Tunable Optical Cavities for Absorption Spectroscopy

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Frequency stability, low power consumption, and the compact nature of Vertical Cavity Surface Emitting Lasers (VCSELs) lead to a number of advantages over existing semiconductor laser technologies for use in tunable diode-laser-based absorption spectroscopy (TDLAS). VCSELs enable selective and sensitive trace-gas analysis, instrumental in environmental monitoring; and combustion research.

With MEMS-tunable VCSELs, the required wavelength tuning to sweep the gas absorption fingerprints is realized through the actuation of a suspended Bragg reflector, leading to physical variation of the optical path length. This results in the ability to tune emitted wavelengths on the order of tens of nanometers. Given the short axial length of a typical VCSEL, displacement of the suspended mirror results in the continuous tuning of a single lasing mode. These MEMS-tunable VCSEL devices have recently shown promise as a high-performance alternative to standard VCSELs for optical gas sensing, with demonstrations of the detection of carbon monoxide and carbon dioxide, as well as ammonia, at the telecom-relevant wavelength range near 1550 nm. We demonstrated the first MEMS-tunable VCSELs that operate within the 760 to 780 nm range, a relevant wavelength range for the detection of O_2.

Project Goals

Our goal has been to establish complex fabrication procedures to reliably reproduce electrostatically tunable MEMS-tunable VCSELs (Fig. 1a) for future miniaturized absorption spectroscopy sensors. In these devices, rapid and wide wavelength tuning is realized through the use of an electrostatically actuated micromechanical Bragg reflector (Fig. 1b). A novel fabrication method based on gas-phase etching of a room-temperature deposited amorphous-germanium (α-Ge) sacrificial layer to generate the suspended mirror was used.

The fabrication procedure for the short-wavelength MEMS-tunable VCSELs is a relatively complex process involving up to 12 lithographic levels for wire-bond enabled devices (Fig. 2). Fortunately, wafer scale processing is possible, which enables higher throughput in the fabrication of arrays of devices. It is also worth noting the strong potential of this platform for the simultaneous detection of various gases, since the critical central emission wavelengths, from visible to near-infrared to shortwave-infrared, depend on the selection and engineering of the epi-material.

Relevance to LLNL Mission

Our project supports several applications at the core of LLNL's national security missions, from Stockpile Stewardship to Homeland Security. It will sustain the development of a new class of compact, fiber compatible optical gas sensors for real-time detection of chemicals. This will facilitate minimally invasive trace-gas analysis for next-generation sensors. The 2-D nature of the technology enables other interesting applications such as multiplexed smart detection systems, adaptive imaging, beam forming, optical computing, and high-power lasers.

FY2008 Accomplishments and Results

In this second year, we have completed the creation and the characterization of the first MEMS-tunable VCSELs

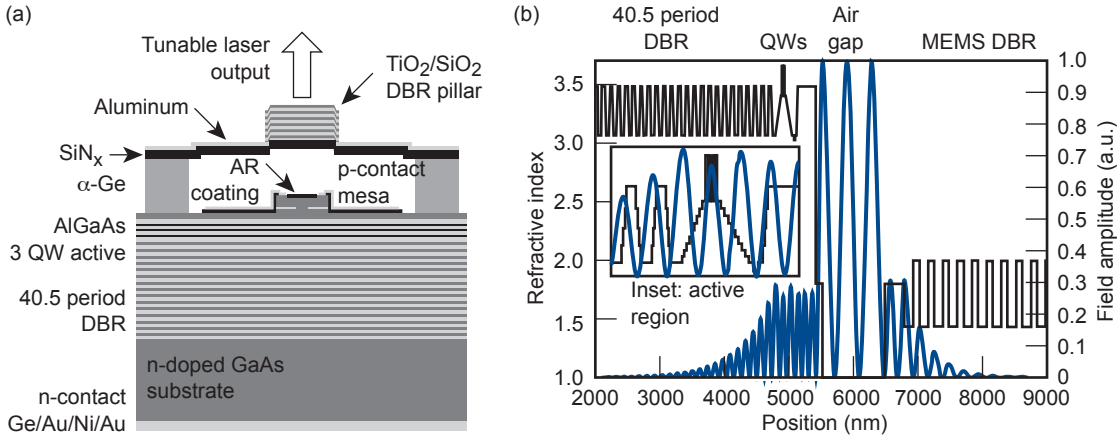

Figure 1. Short-wavelength MEMS-tunable VCSELs. (a) Schematic cross-section of the full materials structure; (b) refractive index profile and electric field intensity generated with a transmission matrix model.

