

## Nanolasers from ZnO nanorods as natural resonance cavities

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Zinc oxide nanowires show remarkable optical properties such as wave guiding and lasing and are promising building blocks for novel miniaturized optical and optoelectronic devices. We studied the effect of metal coating on the optical properties of free-standing ZnO nanowire lasers, which is expected to enhance their performances in terms of a reduced excitation power threshold. Catalyst-free Chemical Vapor Deposition (CVD) was employed to synthesize vertically aligned single crystal ZnO nanowires with fairly developed hexagonal crystal faceting. As suggested by electron microscopy data, the grown ZnO is an ensemble of vertical nanorods of different length (the length varied from 1 to 20  $\mu\text{m}$ , depending on the position of the silicon substrate in the reactor), with mean diameter of individual crystallites of about 0.05-0.5  $\mu\text{m}$  and fairly developed hexagonal crystal faceting. The nanorods were n-type, with a rather low resistivity of 10  $\text{Om}\cdot\text{cm}$ . The nanowire array was coated by an aluminum thin layer (50 nm) by electron beam sputtering, thus forming a high-reflectance mirror facet at one end of each one. After removal from the growth substrate by sonication, a second mirror facet was obtained as an effect of the cleavage along the (0001) crystallographic plane, thus leading to an enhanced axial Fabry-Perot (FP) resonator.

Arrays of hexagonal ZnO nanorods with parallel orientation forming a quasi-two-dimensional structure or radial orientation producing cylindrical microstructures are grown in a controlled manner. Multiple sharp lasing peaks were realized from single nanorods constituting these microstructures. The lasing peaks display successive onset and saturation with increasing excitation power density, and fit well the expected resonance spectrum of guided modes in hexagonal nanorods. Several lasing nanorods with diameter below 150 nm and length 2-40  $\mu\text{m}$  were investigated. Laser thresholds were found to range from 30 to 60  $\text{kW}/\text{cm}^2$ , one order of magnitude lower than in the uncoated nanowires. The spectral distribution of lasing modes differed from the expected Fabry-Perot interference pattern as an effect of the accidental lateral  $\text{Al}_2\text{O}_3$  coating. This modifies the optical resonator introducing higher order modes with a reduced overlap with the active region.

Investigations of emission spectra and images at the scanning cathodoluminescence of the ZnO nanorods with two mirrors on the ends were carried out at temperature 10K. The emission peaks, related to the recombination of the bound excitons and of the band-edge emission in the violet spectral region, have been detected. The space picture of the local photon modes intensity of the nanorod has been determined for different wavelengths. The new method of visualization of bound optical modes in the laser nano- and microresonators was proposed. The produced structures are expected to find many applications in integrated nanoscale optoelectronics, photonics, and sensor technologies.