Fabrication and assembly studies of III-V semiconductor microlaser disks and actuators: toward optical nanoelectromechanical systems

J. A. Lott
Air Force Institute of Technology, USA

Innovations in silicon-based micro-electro-mechanical systems (MEMS) continue to stoke the photonics industry. New products and riotous start-up companies are announced as often as first demonstrations in complex specialty sensors, gimbaled mirror arrays, and dense micro-optical routing circuits. In the nanometer millennium, electromechanical systems will be made from a plethora of materials other than silicon – many with a nanometer constitution. Although silicon and silicon dioxide (oxide) have many desirable mechanical, optical, and electrical properties, these materials lack the ability to efficiently emit light. Selectively released structures based on multiple layers of epitaxially-grown III-V compound semiconductors such as AlGaAs/GaAs and fabricated by conventional microelectronic surface micro-machining techniques can exhibit electro-mechanical actuation, optical waveguiding, and light emission and detection. At the micrometer scale a III-V MEMS technology is useful for the realization of tunable vertical cavity surface emitting lasers (VCSELs) and tunable optical pulse delay lines. At the nanometer scale, the number of useful applications for tiny optoelectromechanical structures will far exceed the future needs of Mother Necessity.

Silicon MEMS are currently available from commercial and research foundries. Conventional foundry MEMS typically consist of multiple, thin, planar layers of silicon nitride, oxide, polycrystalline silicon, and a capping layer of gold. The oxide layers are selectively removed by wet chemical etching using a diluted buffered oxide etching solution. The oxide layers are called release layers or sacrificial layers. In this work I study techniques to fabricate optical micro-electro-mechanical structures made from III-V epitaxial materials. Specially designed VCSEL and related multiple layer structures are grown by molecular beam epitaxy and metal-organic vapor phase epitaxy on GaAs substrates. The VCSEL structures include either sacrificial GaAs layers or AlGaAs layers converted to sacrificial AlGaO layers by wet oxidation. I design, fabricate, and characterize prototype III-V MEMS structures including basic cantilevers, micromirror flexures, and tunable VCSELs. I use AlGaO release layers to create huge numbers of individual VCSEL disks for stacking, placement on silicon-based MEMS, and for studies of fluidic self-assembly. Large output power and efficiency greater than one is obtained from electrically injected VCSEL stacks incorporating tunnel junctions and multiple active regions. These design and fabrication studies of III-V optoelectromechanical structures lay the groundwork for the development of a versatile semiconductor nanosystem technology composed of a variety of hybrid crystalline and polycrystalline materials.