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The vacuum packaging of a flat lamp using thermally grown carbon nano tubes

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Abstract

In this work, we fabricate 1-in carbon nano tubes (CNTs) flat lamp of diode and triode structure. The CNTs have been directly grown on soda-lime glass substrate by thermal growth method. To know the optimized flat lamp structure, we have simulated the electric field distribution in these structures by the Maxwell simulator. The metal-mesh grid is inserted between an anode and cathode plate for dispersion of emitted electrons and decrease of turn-on voltage, and we investigate the trajectory of emitted electrons in the triode structure. Also, we suggest the direct joint packaging method, which needs no exhausting hole and tube. The CNTs flat lamps are successfully packaged and fully emitted with high brightness. The emission and brightness properties of CNTs are investigated for various conditions.

Keywords: Carbon nano tubes (CNTs); Flat lamp; Diode structure; Triode structure; Direct joint packaging method; High brightness

1. Introduction

The carbon nano tubes (CNTs) technology has been rapidly developed because CNTs have a range of electronic properties that are attractive in the electronic and display devices [1]. During the past few years, much work has been performed with the aim to achieve field emission from carbon fiber tips, unoriented films of CNTs, and thick films of CNTs mixed with conductive epoxy [2]. Especially, the CNTs have been reported in the display field, which provides high bright and good uniform emission [3]. Recently, some groups fabricate a bulb-type CNTs lamp similar to the CRT gun shape, which has good light emission properties [4]. But it needs a distance of a few cm from the cathode to anode and a high anode voltage of above 10 kV. Therefore, this structure has limitations of application for potable display owing to large volume and high power. The flat lamp fabrication technology is the most promising method to solve the above-mentioned problems as

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well as to realize an ideal application. To realize the flat lamp, we must develop some technologies such as brightness, light uniformity, and high performance packaging. Also, the packaging technology of vacuum electronic devices has been rapidly improved to enhance their performance characteristics such as lifetime and durability [5,6]. In general, the field emission device has been packaged by the cathode ray tube (CRT)-like method. It has been proven to be limited in terms of the high volume, out-gassing, and metal oxidation by high-temperature process owing to small inner volume. So the new packaging technology is required to optimize flat vacuum devices.

In this work we fabricate the vacuum-packaged CNTs flat lamp of diode and triode structure, according to the results of electric field simulation. Also, we introduce the direct joint packaging method, which needs no exhausting hole and tube. The light emission is observed from 1-inch diagonal CNTs flat lamps packaged by the above methods.

2. Experimental

Fig. 1 shows the geometrical structures of vacuum packaged CNTs lamp. In the case of diode type, as shown in Fig. 1(a), the spacing is 500 μm and the emitted area is 1-inch diagonal. The triode type has the same structure as the diode type but a grid is inserted between the anode and cathode plate for the decrease of turn-on voltage and the dispersion of emitted electron, as shown in Fig. 1(b), and Fig. 1(c) shows the geometrical structure of direct joint method structure, which does not have exhausting hole and tube. The exhausting hole of 6 mm diameter, the gate and cathode electrode lines are formed on the cathode glass plate. And then the CNTs are grown on the cathode plate in an active area as a dot pattern.

Fig. 2 shows the SEM images of (a) catalyst pattern and (b) CNTs grown selectively on soda-lime glass plate. We use the cathode metal of Ti/Cr and catalytic metal of Fe or Ni. Generally, the CNTs are grown in C_2H_2 ambient with pre-treatment of NH_3. CNTs grown on soda-lime glass substrate have a growth temperature of about 500–600°C, which is lower than that of Si-wafer. The CNTs are made in Iljin Nanotech Co. Ltd. The phosphor is deposited by screen print and frit is dispensed on an ITO-coated anode glass. Then it is placed on the cathode glass with exhausting tube followed by heating to 430°C to melt a glass frit in N_2 ambient furnace.

