Progress in Semiconductor Reference Oscillator Development for Coherent Detection Optical Remote Sensing

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***Abstract*-High power 2.05-µm Fabry-Perot and distributed feedback (DFB) ridge waveguide lasers fabricated from epitaxially grown InGaAsSb/AlGaAsSb/GaSb and InGaAs/InP hetero-structures are reported. This work is part of a NASA Earth Science Enterprise Advanced Technology Initiatives Program research effort to develop semiconductor laser reference oscillators for optical remote sensing from Earth orbit. Specifically, local oscillators provide the frequency reference required for active spaceborne optical remote sensing concepts that use heterodyne (coherent) detection. The two most prominent Earth observation applications for this technology are Doppler lidar wind sensing and tropospheric carbon dioxide measurement by laser absorption spectrometry, the currently favored operational wavelength for both of which is 2.05 µm. Frequency-agile local oscillator (FALO) technology is critical in such applications because of the need to compensate for large platform-induced Doppler components that would otherwise compromise data reduction and interpretation. The semiconductor laser-based FALO option offers considerable scope for reduced mechanical complexity and improved frequency agility over equivalent crystal laser devices, while their potentially faster tuning ability holds significant potential for enhanced scanning versatility. Typical uniform DFB semiconductor lasers at the wavelength of interest here exhibit unacceptable linewidth broadening at the high currents and output powers required for operation in an optical heterodyne receiver. Suppression of gain nonlinearities inside the laser cavity that lead to linewidth broadening is achieved by means of corrugation pitch-modulated (CPM) DFB grating structures. CPM-DFB lasers utilize a grating segment of slightly different pitch to achieve added uniform light intensity along the laser cavity. Initial CPM-DFB ridge waveguide lasers have been fabricated from InGaAs/InGaAs/InP material operating at a wavelength of 1.55 µm preparatory to extension of the same approach to similar material grown for the target 2.05-µm wavelength.**

I. Introduction

Frequency-agile reference oscillator technologies are of critical importance to coherent Doppler lidar sensing of tropospheric winds from Earth orbit. Retrieval of vector winds requires multiple perspective line-of-sight velocity measurements of a given air parcel and the most commonly conceived method for enabling this capability is with a conical scanning scheme [1] as depicted in Figure 1.

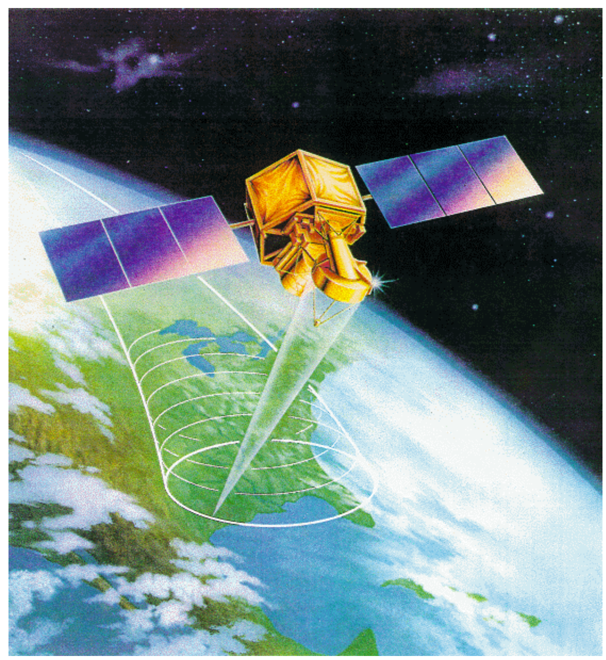

Fig. 1. Canonical Doppler wind lidar configuration in Earth orbit, illustrating the conical scan geometry.

This off-nadir beam scanning geometry induces large platform-induced Doppler components that must be accounted for in the data reduction process. One method of achieving this is by scan-synchronous tuning of a frequency-agile local oscillator (LO) in the heterodyne receiver subsystem. The present baseline wavelength region for global Doppler lidar winds measurement is ~2.05-2.06 µm, the operating wavelength of the Tm,Ho:YLF laser transmitter technology currently under development for this application [2]. Frequency-agile LO devices with the required functionality have been developed using this same material [3-6], however the advantages in flexibility offered by monolithic semiconductor laser approaches afford the potential for improved resistance to environmental disturbances, lower part-count, and more rapid tuning capability (and thus greater operational versatility on orbit).

The Jet Propulsion Laboratory (JPL) is currently evaluating prototype novel architecture semiconductor laser devices for addressing the LO power and spectral purity requirements of spacebased coherent Doppler lidar wind measurement and laser absorption spectrometry for global tropospheric CO_2 sensing [7,8].

This technology development program has followed parallel paths involving two promising laser material systems: InGaAsP/InP and AlGaAsSb/InGaAsSb/GaSb. This approach was adopted for risk reduction purposes. These two material systems and their fundamental characteristics were described previously [9].