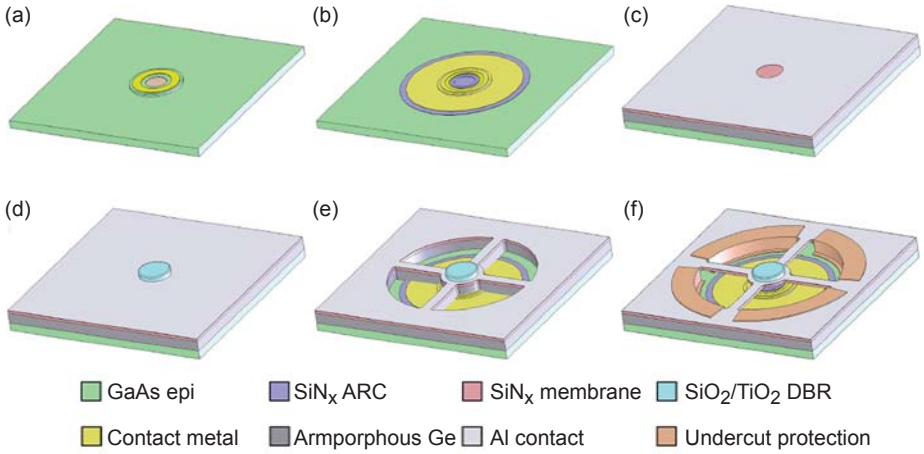

Figure 2. Schematic of the short-wavelength MEMS-tunable VCSEL process flow. (a) Mesa etch, AlGaAs oxidation, p-contact metallization, and contact window etch; (b) definition of the SiN_x AR coating and Ti/Au pad; (c) deposition of the α-Ge sacrificial layer, SiN_x membrane, and Al top contact, followed by patterning of the emission window; (d) blanket SiO_2/TiO_2 DBR evaporation and etch back; (e) ECR etch of actuator geometry; (f) liftoff of SiO_2 undercut protection and release by sacrificial Ge etching in XeF_2.

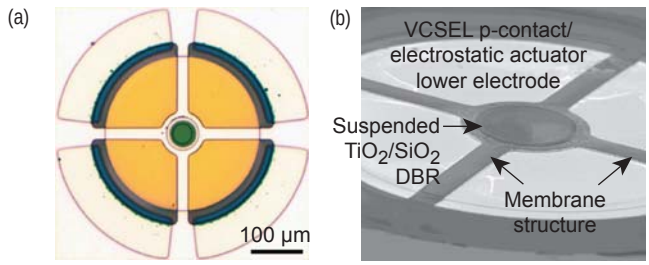

Figure 3. (a) Optical micrograph and (b) SEM photograph of an individual tunable VCSEL.

at emission wavelength below 800 nm with potential for a wavelength tuning range of +/– 30 nm, with scan rates up to 1 MHz (Figs. 3 and 4 show preliminary results). Currently, these devices exhibit multimode lasing operation between 767 and 737 nm. With an improved output power and single-mode emission, short-wavelength MEMS-tunable VCSELs should be extremely attractive as widely-tunable swept sources for unambiguous O_2 sensing.

Related References

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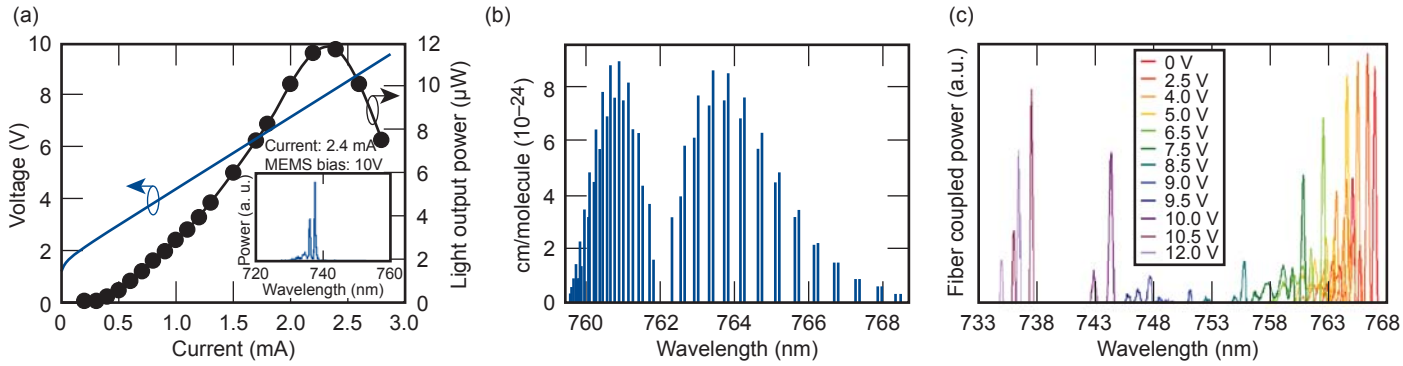

Figure 4. (a) Voltage and light output as a function of drive current for a MEMS-tunable VCSEL with a 13.5 period suspended mirror structure. Inset: tuning response for a constant laser drive current of 2.4 mA over a range of 30 nm. (b) HTRAN O_2 absorption spectrum. (c) Wavelength tuning range as a function of applied voltage.