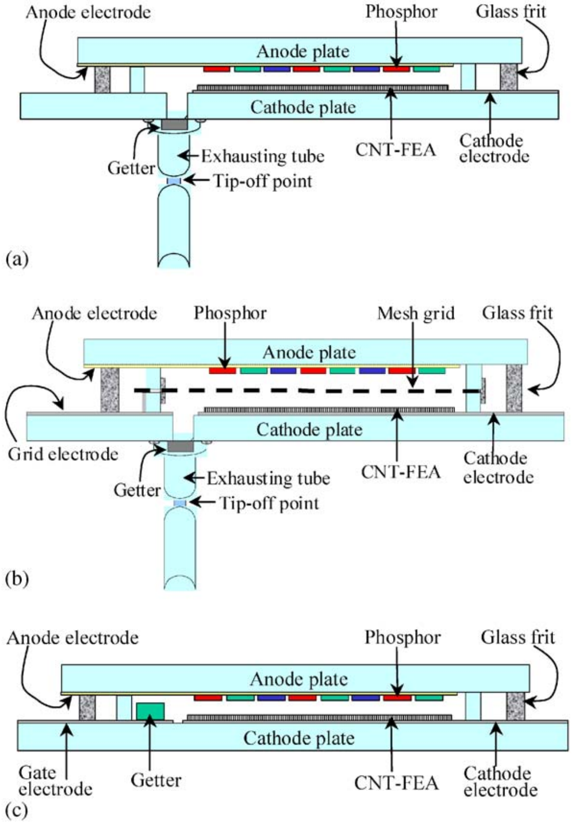


Fig. 1. Geometrical structures of CNTs lamp: (a) diode type; (b) triode type; and (c) direct joint type.

The ZnO:Zn phosphor is printed and the glass frit is dispensed on the anode glass plate. Then it is placed on the cathode glass plate with exhausting tube followed by heating to 430°C to melt a glass frit in N_2 ambient furnace. In the case of triode type, the metal grid of mesh type is inserted between the anode and cathode. However, the panel having opened exhausting tube is successfully fabricated as in the previously mentioned

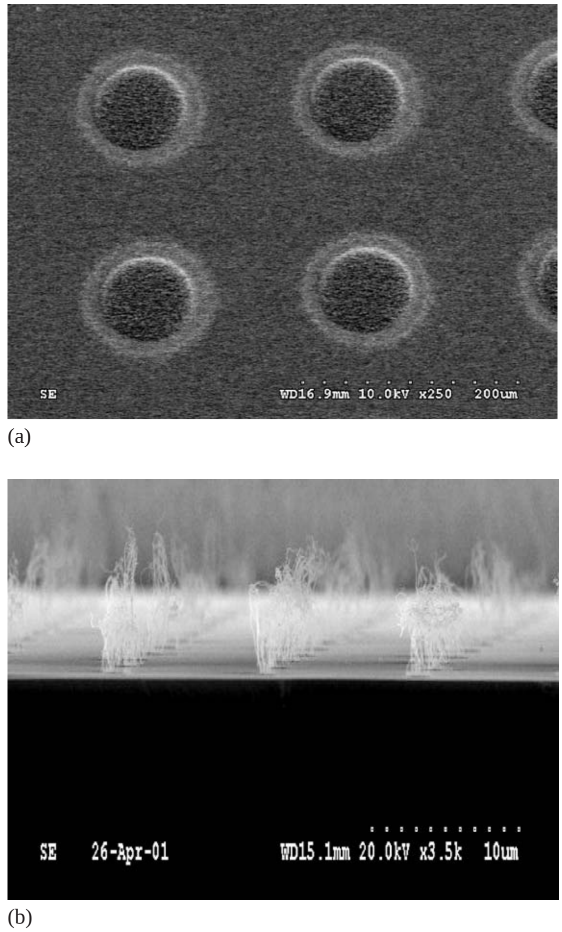


Fig. 2. SEM images of (a) catalyst pattern and (b) CNTs grown selectively on soda-lime glass plate.

process. And a sheet-type getter (ST122) is inserted into the panel through a tube, as shown in Fig. 1. The panel is connected to a tip-off system followed by pumping to 1×10^{-6} Torr.

In the case of the direct joint method, we perform the pre-treatment of glass frit during a burn-out process. It does not have exhausting hole and tube. We fabricate the lumps of 0.3 cm length and 150 μm height at the top of the seal-line. The role of lumps is that of a supporter to make a pumping-out path from the inner to outer panel. The panel is jointed in a vacuum chamber below 10^{-6} Torr at about 350°C. Then, a getter is activated at the same time.

