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Flexible printed circuit boards laser bonding using a laser beam homogenization process

Joohan Kim [a], Haewoon Choi [b,*]

[a] Dept. of Mechanical and Automotive Engineering, Seoul National University of Science and Technology, Nowon-Gu Gongneung-2Dong 172, 139-743, Seoul, South Korea
[b] Dept. of Mechanical and Automotive Engineering, Keimyung University, 704-701, Daegu, South Korea

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ABSTRACT

A laser micro-bonding process using laser beam shaping is successfully demonstrated for flexible printed circuit boards. A CW Ytterbium fiber laser with a wavelength of 1070 nm and a laser power density of 1–7 W/mm^2 is employed as a local heat source for bonding flexible printed circuit boards to rigid printed circuit boards. To improve the bonding quality, a micro-lens array is used to modify the Gaussian laser beam for the bonding process. An electromagnetic modeling and heat transfer simulation is conducted to verify the effect of the micro-lens array on the laser bonding process. The optimal bonding parameters are found experimentally. As the measured temperature ramp rate of the boards exceeds 1100 K/s, bonding occurs within 100–200 ms at a laser power density of 5 W/mm^2. The bonding quality of the FPCB is verified with a shear strength test. Process characteristics are also discussed.

1. Introduction

As multifunctional portable electrical appliances are developed and commercialized, advanced micro-packaging technology for high-density electronic devices becomes necessary, and related research has been carried out [1,2]. In particular, flexible printed circuit boards (FPCB) have been widely adopted in portable electrical devices such as cell phones and laptops, in which folding or sliding mechanisms are required [3–6]. This FPCB is usually connected to other electrical components, such as rigid printed circuit boards (PCB) or transparent substrates of other display units, and the bonding or reflowing process can be accomplished with various heating sources, including hot bars, soldering irons, ultrasonic sources, and convection ovens [7–11]. A hot bar or soldering iron offers a broad heating source, but imperfect or irregular surface contact may lead to bonding or reflowing failure, and tool wear is also a concern. Ultrasonic bonding reduces the local negative thermal effect on electrical boards, but precise contact for vibration transfer can be a problem. A convection oven can be used to heat the entire product for reflowing in non-contact mode, and high throughput can be expected. However, because heat is applied to all parts of the product, other temperature-sensitive components can also be affected. In sum, although each of these processes offers distinct advantages, each is limited to high-precision bonding of ultrafine pitch electrical boards in high-density micro-system packaging. Moreover, it is generally difficult to control the bonding or reflowing temperature of the components to achieve consistent bonding results, as the boundary conditions for the parts being heated (including the heat sources) cannot be defined precisely. Heat loss to the surroundings by radiation or convection is not easily expressed, and irregular contact between the heat source and the FPCB can lead to inconsistent heat resistance. Consequently, imperfect bonding can occur in any of these processes, resulting in a reliability issue for the overall packaging procedure.

A focused laser beam offers unique advantages as a heat source, including high spatial resolution, absence of contact, precision control, and rapid energy delivery. Accordingly, micro-system packaging using lasers has been developed as an advanced manufacturing process [12,13]. Laser irradiation transfers heat to a material and thus provides the mechanism for bonding to a substrate. A laser beam can heat metal inter-connectors, and the heat can be transferred by conduction to a solder paste for bonding. In addition, a laser beam with an appropriate wavelength can penetrate a polymer layer of a PCB, and direct heating can then be applied to a solder paste beneath it. In this case, the upper layer is bonded to the substrate via the melted solder paste. This type of laser soldering is also known as a laser reflow soldering process [14–16]. Laser reflow soldering provides precise control of energy to the reflow solder paste, and hence a precise soldering temperature of the solder paste can be achieved. In this type of laser process, reliability and repeatability can be improved in comparison with conventional procedures. Moreover, the processing time can be

* Corresponding author. Fax: +82 53 580 6725.
E-mail address: hwchoi@kmu.ac.kr (H. Choi).

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considerably reduced because of the rapid non-contact heat transfer of radiation. The spot size of a focused laser beam can easily be held to less than 100 μm, and thus local heating can be achieved with minimal heating of the surroundings. Because the laser beam path can be also controlled with micro-motion stages or a galvano scanner, not only a 1-D heat source, but also a 2-D or 3-D heat source path can be applied. This enables the generation of an optimized heat-source pattern for controlling the temperature of the solder paste with respect to various boundary conditions and material properties.

In this paper, we propose a laser reflow process for bonding an FPCB to a PCB. An FPCB film consists of polymer and metal layers. Solder paste is inserted between the FPCB and the PCB. Therefore, a careful process design must be adopted to achieve successful bonding. A focused laser beam with a Gaussian energy distribution has a higher energy density in the center and can produce an unintended local temperature increase in the material, leading to FPCB damage. Moreover, large spatial and temporal temperature differences can induce internal stress in the boundary, causing micro-cracks. We use a CW IR laser system to reflow the solder paste between the FPCB and the PCB. Laser process parameters to achieve successful bonding are investigated. The laser beam is homogenized with a micro-lens array, and the effect is examined via a finite difference analysis of electromagnetic theory. The mechanical bonding strength is tested to evaluate the bonding quality, and related issues are also discussed.

