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Graphene transparent electrode for enhanced optical power and thermal stability in GaN light-emitting diodes

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Abstract
We report an improvement of the optical power and thermal stability of GaN LEDs using a chemically doped graphene transparent conducting layer (TCL) and a low-resistance contact structure. In order to obtain low contact resistance between the TCL and p-GaN surface, a patterned graphene TCL with Cr/Au electrodes is suggested. A bi-layer patterning method of a graphene TCL was utilized to prevent the graphene from peeling off the p-GaN surface. To improve the work function and the sheet resistance of graphene, CVD (chemical vapor deposition) graphene was doped by a chemical treatment using a HNO_3 solution. The effect of the contact resistance on the power degradation of LEDs at a high injection current level was investigated. In addition, the enhancement of the optical power via an increase in the current spreading and a decrease in the potential barrier of the graphene TCL was investigated.

(Some figures may appear in colour only in the online journal)

1. Introduction

Conventional indium tin oxide (ITO) has been used as a transparent conducting layer (TCLs) in solar cells and light-emitting diodes (LEDs). However, ITO has several drawbacks, such as high cost, instability in chemical solutions, and especially low transparency in the UV region [1]. Graphene is a promising material for optoelectronic devices [2–5] because it has outstanding electrical conductivity and high transparency over a wide range of the optical spectrum [6–12]. However, there are several technical issues to be addressed when applying graphene as a TCL for LEDs.

One of the most important issues is the poor adhesion of graphene to an active semiconducting material, i.e. p-GaN, causing graphene to peel during the patterning process [13–15]. If graphene peeling occurs, current spreading stops at the location of the peeling and does not spread any further in the lateral direction. Therefore, graphene peeling blocks current spreading over a p-type GaN layer and limits the emission area of LEDs. In this paper, we demonstrate a bi-layer photo-resist (PR) patterning method that uses a low viscosity (less than 3 centipoise (cP)) resist at the interface between a high-viscosity PR and a p-GaN surface. This strategy can provide a reliable patterning method with which to preserve graphene films on a p-GaN surface after device fabrication.

Another important technical issue is current crowding at the p-electrodes and the high potential barrier between the graphene and the p-GaN layer due to the large difference in the work functions of the two materials [16–18]. The large work function difference between graphene (4.5 eV) and p-GaN (7.5 eV) results in a substantial Schottky barrier height at the interface. Furthermore, the current injected into the