3. Electric field simulation

The electric fields in diode and triode constructions are simulated to modify the performance such as a low voltage operation and a trajectory of electrons emitted. Fig. 3 shows the electric field distributions for various driving conditions by MAXWELL simulator. The electric field of diode type makes a parallel field along an electrode as shown in Fig. 3(a). In the triode structure, the modified light uniformity can be provided by electron trajectory from emitted electron at a low turn-on voltage. The displacement of electric field distribution is diversely observed when voltage variation is applied, as shown in Fig. 3. The triode type has the same electric field as the diode type, when the grid and anode voltages are 1000 and

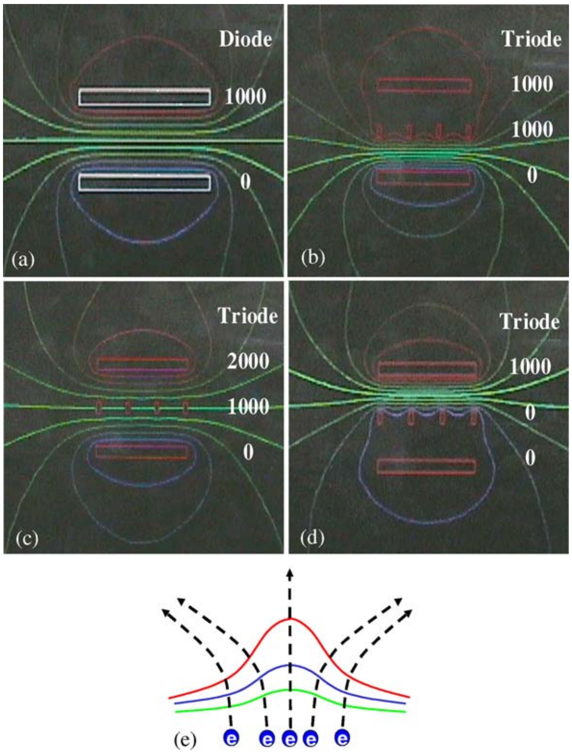


Fig. 3. Simulation results of the electric field distributions for various constructions by MAXWELL: (a) Diode type (anode-1000 V); (b) Triode type I (anode, grid-1000 V; right figure shows the electron trajectory in electric potential); (c) Triode II (anode-2000 V, grid-1000 V); and (d) Triode III (anode-1000 V, grid-0 V).

2000 V_{DC}, respectively (Fig. 3(c)). In the case of Fig. 3(d), the grid does not contribute to electric field distribution because electric field distribution concentrates between the grid and anode only. The electrons have a tendency to move along the electric field vertically. When 1000 V_{DC} is applied to the anode and grid electrode at the same time, the electric field concentrates between cathode and grid, and the electric field between the grid and anode disperses as shown in Fig. 3(e). Therefore, Fig. 3(b) structure has the capability of the electron trajectory to achieve the above purpose.

4. Diode-type CNTs flat lamp packaging

Fig. 4 shows the photographs of light emission from diode-type CNTs flat lamp packaged. Fig. 4(a) is red, (b) is green, and (c) is blue. Fig. 5 shows the measured light emission and brightness variation as a function of driving voltage. We measure a brightness of 14.8 Kcd/m^2 from CNTs flat lamp packaged. But packaged lamp has lower brightness than that before the tip-off process. The field emission characteristics of CNTs flat lamp are compared with those before packaging, before tip-off, and after tip-off, as shown in Fig. 6. The operation voltages through packaging process shift towards the right direction in spite of a decrease of spacing (Fig. 6(a)). Fig. 6(b) shows the emission characteristics for the electric field, where we can observe an increasing electric field of about 1 V/μm after packaging. CNTs grown on soda-lime glass have a turn-on voltage of 2.5–3.5 V/μm, which is higher than that of silicon wafer, 1–1.5 V/μm [7]. I think that the increase of turn-on voltage is caused by the CNTs contamination during glass frit sintering and the worse vacuum level by out-gasses during tip-off packaging. Although the small quantities of gas are absorbed by the getter, out-gasses of extremely small quantities induce a fatal consequence in the vacuum level of FPD.

5. Triode-type CNTs flat lamp packaging

In this triode structure, a grid electrode is inserted between the anode and cathode plate as shown in Fig. 1(b). We insert the metal grid of mesh type, which has two effects. One is the decrease of turn-on voltage by reduced spacer

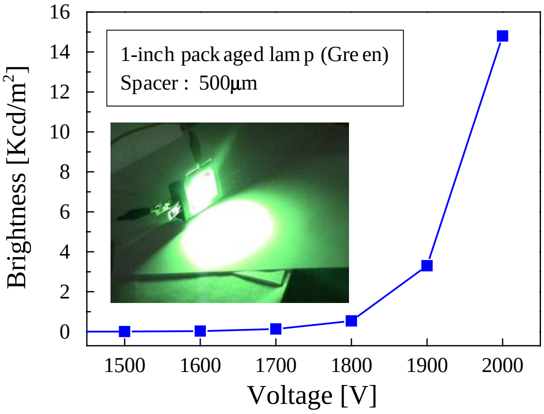


Fig. 5. Brightness variation when voltage is applied to packaged lamp.