2. Experimental setup and procedures

2.1. Experimental materials

A commercial FPCB, of the type used in cell phones, was prepared for laser reflowing, and its configuration is shown in Fig. 1. The FPCB consists of a polymer stiffener, polymer insulators, connectors, and conducting lines. Electrical signals are transferred through the connectors of the PCB and FPCB, which are bonded with lead-free solder. This connecting layer is usually thinner than the other layers, making the component flexible and enabling physical movement of the FPCB. It consists of a polymer stiffener (polyimide: PI) and Cu. Micro-holes are fabricated to connect the top and bottom of the Cu layer when the solder paste is melted. The bonding substrate is a PCB, and solder paste is placed at each connecting point (Cu layer). The solder paste is Sn–3.0Ag–0.5Cu (wt%), and the melting temperature is 217–220 °C (or 490–493 K). The alignment of the FPCB and PCB connectors is achieved with a bonding jig, which is used to install other optical delivery devices such as lenses. The material properties of the solder paste and the FPCB composites are given in Table 1.

Since bonding is accomplished using a laser beam source, material interaction with the laser (such as laser absorption) is important to the design and evaluation of the reflowing process. As mentioned above, the main components of the FPCB are a PI layer and a Cu layer with an Au coating. When the laser beam irradiates the FPCB layer, the Cu layer and Au coating directly interact with the laser beam. As the laser beam spot moves across the FPCB, the polymer layer is also exposed to the beam. The absorption characteristics of these two materials (PI and Cu) as well as Au with respect to wavelength were measured. The optical properties can be dependent on the surface topography. So, we measured the optical properties of the material used in the experiment by using spectroscopy. The measured data are shown in Fig. 2.

Generally speaking, a high absorption rate is obtained for Cu in the UV wavelength range. However, the absorption decreases rapidly for relatively long wavelengths (in the vicinity of 1 μm). Moreover, the Cu layer is coated with a thin gold film with prior Nickel diffusion barrier, and thus the absorption rate is assumed to be slightly lower than that of a bulk Cu layer. Because the absorption rate is also dependent on the surface roughness, the actual rate will be somewhat different. For polyimide (the base material for the FPCB stiffener), the absorption also decreases rapidly as the wavelength increases. At a wavelength of 1.07 μm (the wavelength used herein), most of the laser energy will be transmitted to the solder paste or the PCB layers. In terms of the optical properties, the metal layer is mainly heated by the laser beam, and the heat is diffused to the contacting layers (solder paste and polyimide). When an IR laser beam is irradiated, it is to

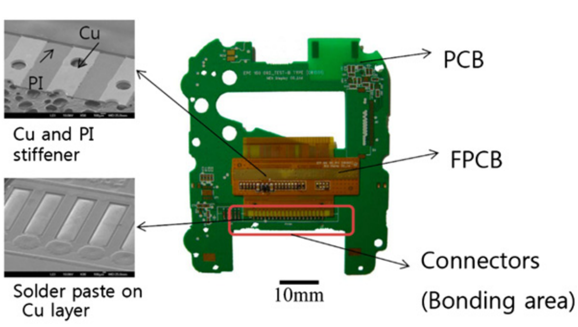

Fig. 1. Photographs of the FPCB and PCB.

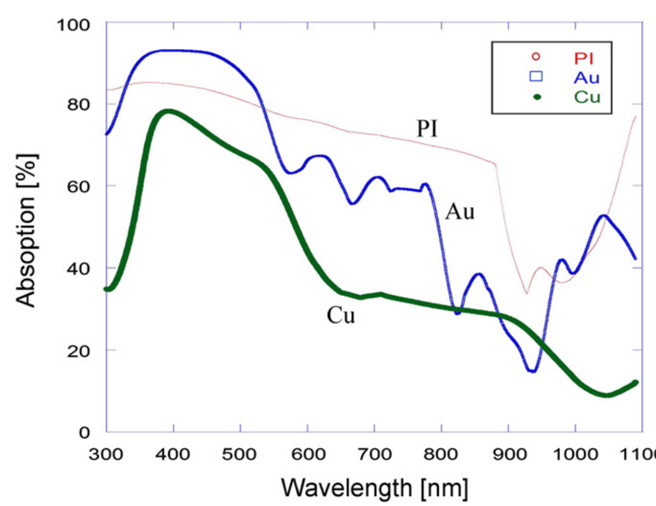

Fig. 2. The optical absorption spectra of PI, Au and Cu.

Table 1
Thermal properties of the solder paste and the FPCB [20].

Material	Thermal Conductivity (W/(m·K))	Specific Heat (J/g·K)	Melting Point (°C or K)
Polyimide	0.174–0.317	1.00–1.42	None
Cu	401	0.39	1083 (or 1356 K)
Solder paste (Sn–3.0Ag–0.5Cu)	57	0.22	217–220 (or 490–493 K)