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Annealing effect on the electrical and optical properties of Au/n-ZnO NWs Schottky diodes white LEDs

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ABSTRACT

We report the post-growth heat treatment effect on the electrical and the optical properties of hydrothermally grown zinc oxide (ZnO) nanowires (NWs) Schottky white light emitting diodes (LEDs). It was found that there is a changed in the electroluminescence (EL) spectrum when post growth annealing process was performed at 600 °C under nitrogen, oxygen and argon ambients. The EL spectrum for LEDs based on the as grown NWs show three bands red, green and blue centered at 724, 518 and 450 nm respectively. All devices based on ZnO NWs annealed in oxygen (O_2), nitrogen (N_2) and argon (Ar) ambient show blue shift in the violet and the red emissions whereas a red shift is observed in the green emission compared to the as grown NWs based device. The color rendering index (CRI) and the correlated color temperature (CCT) of all LEDs were calculated to be in the range 78–91 and 2753–5122 K, respectively. These results indicate that light from the LEDs can be tuned from cold white light to warm white light by post growth annealing.

1. Introduction

Zinc oxide (ZnO) is a promising II–VI compound semiconductor, due to its characteristics like a wide band gap of 3.37 eV and relatively large exciton binding energy of 60 meV, which makes it attractive

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material for potential applications in optoelectronic devices such as ultraviolet light emitting diodes, and highly transparent electron devices and lasers diode.

It is well known that ZnO exhibits a wide emission from the UV near-band-edge emission and covering the whole visible range [1]. Over the past decade, various ZnO nanostructures such as nanowires, nanorods, nanotubes etc. have been intensively studied due to their potential applications in diverse fields due to the fact that at the nanoscale level materials exhibit distinguished surface morphology and size confinement behavior remarkably different from their bulk counterpart.

ZnO nanostructures, possesses relatively a large number of radiative intrinsic deep level defects [2,3] particularly, besides the ultraviolet (UV) emission, ZnO emit blue, green, yellow and red colors; which covers the whole visible region ranging from 400 nm to around 700 nm [4]. Therefore, the optical properties of ZnO have been extensively studied. ZnO typically exhibits one sharp UV peak and possibly one or two wide bands or the so called broad deep band emission (DBE) due to deep radiative defects within the band gap [5].

As a result of the quantum size effect, the oscillation strength of excitons is greatly enhanced in ZnO nanowires (NWs), which is favorable to radiative recombination of excitons at room temperature [6]. ZnO NWs have an internal electric field in the direction of the *c*-axis to facilitate charge transport and will suppress the recombination of injected electrons [7]. In addition, each NW acts as a wave guide, minimizing side scattering of light, thereby enhancing light emission and extraction efficiency [8]. One of the main advantages of ZnO NWs is that they can easily be synthesized using the hydrothermal method [9] but usually hydrothermal grown ZnO NWs have low crystal quality and incorporate considerable lattice and surfacedefects [10,11]. A defect produces a potential well that can trap and affect the movement of carriers, and degrade device performances [12]. The luminescence emission and electronic properties of any semiconductor device depend on its energy band gap, which is extremely sensitive to its crystal perfection and surface defects. Different post-growth methods have been investigated to improve the crystal quality. Post growth heat treatment such as thermal annealing which can play important role to improve crystalline quality and hence controlling the optical emissions of the ZnO NWs by reducing nanoradiative related defects.

In this regard various atmospheres such as oxygen, nitrogen, hydrogen can be employed in order to get a better crystalline quality. Thermal treatment plays an important role to increase the performance of a device and to suppress or eliminate detrimental surface defects. As a result, a surface defect is unable to trap carriers again. Till now, various groups have studied and reported annealing effect on the optical and electrical properties of ZnO thin films [13,14], nanorods [11,15–19] and nanotubes [20]. But to the best of our knowledge no report has dealt with Au/n-ZnO nanowires (NWs) based Schottky diodes anneal in different ambient.

The production of high quality ZnO nanostructure-based homojunctions has proved elusive because ZnO still suffers from the lack of reproducible and high quality p-type material as unintentionally undoped ZnO shows typically n-type properties, acceptors may be compensated by intrinsic defects such as *Zinc interstitials* (Z_{in}), oxygen vacancies (V_O), or background impurities such as hydrogen. So in order to solve the problem of stable and reproducible p-type doping, an alternative approach such as the fabrication of heterojunctions and Schottky contacts on n-ZnO nanostructures allows the realization of these electronic devices.

In this work, we study on the ambient annealing effects on the electrical and optical properties of the Au/n-ZnO NWs Schottky white light emitting diodes (WLEDs). The results showed that the ambient in which the post-annealing takes place strongly influenced the light emission and the color-rendering properties of the ZnO NWs-based LEDs.

2. Experimental

The ZnO NWs used in this study were grown on n-SiC epilayer substrate with doping concentration of 1×10^{17} cm^{-3}. The SiC is a good candidate as a substrate for ZnO nanostructure growth and further applications. The SiC and ZnO have the same wurtzite crystal symmetry and relatively small lattice mismatch (~5%). In addition, SiC has useful properties which include excellent electron mobility, high transparency, high break down field, and high thermal conductivity. The SiC substrates were sequen-