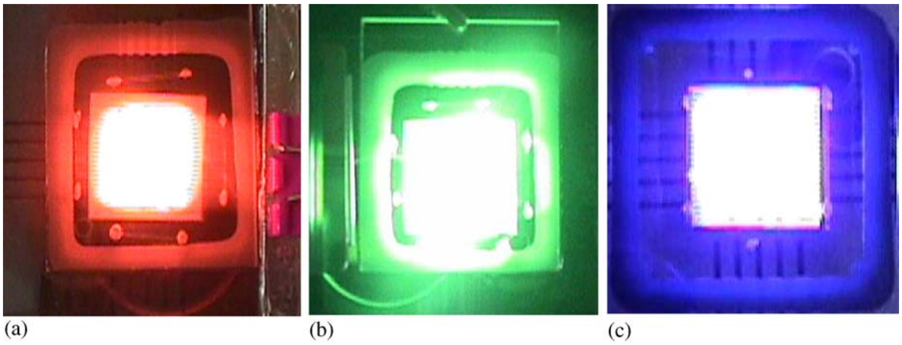


Fig. 4. Photographs of light emission from packaged diode-type lamps: (a) red; (b) green; and (c) blue color.

height between the anode and cathode. Fig. 7 shows the driving voltage change for different spacer height. Then turn-on electric field is about 2.6 V/μm. When the spacer height decreases, the driving voltage decreases exactly. Therefore, the narrow spacing control is a very important factor to obtain the low voltage driving. Also the spacing of below 300 μm easily generates the arcing between grid and cathode electrodes during application of voltage.

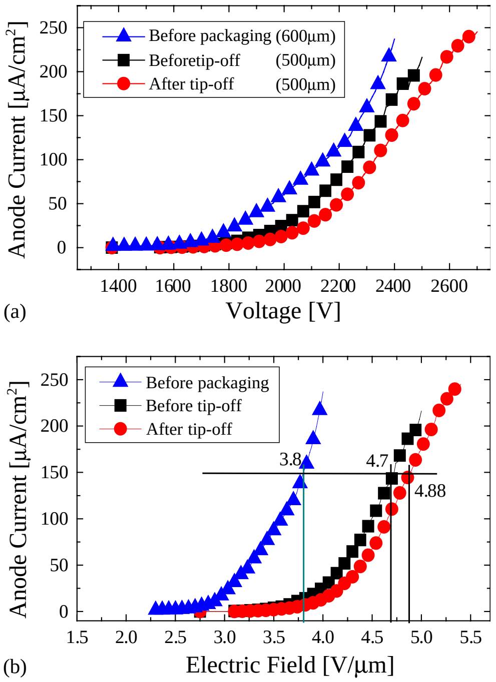


Fig. 6. Emission characteristics when (a) voltage variation and (b) electric field variation are applied during package process step.

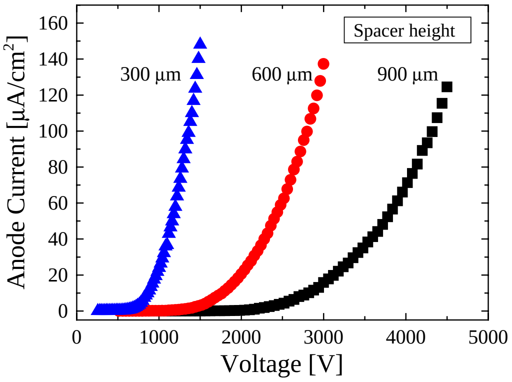


Fig. 7. Comparison of turn-on voltage for different spacer height.

The other is the dispersion of emitted electron flight path to obtain uniform brightness. This is discussed in electrical simulation results (Fig. 3). Fig. 8(a) shows the photograph of a mounted metal mesh grid, which has hexagonal holes of 250 μm diameter and 30 μm pitch. The grid is connected with the electrode on the cathode plate. Fig. 8(b) shows the light emission image from packaged triode-type lamp when voltage variation is applied. When 1700 V_{DC} is applied to anode and grid electrodes, the light emission is observed as round objects, which is thought to be the electron trajectory effect by grid electrode. The full light emission is observed from CNTs flat lamp at 2500 V_{DC}.

