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Optical properties of hydrogen plasma treated ZnO nanoneedles

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We report on the effect of hydrogen plasma treatment on optical properties of ZnO nanoneedle arrays by time-integrated (TI) and time-resolved (TR) photoluminescence (PL) spectroscopy. Among many semiconductor materials for optoelectronic devices, ZnO offers some fascinating properties including the large free exciton binding energy (~ 60 meV).[1] Recently, previous research has shown that ZnO nanomaterials also exhibit excitonic emissions and stimulated emissions at room temperature.[2],[3] Although spectral PL of ZnO nanomaterials have been examined, a thorough study of the recombination mechanism requires both temporal and spectral PL measurements. For the PL characterizations, high purity and quality ZnO nanoneedle arrays were grown on Si (100) substrates. As-grown ZnO nanoneedle arrays were treated by rf-plasma under hydrogen environment. TIPL, TRPL, and electrical conductivity measurements were performed in order to investigate physical properties of ZnO nanostructures after the hydrogen plasma treatement. TIPL and TRPL spectra of the samples were measured in the range from 10 K to room temperature. Figure 1 shows TIPL spectra of as-grown and hydrogen plasma treated ZnO nanoneedle arrays. According to the TIPL spectra, the intensity of neutral donor bound exciton (D_oX) peak including I_4 line assigned to hydrogen as a chemical identity was increased after hydrogen plasma treatment. Figrue 2 shows TRPL spectra of as-grown and hydrogen plasma treated ZnO nanoneedle arrays showing the decay profiles at 10 K. The decay profiles were of double-exponential form, and lifetimes of excitons in hydrogen plasma treated ZnO nanoneedles were decreased as plasma power increased. The temperature dependent behavior of effective lifetime of excitons in hydrogen plasma treated ZnO nanoneedles is similar to that of as-grown ones. The introducing donor states or the passivation of nonradiative recombination center can be considered as the origin of observed TIPL and TRPL spectra. The increase in the intensity of D_oX and the decrease in the effective lifetime of excitons can be occurred by the hydrogen doping. To examine a role of hydrogen in ZnO nanoneedles, electrical conductivity measurement was performed. The increase in the electrical conductivity of ZnO nanoneedles strongly suggests that hydrogen acts as a dopant in ZnO nanoneedle. The hydrogen doping effect is coincident with the theoretical prediction that hydrogen only act as a shallow donor in ZnO.[4]

In conclusion, we performed temporal and spectral PL spectroscopy to investigate recombination dynamics and excitonic emission properties of hydrogen plasma treated ZnO nanoneedles. Through a series of optical characterizations, we observed the increase in the intensity of D_oX peak and the decrease in the effective lifetime of excitons after hydrogen plasma treatment. The results in the PL spectra and the increase in the electrical conductivity indicate that the origin of the behaviors in PL spectra of hydrogen plasma treated ZnO nanoneedles is hydrogen doping.

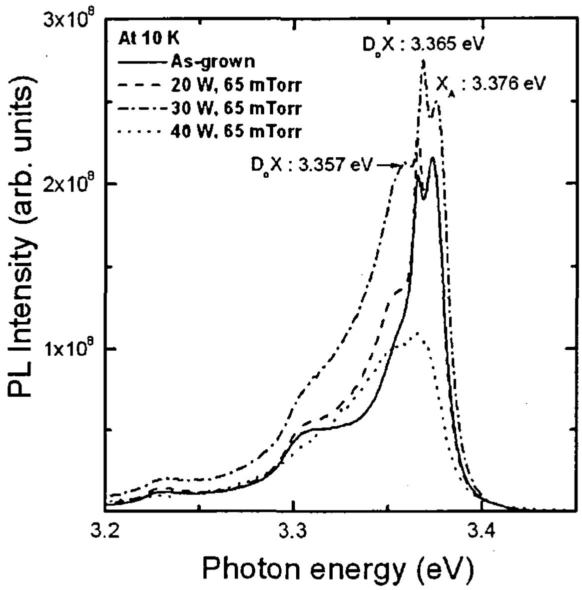

Figure 1. Time-Integrated PL spectra of as-grown and hydrogen plasma treated ZnO nanoneedles

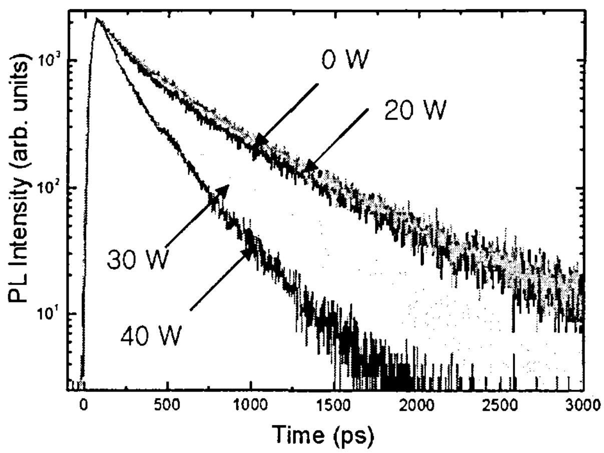

Figure 2. Time-Resolved PL spectra of as-grown and hydrogen plasma treated ZnO nanoneedles at 10 K

[References]

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