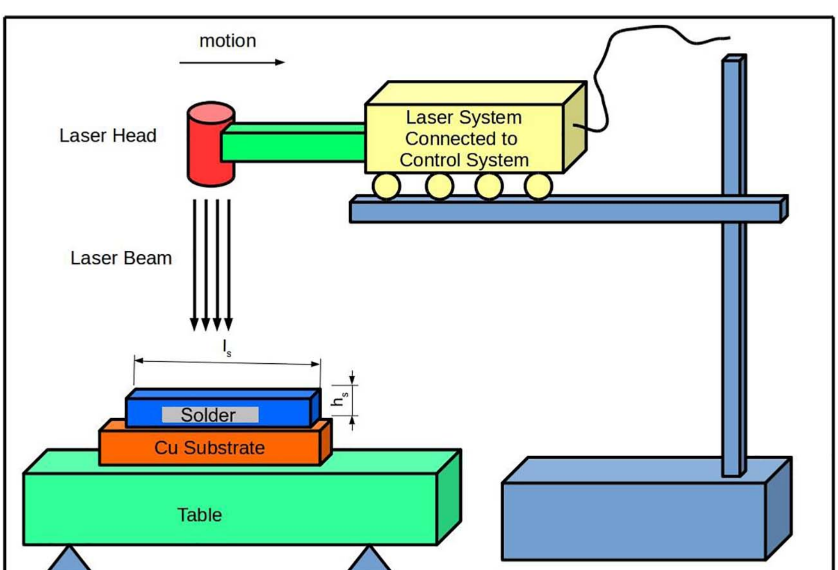

Fig. 1. A schematic sketch to illustrate the experimental setup for laser soldering procedure. In the figure l_s = 4 mm and h_s = 0.2 mm.