Abstract

Silicon nanocrystals (SiNCs) of sizes below approximately 5 nm are a material with an efficient room-temperature photoluminescence (PL) and optical gain. Optical gain is a prerequisite for obtaining stimulated emission from a pumped material, and the achievement of stimulated emission (and lasing) from Si-based nanostructures is of particular interest of the field of silicon photonics. The aim of this work was (i) to investigate fundamental optical properties of SiNCs, (ii) to design and prepare a photonic crystal with enhanced light extraction efficiency and (iii) to explore a possibility of enhancing optical gain of light-emitting SiNCs by combining them with a two-dimensional photonic crystal. First, free-standing oxide (SiO_x/SiO_2)-passivated SiNCs were prepared by electrochemical etching of a Si wafer. Their optical properties were studied by employing time-resolved spectroscopy, also at cryogenic temperatures. The fast blue-green emission band of these SiNCs was linked with the quasi-direct recombination of hot electrons and holes in the vicinity of the Γ-point. Furthermore, the spectral shift of the slow orange-red band (of these SiNCs) as a function of temperature was explained on the basis of an interplay between tensile strain and bulk Si temperature-induced indirect bandgap shift. The optical gain coefficient was measured using the standard "Variable stripe length" (VSL) method supplemented with the "Shifting excitation spot" (SES) technique. It was shown that SiNCs (prepared by etching) embedded in a SiO_2-solgel derived matrix possess optical gain of the order of tens of cm^{-1} at both emission bands. The presence of ultrafast gain was investigated in the oxide-passivated SiNCs dispersed in ethanol. However, no optical gain was observed on the ultrafast component of luminescence due to the insufficient power of excitation pulses. Also other types of SiNCs, methyl-capped ($-CH_3$) free-standing SiNCs and SiNCs/SiO_2-multilayers, were experimentally studied. In the former, zero net optical gain coefficient was measured most probably due to the very low concentration of SiNCs in the sample. In the latter, free carrier absorption (FCA) losses prevented the onset of stimulated emission and thus no positive net optical gain was observed. Optical gain can be enhanced by employing periodic dielectric structures, photonic crystals. By employing Finite-difference time-domain computer simulations, it was shown that stimulated emission from a low-gain medium can be achieved by embedding it into a two-dimensional photonic crystal with well-designed dimensions. With this keeping in mind, a two-dimensional photonic crystal was fabricated on the top of a silica layer with embedded SiNCs. It was shown that such a structure allows, compared to a plane layer, an effective enhancement of extraction efficiency of light (emitted from SiNCs) into air. Up to 7-fold increase of intensity was achieved for modes propagating in the direction normal to the sample plane. This effect was attributed to the Bragg-diffraction of guided modes on the surface periodicity. However, the onset of stimulated emission was not observed most probably due to high FCA losses present in this sample. Up to 6-fold enhancement of extraction efficiency was also measured for nanocrystalline diamond (NCD) layers with a two-dimensional photonic crystal etched on their surface compared to plane NCD layers. The sources of light were in the case of the NCD layers various defects (not SiNCs) introduced during the fabrication process. The oxide-passivated SiNCs (prepared by etching) drop-casted on such periodically patterned NCD layers exhibited the modification of their PL spectrum. We proposed some further steps for future sample improvement.