Applied Physics Letters

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Citation: Appl. Phys. Lett. **95**, 126101 (2009); doi: 10.1063/1.3234375
View online: http://dx.doi.org/10.1063/1.3234375
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v95/i12
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Comment on "Influence of growth mode on the structural, optical, and electrical properties of In-doped ZnO nanorods" [Appl. Phys. Lett. 94, 041906 (2009)]

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(Received 22 July 2009; accepted 1 September 2009; published online 24 September 2009)

[doi:10.1063/1.3234375]

In a recently published paper by Chang *et al.*,[1] the authors investigated the growth behavior, photoluminescence, and electrical properties of In-doped ZnO nanorods, which were prepared by simple vertical vapor phase transportation method with the source material of indium and zinc powders mixture. The authors claimed that the indium atoms had successfully incorporated into the ZnO nanorods, which was confirmed by the scanning electron microscopy and energy dispersive x-ray analysis (SEM/EDX) results. Moreover, Hall effect measurement was used to evaluate the carrier concentration of ZnO:In nanorods. The results are interesting and novel if their conclusions are reasonable and convincible. Unfortunately, there are some points doubtful in this publication which are shown in the following.

The first concern is about the SEM/EDX results for indium atoms concentration in Fig. 3, which was considered to be the direct proof for the final conclusion of indium atoms incorporation, while there is some doubt for the EDX results. In Fig. 3 the authors claimed that the indium concentration distribution along the ~1 μm ZnO nanorod vary from 0.1 to 0.5 at. %. However, the spatial resolution of the EDX should not be as high as the authors' imagination. Normally, EDX analysis, which is known as a valuable tool for qualitative and quantitative element analysis, allows a fast and nondestructive chemical analysis with a spatial resolution in the micrometer regime and probes a volume of one or several μm^3 due to electron scattering in the sample.[2] Obviously the EDX analysis is impossible to detect three different points on the surface of ~1 μm ZnO nanorod for the Indium concentration. Furthermore, the detect sensitivity of SEM/EDX analysis is typical ~0.5 at. %, thus we suppose the indium concentration in ZnO:In nanorod could not be obtained precisely, as shown in the figure. So the claim of an increase for In atoms concentration from bottom to top along ZnO nanorod is not convincible, at least only the current EDX measurements were not enough to support such statements. Accordingly, the proposed diffusion induced growth model is not so confirmable.

The second doubtful point exists in the electrical properties measurement by Hall effect with the van der Pauw configuration. The authors indicated that they tested the electrical properties of the transition layer between the substrate and ZnO:In nanorods by Hall effect measurement and used the testing results to evaluate the carrier concentration of ZnO:In nanorods. This suggestion is quite questionable because the electrical properties including carrier mobility and resistivity should be quite different for films and nanostructures even the indium doping concentration is the same. Furthermore, for Hall effect measurement, there exists an equation to describe the relationship[3] between carrier concentration (n), mobility (μ), and conductivity (σ) or resistivity (ρ),

$$\sigma = 1/\rho = ne\mu, \tag{1}$$

where e is the electron charge. While the proportions for the data in Table I were not consistent with the above equation. Moreover, the carrier concentration up to 8.88×10^{20} cm^{-3} is also suspicious for the 0.33 at. % In-doped sample even if each indium atom donates one electron during the doping process.

In summary, the authors' conclusion that the indium atoms incorporation into the ZnO nanorods based on SEM/EDX results is not convincible. More careful and precise methods are needed to detect the low concentration dopants in those nanorods samples. Suitable techniques are also required to investigate the electronic property for indium doped ZnO nanorods, as the Hall effect measurement is always not suitable for nanorods samples.

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0003-6951/2009/95(12)/126101/1/$25.00