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PAPER

Luminescence mechanism for Er^{3+} ions in a silicon-rich nitride host under electrical pumping

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Abstract

A combined experimental and theoretical study on the electroluminescent excitation mechanism for trivalent erbium (Er^{3+}) ions in a silicon-rich nitride (SiN_x) host is presented. Direct impact by hot electrons is demonstrated to be the fundamental excitation mechanism. The Er^{3+} excitation by energy transfer from silicon nanostructures and/or defects is shown to be marginal under electrical pumping. A bilayer structure made of a SiO_2 electron-accelerating layer and an Er-implanted SiN_x layer has been sandwiched between a metal–insulator–semiconductor structure with a highly doped N-type silicon substrate and an indium–tin–oxide window functioning as a transparent electrode. Monte Carlo (MC) simulations are used to model hot electron transport in the proposed device structure. Acoustic, polar and non-polar optical electron–phonon scattering mechanisms are considered as well as a new scattering process related to the trapping/detrapping on energetically shallow traps in the band gap of silicon nitride. For SiO_2 layers around 20 nm-thick and beyond, the number and kinetic energy of hot electrons before entering the SiN_x layer are maximal. A significant enhancement of the 1.54 μm electroluminescence power efficiency of two orders of magnitude is observed in devices composed of a 20 nm-thick SiO_2 layer compared to those composed of 10 nm-thick SiO_2. We demonstrate by MC simulations that such a difference, in terms of power efficiency, is ascribed to the high-energy tail of the hot electron energy distribution, which becomes more pronounced as the SiO_2 electron-accelerating layer thickness increases. It is also unveiled that direct excitation of the 1.54 μm Er^{3+} main radiative transition requiring an excitation energy of only 0.8 eV is inefficient, and that the major part of the Er^{3+} ions are excited via higher level energy states. The obtained results are sufficiently consistent to be extended to other trivalent rare-earth ions inside similar insulating material environments.

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