Tunnel Coupled Quantum Well-Quantum Dots Active Medium for High-Frequency Semiconductor Lasers

CNF Project # 780-99
Principal Investigator: Serge Oktyabrsky

Abstract:
The project is focused primarily on materials, technologies and components for the III-V optoelectronic devices integrated with a silicon platform. The goal is to provide design and technology for light emitters and photodetectors with high thermal stability and high bandwidth suitable for hybrid microintegration on Si electronics into massively parallel arrays [1]. The major focus is on the microcavity optoelectronic devices, such as vertical cavity surface-emitting lasers (VCSELs), microcavity light-emitting diodes, and resonant cavity photodetectors, which are anticipated to play the major role in the future chip-level optical interconnect technology. In 2005/06, structures of tunnel coupled pairs consisting of InGaAs quantum wells grown on top of self-assembled InAs quantum dots (QW-on-QDs) were employed to improve the gain medium in thermally stable semiconductor QD laser diodes. We have developed a tunnel QW-on-QDs structure with a QD resonance transition which is red-shifted ~ 35 meV relative to the QW ground state (GS). Edge-emitting lasers utilizing this active medium were developed and characterized. All-epitaxial vertical cavity surface emitting lasers with triple-pair tunnel QW-on-QDs medium demonstrated continuous wave mode lasing with 5.7 mA minimum threshold current at QD ground state emission wavelength, 1131 nm [2].

Summary:
QD-on-QW active medium was developed and characterized in edge-emitted lasers. Our approach is to use multiple pairs of tunnel coupled QWs grown on QDs structures (QW-on-QDs) as opposed to multiple QD layers for a single QW [2]. Optimized energy separation between ground energy states of QW and QDs within a pair was found to be ~ 35 meV, which is close to the energy of LO phonon. This transition with narrow linewidth, 21.6 meV at T = 77K, indicates an efficient LO-phonon assisted tunneling of carriers from QW into QD ensemble states. The highest gain ( > 50 cm^{-1} in waveguide lasers) was achieved with a QW-on-QDs active medium with GS relative separation of c 35-40 meV. VCSELs with 3 x (QW-on-QDs) active medium were designed, grown, and processed. The design was based on AlGaAs/GaAs all-epitaxial distributed Bragg reflectors (22 and 34 pairs in the top and bottom reflectors, respectively) intracavity p-contact, and single selectively oxidized current aperture. The devices demonstrated relatively high operating voltage (> 5V), likely because of high resistance of intracavity contact. Nevertheless, CW lasing mode of first QD-based VCSEL with tunnel-coupled medium was demonstrated with oxide aperture sizes from 5 to 17 µm at room temperature. Best measured differential efficiency of ~ 6.2% was observed in small-aperture lasers [3].

References:
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- Active medium consisting of InGaAs Quantum Wells grown on top of self-assembled InAs Quantum Dots (QW-on-QD) coupled by tunneling was developed.
- Damping-limited bandwidth of QW-on-QD active medium is estimated at 30 GHz.
- VCSELs with tunnel-coupled QW-on-QD were fabricated.
- Threshold current density of ~ 4kA/cm² at 1130 nm was measured.

Figure 1, top left: Schematic band diagram of tunnel coupled Quantum Well-Quantum Dot medium.

Figure 2, bottom left: TEM (200) dark field cross-section of QD-on-QW medium.

Figure 3, above: Light-current characteristic of all-epitaxial tunnel coupled QD-on-QW VCSEL.