Low-Dimensional Semiconductor Structures for Lasers and Light Emitters: Microcavities and Nanowires

J. A. Lott, N. N. Ledentsov, V. M. Ustinov, A. R. Kovsh, and D. Bimberg
Air Force Institute of Technology, Ioffe Physical Technical Institute, and TU-Berlin

The magnificent O's, – Bio, Micro, Nano, Info, Opto – are unquestionably powerful and trendy tools for professors and marketeers alike in a seemingly endless quest to extend research funding or sell new products. Others perhaps are more comfortable working in the realm of the lesser O's (electro, magneto, thermo, femto, etc.) – lesser only in terms of immediate monetary appeal. The current trend in semiconductor lasers is toward peak emission in the blue/UV and at wavelengths longer than two micrometers for memory storage and spectroscopy, and toward assemblies of point source arrays for optical communications and interconnects. The continued scaling of semiconductor devices from micrometer to nanometer-scale dimensions has been motivated in part by economics and in part by discoveries of exotic new quantum phenomena which arise when electrons and holes are confined in very small dimensional structures. The optical properties of nanometer-scale structures such as semiconductor quantum wells, wires, and dots are amazing and complex, especially when incorporated as the active elements in optoelectronic devices. A quintessential semiconductor optical device for studying lateral scaling effects is the selectively oxidized vertical cavity surface emitting laser (VCSEL), which is in essence a planar, asymmetric, multilayer Fabry-Perot etalon structure, wherefrom the Purcell effect is readily observed. Another interesting light-emitting device is the cylindrical nanowire microresonator, whose longitudinal mode spacing is readily tuned by adjusting the length of the semiconducting wire. In this paper we describe the gallium-arsenide based epitaxial growth and engineered properties of three-dimensional, self-assembled quantum dots by means of the Stranski-Krastonov growth mode. We demonstrate and analyze the performance of VCSELs with microcavity active regions composed of sheets of quantum dot ensembles. We model, measure, and discuss the three-dimensionally confined optical cavity modes as a function of radius and the extension of the peak emission wavelength from one toward two micrometers. We compare and contrast the vertical microcavity lasers to evolving crystalline single-nanowire (horizontal) lasers and light emitting diodes, focusing specifically on scaling and fabrication limitations. We also investigate the possibility of constructing a nanowire laser that utilizes distributed Bragg reflector mirrors and either a quantum well or quantum dot microcavity active region. Finally, we describe a general purpose growth and fabrication technology wherein VCSELs and related microcavity devices can be integrated with mesoscale electromechanical sensors and actuators, thus enabling the possible/eventual development of versatile integrated nanooptoelectrothermo-mechanical systems – clearly a provocative collection of prefixes.

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