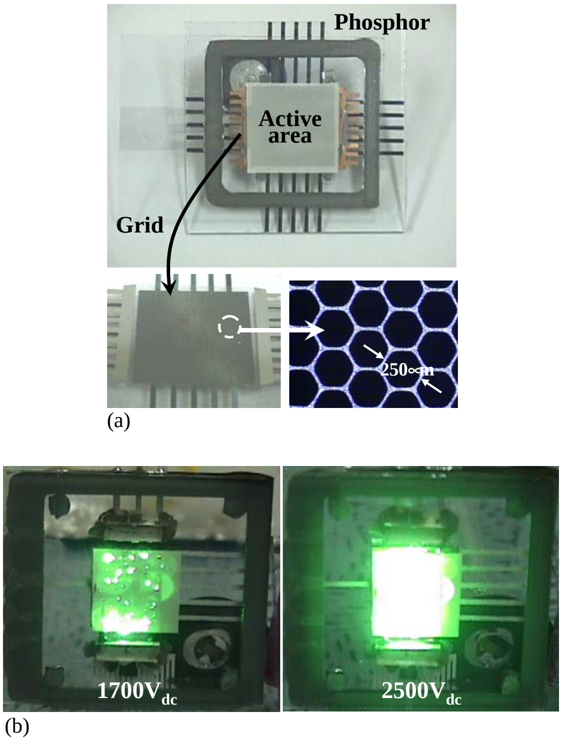


Fig. 8. The photographs of (a) a mounted grid on cathode plate and (b) a light emission from packaged lamp.

6. Direct joint packaging

The direct joint method needs no exhausting hole and tube. Both anode and cathode plates are inputted in the vacuum chamber. Fig. 9 shows the schematic diagrams of a pumping-out path and the cross-sectional view of the formed lump, respectively. The role of lumps is that of a supporter to make a pumping-out path from the inner to outer panel. The pumping-out path dimension is related to a pumping efficiency, which can be calculated by combination of conductance. This is the ability of pipe to allow a unit volume of gas to pass through in a time period [8].

We calculate the conductance assuming that the shape of pumping path is rectangular. Then, conductance [C] for one path becomes

$$C = 31.1 \times \frac{L^2H^2}{(L+H)W} \quad (\lambda/\mathrm{s}), \tag{1}$$

$$C_t = C_1 + C_2 + C_3 + C_4\ldots \quad (\lambda/\mathrm{s}), \tag{2}$$

where L is an interval length of lumps, H is a lump height, and W is a represented seal-line width. In this experimental, a pumping-out path of 7 mm distance and lump of 3 mm length and 150 μm height are formed. Then the seal-line width is 3 mm, the calculated conductance is 0.014 λ/s per 1 cm seal-line, which is similar to a conductance of exhausting tube of 2 mm diameter and 4 cm length. Therefore, we can increase linearly a conductance for display panel size because of the many paths along the seal-line. Based on the theoretical calculation, we obtain the total conductance of 0.27 λ/sec in our panel with a seal-line of 20 cm length. If we apply this method to FPD, the vacuum efficiency of panel will be enhanced. Also, the partial vacuum level in the panel will be improved because a pumping-out path exists at all sides of the panel. Since the conductance increases linearly with increasing panel size, it is able to overcome the limitation of pumping-out problem which the conventional method has.

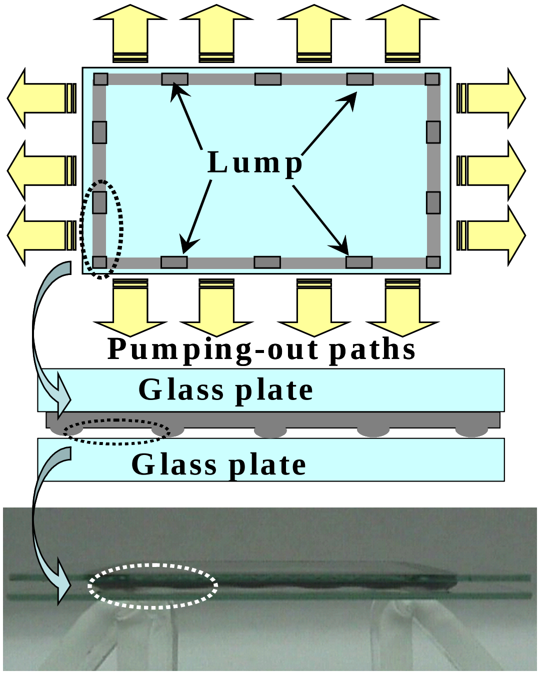


Fig. 9. Schematic diagrams of the lumps and the pumping-out paths view.

