High Power Light Emitting Diode with Graphene Transparent Electrode

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Summary

High performance LEDs were fabricated using graphene transparent conducting electrode in ultraviolet (UV) and green region. In order to prevent the graphene delamination, two-layer lithographic patterning consisting of non-photosensitive low viscosity layer and common photoresist, was first demonstrated. Here we introduce the low-viscosity interfacial layer which prevents the strong interaction between photoresist and chemical groups on graphene. CVD (Chemical Vapor Deposition) graphene was doped by chemical treatment process using HNO_3 solution. O_2 plasma treatment process was introduced to increase the adhesion between Cr/Au electrode and p-GaN. Two layer lithograpjhic patterning and chemical doping of graphene resulted in enhancement of the current spreading over the p-GaN and the high power LED operation.

Motivation

Graphene, which is a high transparency from UV to near-infrared region, and the high thermal and electrical conductivity, graphene holds promise for use in LEDs as a transparent conductive electrode [1,2]. Indium tin oxide (ITO) has been conventionally used as the transparent conductive electrodes in solar cells and LEDs. However, ITO is an expensive material, unstable in chemical solutions and has low transparency in the UV region [3]. In addition, the high thermal conductivity of graphene is advantageous for lowering the operating temperature of high power LEDs.

However, irrespective of these outstanding advantages, at cleaning process of residual photoresist after patterning, the strong dipole bonding between photoresist and graphene, cause graphene delamination due to the absence of interfacial bonds to the substrate. This graphene delamination blocks the current spreads over entire graphene sheet. Therefore it is essential to obtain reliable lithographic patterning without graphene delamination to produce large area current spreading over p-GaN.

The large work function (Φ) difference between p-GaN and graphene (respective Φ values are 7.5 and 4.5 eV) results in a substantial Schottky barrier height at the interface. Thus, it is prerequisite to tune the electrical/electronic properties of graphene in order to attain a better electrical coupling between graphene and p-GaN. Chemical charge transfer doping has been shown to increase the Φ of graphene as a result of modification of Fermi level [4-6]. Chemical doping can reduce the Rs and thus improve the conductivity.

Results

Graphene delamination was overcome by introducing the two-layer lithographic procedure. The sheet resistance of CVD-FLG was decreased from 700 ~ 1200 Ω/sq to 90 ~ 150 Ω/sq by immersing FLG into HNO_3 solution. Current spreading over the p-GaN was increased from preventing graphene delamination. The adhesion between Cr/Au electrode and p-GaN was improved by O_2 plasma ashing and it prevents the metal peeling off during LED operation.

The Vf defined at an injection current of 20 mA is found to be 5.72 V for the LEDs with as-grown MLG electrodes. When a doped MLG electrode is applied to the LED, the Vf is reduced to a value of .4.59V and the current spreading is significantly improved. LED power was increased ~ 96 % from the adoption of graphene transparent electrode and ~ 14.3 % from the HNO_3 chemical doping of graphene sheet, respectively.

From above results, high power LED operation more than 60 mW in green is expected from the previous experimental conversion between non-integrating sphere and integrating sphere measurement. More details about the process optimization, power increase due to LED structure (electrode pattern design and chip shape), and analysis are to be discussed at the conference.

References

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Figures

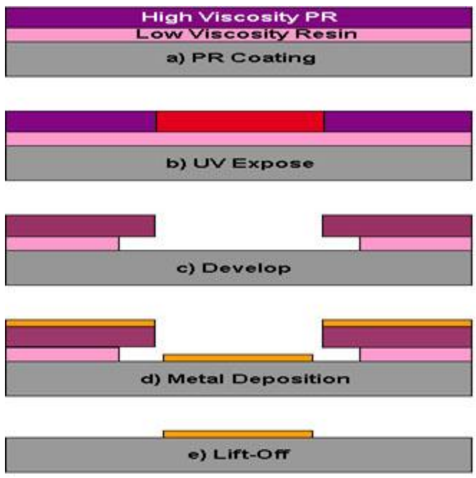

Fig. 1

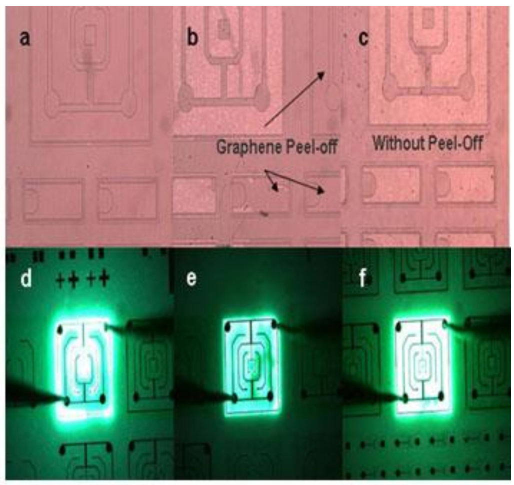

Fig. 2

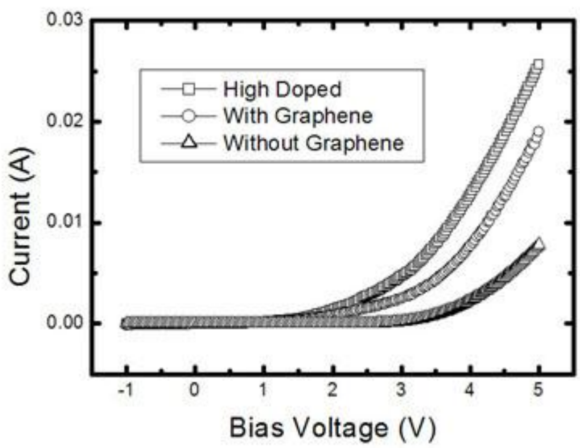

Fig. 3

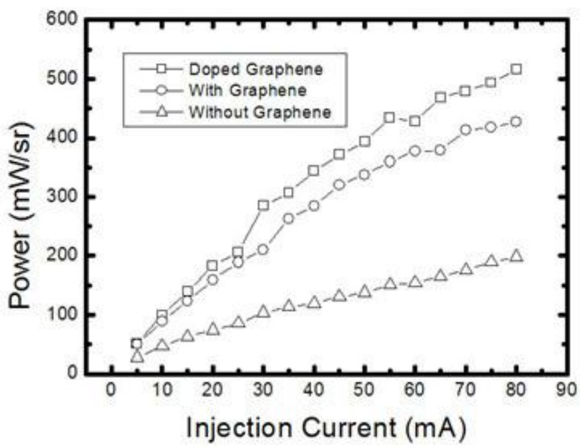

Fig. 4

Figure caption

Fig. 1: Two-layer lithographic patterning Method.

Fig. 2: Correlation between graphene delamination and current spreading. a) LED pattern after p-GaN etching without graphene electrode, b) LED pattern with graphene delamination, c) LED pattern without graphene delamination, d) current spreading limitation only at the electrode, e) current spreading limitation due to graphene delamination, f) current spreading over entire p-GaN.

Fig. 3: Increase in current spreading due to chemical doping of graphene using HNO_3 solution.

Fig. 4: Increase in LED power due to adoption of grapheme transparent electrode and chemical doping of graphene.