Optics & Laser Technology 89 (2017) 92–96

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Full length article

Enhanced light extraction efficiency of chip-on board light-emitting diodes through micro-lens array fabricated by ion wind

Jingcao Chu[a], Xiang Lei[a], Jiading Wu[a], Yang Peng[a], Sheng Liu[b], Qian Yang[b], Huai Zheng[b,*]

[a] *School of Mechanical Science & Engineering, Huazhong University of Science & Technology, Wuhan 430074, China*
[b] *School of Power & Mechanical Engineering, Wuhan University, Wuhan 430072, China*

ARTICLE INFO

Keywords:
Light-emitting diodes (LEDs)
Micro-lens array
Chip-on board (COB) packaging
Light extraction efficiency (LEE)
Ion wind

ABSTRACT

Low light extraction efficiency (LEE) is a key challenge of chip-on board (COB) packaging light-emitting diodes (LEDs). In this paper, a facile preparation of micro-lens array was proposed based on the ion wind patterning. The geometries and sizes of the micro-lens arrays were controlled through adjusting the voltage parameter of the ion wind generation. Consequently, the micro-lens array with the diameter of 180 μm and the gap distance of 15 μm has been fabricated. Benefitting from this micro-lens array, the LEE of COB packaging LEDs was enhanced by 9%. This facile fabrication of micro-lens array would be a promising method to improve the LEE of COB packaging LEDs.

1. Introduction

Due to their high reliability, long lifetime, tunable color, and energy saving, light-emitting diodes (LEDs) have been widely applied in displaying backlighting, street lighting, vehicle headlights, interior illumination and so on [1–3]. With the development of LED technology and the broad applications of LEDs, the requirements of less cost and higher power LEDs are rapidly increasing. Exactly, the chip-on board (COB) packaging LEDs meet these requirements. Moreover, the COB packaging technology has numbers of advantages compared with the single-chip packaging, including low manufacturing cost, high optical power, and more compact size [4]. So the COB packaging technology has been greatly developed, which undoubtedly has tremendous development potentiality for improving LED technology. In the meantime, there are also some unsolved problems in the COB packaging technology, and the low light extraction efficiency (LEE) is one of the challenge points [5].

At present, the reported highest LEE of a single-chip LED with the good packaging technique is about 180–200 lm/W in the market, while that of a COB packaging LED is just 160–180 lm/W generally. One of the reasons is the total internal reflection (TIR) at the flat light-emergent surfaces of silicone gel [5]. The TIR results in light trapping into the COB packaging modules, and the light power transforms into the thermal energy [6]. Currently, there are some methods for diminishing the TIR for COB packaging LEDs, such as patterning structure on LED chip or substrate [7,8], and patterning encapsulation layer [6,9–11]. Moreover, packaging with micro-lens array on the surfaces of the silicone gel is an effective method to enhance the LEE of the COB packaging module, which has been investigated by the simulation introduced [9,10].

In order to fabricate the micro-lens array, some techniques have been introduced, such as inkjet printing technology [12], liquid trapping technology [13], and compression molding method [14]. Although nearly all of these methods have effectively made important contributions to the fabrication of high quality micro-lenses, they highly rely on the strict precision, complex fabricating process, or expensive molds. Thus, there are strong needs for developing new methods for fabricating micro-lens array.

In this paper, a novel method was proposed to fabricate the micro-lens array by means of ion wind. By exerting the ion wind on the silicone gel, a micro-lens array encapsulation layer was obtained on the indium tin oxides (ITO) conductive glass. The detailed theory and fabricating process were investigated, and the COB packaging module with micro-lens array was introduced. This is the first research about using the ion wind to drive the silicone gel and form microstructure patterns. Compared with the flat glass packaging module, the micro-lens packaging module can significantly improve the LEE of COB packaging LEDs. In comparison with the reported fabrication technologies, the ion wind method introduced in this paper has many advantages, such as smooth surface of the lens, low cost, and rapid manufacturing.

2. Formation process of micro-lens array

2.1. Principle

Ion wind is a well-known phenomenon in the field of electrohy-

* Corresponding author.
E-mail address: Huai_zheng@whu.edu.cn (H. Zheng).

http://dx.doi.org/10.1016/j.optlastec.2016.09.045
Received 21 July 2016; Received in revised form 19 September 2016; Accepted 28 September 2016

drodynamics (EHD), which was first reported about 300 years ago [15]. The ion wind is generated by corona discharge. The high voltage is applied between the two electrodes with radius of curvature of different sizes, and the gas medium is ionized while producing electrons and ions. When the local electric field intensity is higher than gas ionization field intensity, the ion avalanches occur [16]. The electrons and ions under the action of coulomb role are forced to the electrode movement [17,18].

Fig. 1 shows the formation principle of the micro-lens array by means of ion wind. A high voltage is applied between the corona electrode and the collector electrode. Air molecules become ionized into positive ions and electrons by the influence of high voltage. Under the effect of electric field, the positive ions move to the collector electrode, and the electrons move towards the corona electrode. As the voltage aggrandizes, there are more and more positive ions moving to the collector electrode. However, the silicone gel is non-conductive and obstructs positive ions moving to the collector electrode. With the number of positive ions increasing, the silicone thin film is imploded by ions and breaks up into lots of micro-lenses. Then, the micro-lens array appears on the collector electrode.

2.2. Experiments

The experimental set-up is shown schematically in Fig. 2. The diameter of the needle tip regarded as the corona electrode is 73 μm as small as fit, so that there are more charged particles, and the ions move faster [19]. Through the optical microscope, the deformation of the silicone film can be observed on the computer screen in real time. The high-voltage power is supplied by a high voltage DC power which can provide voltage from 0 to 30.0 kV continuously. In the course of experiment, the voltage was changed between the needle and the collector electrode, and the current of the circuit was measured.