The glass frit is dispensed on anode glass plates as seal-line and lumps. And then the anode plate is annealed in the furnace in N_2 gas ambient. To use the direct joint packaging method, the sintering process of glass frit is very important. The glass frit is mainly composed of PbO, SiO_2, and organic binder. If we do not perform a burn-out process, the device surface is contaminated by Pb, C, and O, which is analyzed by auger electron spectroscopy (AES), as shown in Fig. 10. However, the CNT flat lamps are packaged successfully by the above method. If we can not control the packaging

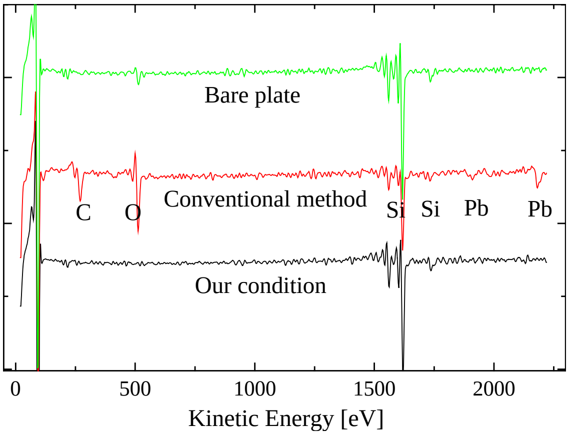
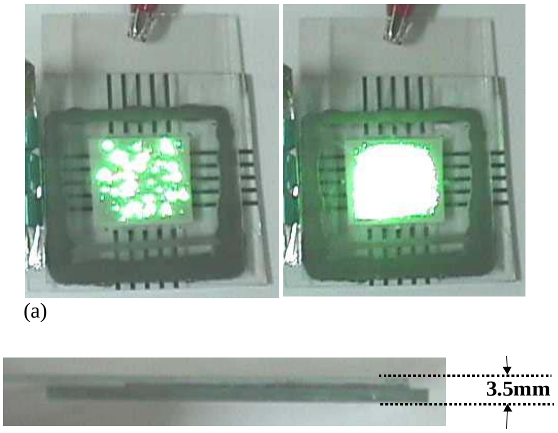


Fig. 10. Contamination analysis on silicon wafer surface by AES.



(a)

(b)

Fig. 11. Light emission photographs of direct joint packaged CNTs flat lamp: (a) top view and (b) side view.

conditions such as pre-treatment and packaging temperature, many bubbles will be generated in glass frit. Fig. 11(a) shows the light emission photograph from direct joint packaged CNTs flat lamp without exhausting hole and tube. The anode and cathode plates are directly jointed by glass frit. The 1-in CNT flat lamp is fully emitted during the increase of applied voltage. Then the brightness is up to 5.4 Kcd/m^2 at 2800 V. The total panel thickness is less than 3.5 mm, as shown in Fig. 11(b).

7. Conclusion

In this paper, we have packaged 1-in CNT flat lamps of three types such as diode, triode, and direct joint method. CNTs have been grown directly on soda-lime glass substrate by the thermal growth method. To investigate the optimized flat lamp structure, we have simulated the electric field distribution in these structures by the MAXWELL simulator. The diode-type CNTs flat lamp is successfully packaged and fully emitted as 15.4 Kcd/m^2. In the triode structure, the metal grid of mesh type is inserted between the anode and cathode plate for dispersion of emitted electron and decrease of turn-on voltage. We show the light emission of brightness of 7.3 Kcd/m^2 at 2500 V$_{DC}$ from packaged CNTs flat lamp. Also, we introduce the direct joint method without exhausting hole and tube. It can provide advantages such as simple, short time, small cost process and thin panel packaging. This fact is revealed through the vacuum efficiency modeling and experimental results. The packaged CNTs flat lamps have light emission of brightness of 5.4 Kcd/m^2.

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