II. Narrow Linewidth Devices

Line narrowing of semiconductor laser devices is generally achieved by means of distributed gratings written into the active waveguide structure. The linewidth performance typically available with uniform grating distributed feedback (DFB) lasers at the near-IR wavelengths of interest in this work is ~1-2 MHz. Broadening effects increase with high drive currents and output powers; to attain <1-MHz linewidth, special non-uniform grating designs become necessary because of broadening due to gain nonlinearities such as spatial hole burning within the laser cavity. For this technology development effort the corrugation pitch-modulation (CPM) approach was selected [10]. This arrangement utilizes a dephased central grating section to prevent intensity peaking in the center of the cavity, thus suppressing the longitudinal spatial hole burning that gives rise to power broadening in semiconductor laser devices. The CPM-DFB grating concept is depicted schematically in Figure 2.

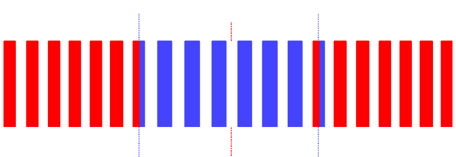

Fig. 2. Diagrammatic representation of the CPM-DFB grating concept.

The grating is designed such that each of the three sections comprises an equal number of periods, N, but the length of the center section L_2 is longer than the flanking sections ($L_1 = L_3$) by one half-period ($\Lambda_1 = \Lambda_3$):

$$\Lambda_2 = \frac{2N+1}{2N\Lambda_{1,3}} \quad ,$$

where $N = L_{1,3}/\Lambda_{1,3}$.

Previously we had reported on the performance obtained with uniform-DFB structures in multi-quantum well (MQW) compressively strained devices based on InGaAsP/InP material and operating at 2.065 µm [9]. CPM-DFB lasers have yet to be fabricated for the 2-µm spectral region of interest, but promising results have been obtained for CPM devices in InGaAsP/InP material produced at JPL operating at 1.55 µm. The mode structure of these lasers is shown in Figure 3, along with the equivalent performance of uniform DFB devices fabricated in the same material.

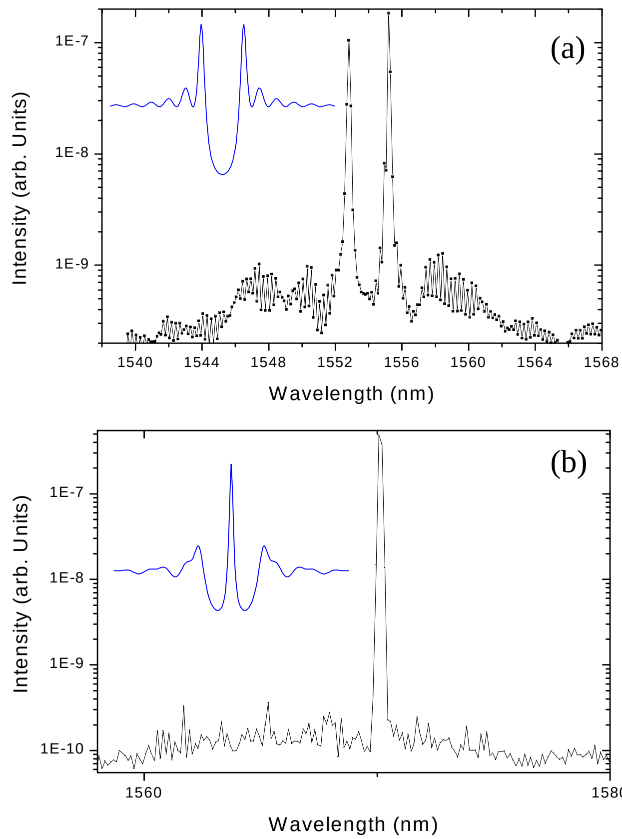

Fig. 3. Mode structure of 1.55-µm (a) uniform and (b) CPM-DFB lasers. The blue inset traces denote the theoretical expected behavior in each case.

It can be seen from Fig. 3 that the CPM architecture efficiently suppresses the degenerate bimodal behavior evident in the uniform DFB with both facets anti-reflection coated. As such, these devices conform well to theoretical expectations (indicated by the blue spectra in Fig. 3) and auger well for transfer of the CPM lithography process to the 2-µm laser architectures currently under development. Fig. 4

provides the measured pulsed mode current-power characteristic of these lasers.

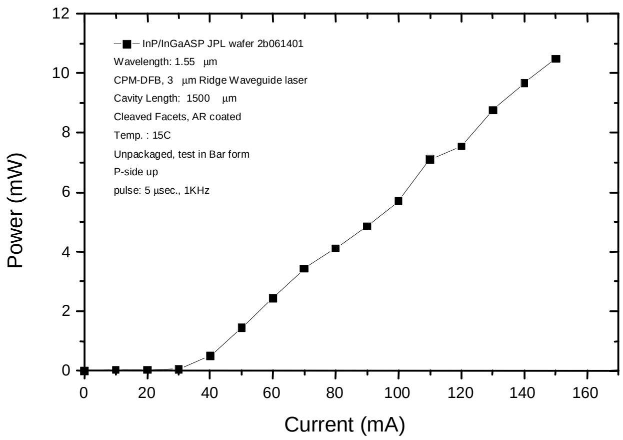

Fig. 4. Pulsed current-power characteristic of InGaAsP/InP CPM-DFB ridge waveguide laser operating at 1.55-µm.

