Recombination processes and localization effects in GaNAsP nanowires

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The GaNAsP material system, belonging to the family of dilute nitride alloys, has shown significant promises as a candidate for intermediate band solar cells (IBSCs), due to its high band gap tunability and an attractive band structure. Owing to very recent advances in fabrication techniques, it has become possible to fabricate GaNAsP in the nanowire (NW) geometry, which may reduce costs for device fabrication and also opens a door for integration of the IBSC concept with the promising NW architecture.

In this work we perform systematic optical studies of such novel GaNAsP NWs grown by molecular beam epitaxy on Si substrates, combined with comprehensive structural characterization of the wires. Based on the performed transmission electron microscopy and Raman studies, we show that the fabricated NW arrays have good structural and optical quality, in spite of a large difference in electronegativity and sizes between N and replaced As/P atoms. The arrays are also found to exhibit excellent compositional uniformity among individual wires. Based on temperature-dependent photoluminescence (PL) studies, we show that random alloy disorder causes localization of photo-generated carriers at low temperatures. The localization potential increases in N-containing wires as compared with reference GaAsP NWs. In some regions, it leads to three-dimensional carrier confinement, based on the observation of sharp and discrete PL lines in μ-PL spectra from individual NWs. Localization effects, however, are found to have negligible influence on carrier recombination at room temperature (RT) owing to thermal activation of the localized carriers to extended states. From time-resolved PL measurements, the prolonged room-temperature carrier lifetime at RT was found in N-containing wires. As the carrier lifetime under these conditions is typically governed by non-radiative recombination via surface states, this finding implies N-induced suppression of surface recombination. The presented results, therefore, show that GaNAsP NWs hold great promises for future applications of this material system in nano-optoelectronic and photonic devices.

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