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A comparative study of guided modes and random lasing in ZnO nanorod structures

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Abstract
Hexagonal and arrow-headed ZnO nanorod structures have been grown by low pressure chemical vapour deposition (CVD) and atmospheric pressure metal-organic CVD. The technology ensures a high optical quality of the produced nanostructures to act as gain medium for stimulated emission in the ultraviolet spectral region in combination with high quality factor laser resonators. Multiple sharp lasing peaks related to the guided modes were realized from single hexagonal nanorods and arrays of hexagonal ZnO nanorods. A comparative analysis of the variations of lasing spectra from shot to shot of pumping, and the dependence of lasing threshold on the area of pump beam spot on the sample surface in disordered agglomerations of hexagonal nanorods and in layers consisting of arrow-headed nanorods, demonstrate that lasing is determined by the superposition of guided modes in the first case, while random lasing occurs in the second case.

1. Introduction

With a wide bandgap of 3.36 eV at room temperature and large exciton binding energy of 60 meV (excitons being stable up to room temperature), ZnO holds promise for blue and ultraviolet optical devices [1], including ultraviolet microlasers. Due to the possibility of multiple and switchable growth directions of the wurtzite structure and the high ionicity of its polar surfaces, ZnO provides conditions for the formation of a rich diversity of micro/nanostructures [2–5] many of which may be suitable for lasing. Remarkable lasing properties have been demonstrated with epitaxial and microcrystalline thin films [6–8], arrays of ZnO nanorods [9–17], nanowires [18], nanoneedles [19] and nanobelts [20]. The corresponding emission mechanism was assumed to be related to the near-band-edge radiative recombination of free excitons (FE, ~3.375 eV), exciton–exciton scattering (EES, ~3.18 eV) and electron–hole plasma (EHP, ~3.14 eV) recombination [20]. However, it has been recently shown that the excitonic and biexcitonic recombination processes and the stimulated emission based on them are good candidates to explain lasing in ZnO preferentially at temperatures below RT, up to about 200 K, and moderate densities [21]. The stimulated direct recombination in an EHP works only at densities above the effective density of states, where inversion is reached. A process has to be considered in between with the recombination of coulomb correlated electron–hole pairs by scattering with either a free carrier in the recombination process or with emission of one or more plasmon–phonon mixed state quanta [21]. The lasing characteristics are to a

