Population Inversion in Compositionally Graded Quantum Dots using Direct Current Electrical Pumping

Victor I. Klimov

Center for Advanced Solar Photophysics, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

klimov@lanl.gov, http://quantumdot.lanl.gov

Since the invention of expitaxially-grown semiconductor laser diodes, these devices have become ubiquitous in our daily life and can be found in applications ranging from barcode readers in grocery stores to broadband optical communication and ophthalmic surgery. Chemically synthesized quantum dots (QDs) can potentially enable a new class of highly flexible laser diodes processible from solutions without complications associated with vacuum-based epitaxial techniques. Colloidal QDs feature near-unity emission quantum yields and widely tunable emission wavelengths controlled by their size and/or composition. Further, a wide separation between electronic levels and low degeneracies of band-edge states reduce the lasing threshold and enhance temperature stability compared to semiconductor quantum wells used in traditional laser diodes. Despite a considerable progress over the past years [1-2], colloidal-QD lasing is still at the laboratory stage and an important challenge - realization of lasing with electrical injection - is still unresolved. A major complication, which hinders the progress in this field, is fast nonradiative Auger recombination of gain-active multi-carrier species [3-5]. Here we present the first successful demonstration of population inversion in colloidal QDs achieved using direct current (*dc*) electrical pumping, which is a necessary step on the path to QD laser diodes. The key element of this work is a new generation of compositionally graded type-I QDs (*cg*-QDs) that demonstrate a considerable suppression of Auger decay to the extent that it can be outpaced by electrical injection [2]. To obtain large QD occupancies required for population inversion, we apply a special "current-focusing" device architecture, which allows for producing high current densities (up to ~12 A cm^{-2}) without damaging either the QDs or the injection layers [6]. The quantitative analysis of electroluminescence spectra indicates that at ~3.4 A cm^{-2}, we achieve the population inversion for the band-edge 1S transition, and with the highest current, approach the threshold for inverting the transition involving the 1P electron state. These results suggest the feasibility of single- and even two-color QD lasing under *dc* electrical injection.

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