The silicone micro-lens array was fabricated on the glass surface by the ion wind. Firstly, the flat thin film of silicone gel with the thickness of 60 μm was spin-coated on the ITO conductive glass. The ITO conductive glass was used as the substrate and well-connected to the collector electrode. The distance between the needle tip and the upper surface of the glass was 10 mm. Then, the voltage was operated from 3.0 to 10.0 kV to form the silicone microstructure. At last, the silicone micro-lens array was heated under 120 °C for 10 min to guarantee the silicone solidified.

The packaging process of COB LED module packaged by ITO glass with silicone micro-lens array is shown in Fig. 3. Firstly, the micro-lens array was fabricated on the ITO glass. Meanwhile, the silicone gel was dispensed and vacuumized in the COB packaging module. Then the glass with micro-lens array was attached on the COB packaging by the liquid silicone gel. The different ITO glasses with different diameter micro-lens arrays were used to bond on the identical COB packaging module. On the other hand, for the traditional COB packaging LEDs, the identical COB module was packaged by the ITO glass without silicone layer. The identical COB packaging module was used during the comparison experiments in order to eliminate the influence of different modules on the LEE.

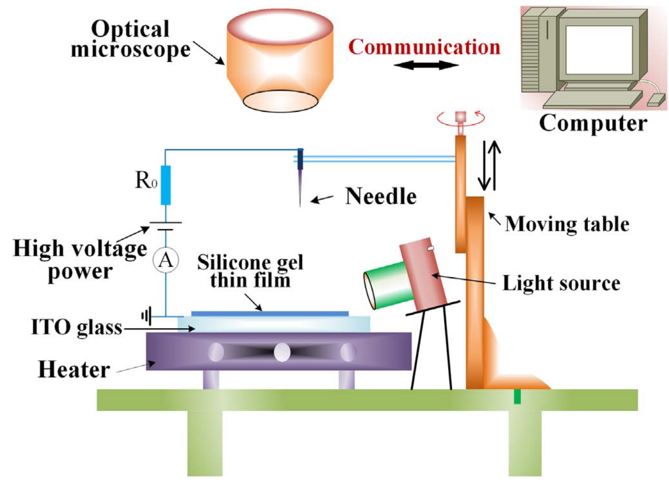

Fig. 2. Schematic diagram of experimental set-up structure and operation.

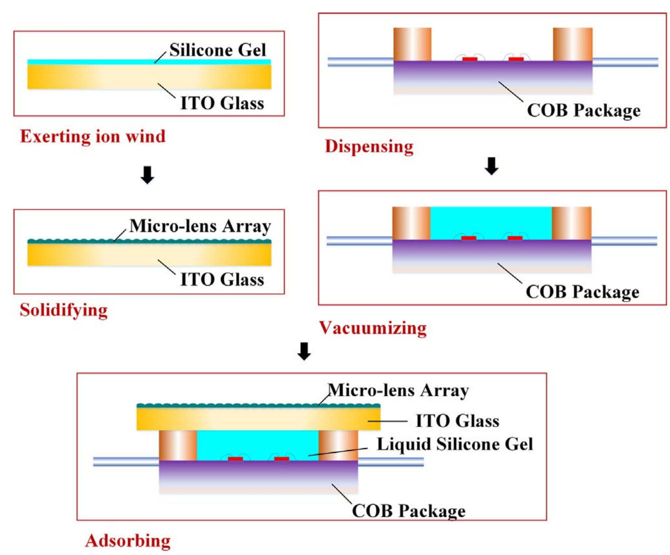

Fig. 3. Schematic diagram of packaging process for COB packaging module with micro-lens array.

In this study, horizontal injection GaN LED chips were used and the chip size is 45×45 mils. The main wavelength was maintained at 457 nm, and the peak wavelength was maintained at 451 nm. The figures of the real-time samples were obtained by digital camera. The top surfaces of samples were observed by digital microscope (VHX-600, KEYENCE, Japan). The optical performances of the COB packaging LEDs were measured by a high accuracy array spectroradiometer

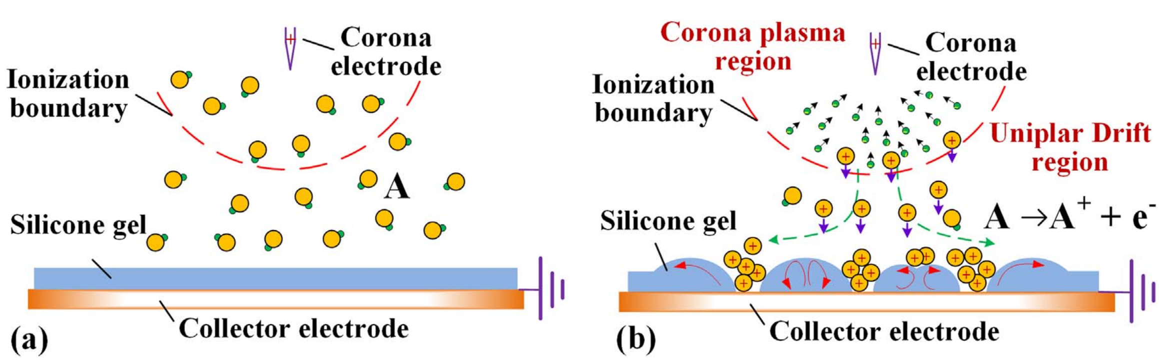

Fig. 1. Formation principle of micro-lens by ion wind.