

Modeling of copper wire bonding process on high power LEDs

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ABSTRACT

In this paper, a couple thermal mechanical transient dynamic finite element framework of copper wire bonding process on high power lighting emitting diodes (LEDs) is developed, which considers the thermal heating effects of friction and plastic deformation. The whole wire bonding process is simplified to consist of impact and ultrasonic vibration stages. Parametric studies are also carried out to examine the effects of ultrasonic vibration amplitude and bonding force on stress/strain distribution and friction thermal heating effect during wire bonding process. Different friction coefficients of interface between the free air ball (FAB) and the bond pad are taken in the simulation to examine the effects of friction on the stress and strain level of electrode structure. Modeling results show that the stress/strain distribution and temperature evolution of wire bonding system are significant influenced by the ultrasonic vibration amplitudes, bonding forces and friction coefficients. Discussion and comparison are conducted between the copper and the gold wire bonding processes on the high power LEDs by numerical simulation. The results have disclosed that higher stress/strain in the bond pad and the ohmic contact layer is induced during the copper wire bonding process. Therefore, the process parameters of copper wire bonding should be controlled carefully. This numerical simulation work may provide guidelines for the copper wire bonding process virtual window development of high power LEDs packaging.

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1. Introduction

Solid state lighting, in terms of high power LEDs will be the fourth illumination source to substitute the incandescent lamp, fluorescent lamp and high pressure sodium lamp [1]. LEDs have superior characteristics such as high efficiency, low power consumption, high reliability and long life [2]. Currently, high power LEDs have found applications in outdoor and indoor illumination, automotive front lighting, backlighting for large LCD displays and city improvement engineering. The market for high power LEDs has been growing rapidly [3–5].

Wire bonding is one of the main processes of the LED packaging which provides electrical interconnection between LED chip and lead frame. The gold wire bonding process has been widely used in LED packaging industry currently. However, due to the high cost of gold wire, copper wire bonding is a good substitute for the gold wire bonding which can lead to significant cost saving. Wire bonding using copper wire has many other advantages over the gold wire. Copper wire has better thermal and electrical properties, excellent ball neck strength, high-loop stability and better looping control [6]. But copper wire has higher hardness and stiffness than

gold wire which may induce higher stress and strain in the electrode structure. Improper copper wire bonding parameters may lead to the reliability problems such as bond pad cratering, peeling and cracking below the bond pad.

Numerical studies with finite element method (FEM) can provide guidelines for the wire bonding process development which has been proven by many researchers. Failure estimation of a silicon chip and a GaAs chip during a gold wire bonding process was presented by Ikeda et al. [7]. A transient nonlinear dynamic finite element framework which integrates the gold wire bonding process and the silicon devices under bond pad is developed by Liu et al. [8–10]. Yeh et al. [11–13] conduct transient analysis to investigate response of the Cu/Low-K structure during the impact and ultrasonic vibration stage of gold wire bonding. The induced stresses during the copper wire bonding process on Cu Low-k wafers were studied by Degryse et al. [14]. Transient heat transfer during the ball bonding process of ultrasonic wire bonding was considered by Jeon [15]. The temperature rise during ultrasonic vibration of wire bonding process was monitored using finite element method by Ding and Kim [16]. It was assumed that there was no relative movement between the capillary and the wire and the frictional energy was applied at the bonding interface. The application of CMOS compatible thermopile sensor to monitoring of the wire bonding process at operating temperatures was demonstrated by

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Suman et al. [17]. And the thermal modeling was also performed to devise an approach to monitor US power as well as ball deformation through applying a constant interfacial heat source at the interface of ball and pad by them.

In this paper, numerical simulations are carried out by a couple thermal mechanical transient dynamic finite element methods to investigate the stress/strain distribution and temperature evolution of the electrode structure of the high power LEDs during the impact and ultrasonic vibration stages of copper wire bonding process. The plastic and friction heating effects are considered in these models. Parametric studies are also carried out to examine the effects of the ultrasonic vibration amplitude and bonding force of the wire bonding on the stress/strain distribution and the friction heating effect during wire bonding process. Different friction coefficients are selected in the simulations to examine the effects of friction between the FAB and the bond pad on the stress/strain level and potential of structural defects in the ohmic contact layers. Finally the copper and gold wire bonding processes on the high power LEDs are compared and discussed.

2. Physical model of wire bonding process

The schematic diagram of copper wire bonding on the high power LEDs is shown in Fig. 1. It involves the capillary, the copper FAB, the heat affected zone (HAZ), the bond pad, GaN layer and the sapphire substrate. A local model is taken in our numerical studies. The thicknesses of GaN layer and sapphire substrate are 3 μm and 50 μm respectively. The length of GaN and the sapphire substrate is 200 μm . The electrode structure of LED chip consists of the Indium Tin Oxide (ITO) and Titanium layers as the ohmic contact layers which are covered by the gold bond pad. The ITO layer and Ti layer are both thin films which thicknesses are both set as 0.1 μm respectively. The ITO and Ti layers thin film are deposited by the electron beam evaporation. The thickness of the gold bond pad is 1.5 μm and the length of the electrode structure is 120 μm in our model.

The geometry of capillary is shown in Fig. 2. A specific set of parameters $d1 = 30 \mu\text{m}$, $d2 = 60 \mu\text{m}$, $d3 = 100 \mu\text{m}$, $\alpha = 3^\circ$, $\beta = 90^\circ$, $R1 = R2 = 3 \mu\text{m}$, $R3 = 5 \mu\text{m}$ are applied. The diameter of copper wire is 25 μm . Generally the diameter of the FAB will be 1.5–4 times thicker than that of the bonding wire. The diameter of the FAB is chosen to be 70 μm in present work.

Typically the whole wire bonding process consists of five stages. As shown in Fig. 3, they are generation of FAB by heating up the bonding wire tip, vertical motion of the capillary and FAB, impact of FAB with bond pad, input of the ultrasonic vibration energy and move up of the capillary. Usually, after the initial impact of FAB on the bond pad, the ultrasonic vibration and the compression of capillary are conducted at the same period of time till the final smashed ball is formed.

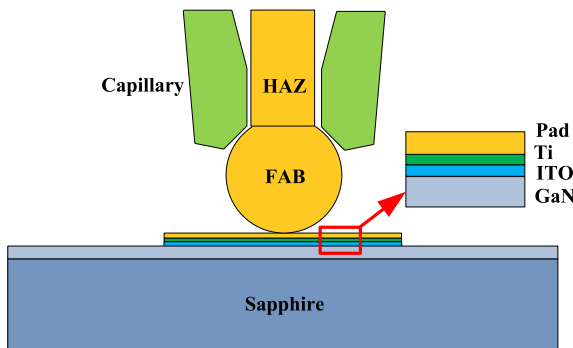


Fig. 1. Wire bonding system on the high power LEDs.

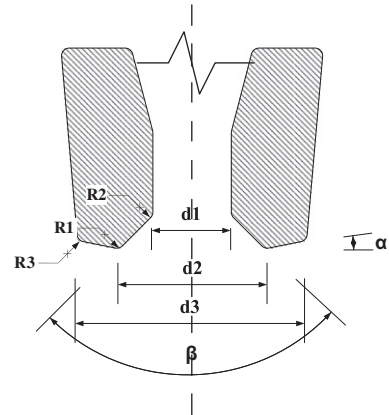


Fig. 2. Geometry of capillary.

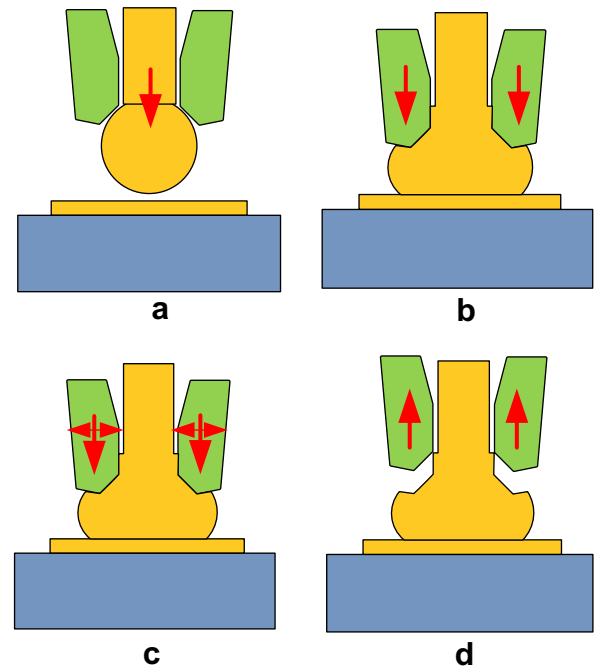


Fig. 3. Schematic diagram of wire bonding process: (a) FAB generation and vertical motion stages; (b) impact stage; (c) horizontal ultrasonic vibration and compression stage; (d) move up of capillary stage.

During the wire bonding process, the LED device is placed on a heated pedestal which is kept at a certain temperature and transmits heat to the bond pad through the conduction mode. Large plastic deformation occurs in the FAB and bond pad during the impact and ultrasonic vibration stages which will induce plastic heat. Friction between the FAB and the bond pad during the ultrasonic vibration stage will also induce friction heat to the wire bonding system. Materials in the wire bonding system such as FAB and bond pad will also be heated up by absorbing energy of the ultrasonic. Elevated temperature of the bond pad will enhance atomic diffusion on the interface between the FAB and the bond pad which will help to achieve better bonding quality. The governing equation of transient conductive heat transfer is given by

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(\lambda_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda_z \frac{\partial T}{\partial z} \right) + \dot{Q} \quad (1)$$

where ρ is the density, c is the specific heat, T is the temperature, t is the time, λ is the thermal conductivity, x , y and z are the spatial

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