III. Antimonide Laser Devices

Significant progress has been made in the fabrication and verification of InGaAsSb/AlGaAsSb/GaSb heterostructures for laser operation in the 2-µm spectral region. Fabry-Pérot laser structures have been fabricated in material wafers epitaxially grown at the MIT Lincoln Laboratory. Optical output powers in excess of 50 mW multimode at 1-kHz PRF have been achieved with the devices produced thus far. Fig. 5 shows the output spectrum of a device with a 5-µm waveguide.

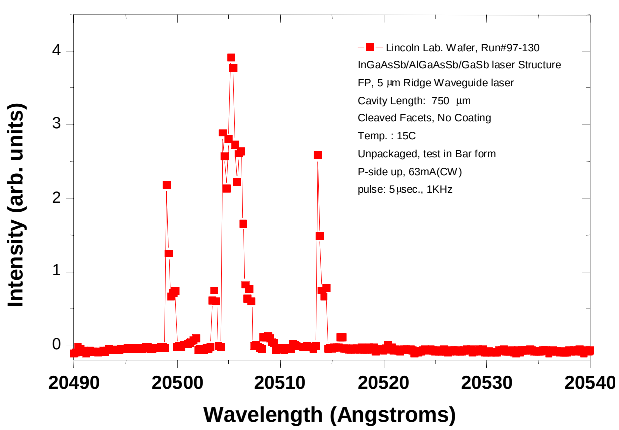

Fig. 5. Output spectrum of Fabry-Pérot 5-µm ridge waveguide laser in InGaAsSb/AlGaAsSb/GaSb.

The measured pulsed mode current-power characteristic of this laser is shown in Fig. 6(a), along with the measured performance of an analogous device with a 10-µm waveguide. Output powers up to 30 mW at 1-kHz PRF are available from the former device, while the latter is capable of delivering more than 50 mW at 15°C.

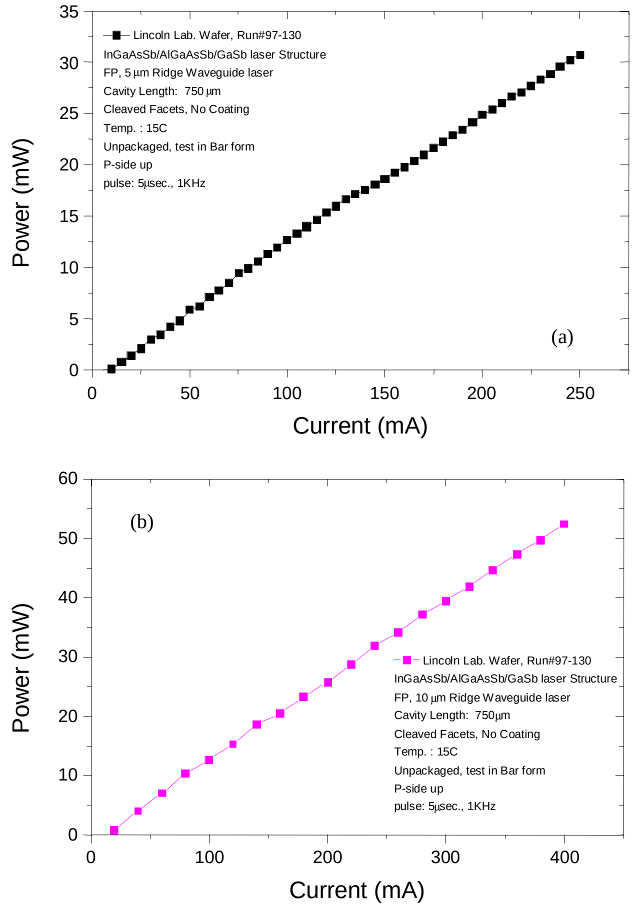

Fig. 6. Pulsed current-power characteristics of Fabry-Pérot lasers in InGaAsSb/AlGaAsSb/GaSb with (a) 5-µm ridge waveguide, and (b) 10-µm ridge waveguide.

IV. Conclusion

This report has summarized progress to date on the development of semiconductor laser devices suitable for incorporation into optical heterodyne receivers. Corrugation pitch-modulated DFB lasers have been demonstrated at 1.55-µm prior to application of this methodology to 2-µm material currently in hand.

Fabry-Pérot ridge waveguide lasers fabricated from InGaAsSb/AlGaAsSb/GaSb material have been produced with up to 50 mW cw-equivalent power extraction capability at 2.05-µm. Fabrication of hybrid Bragg grating-DBR laser architectures in this material is being pursued to enable narrow linewidth (<500 kHz) operation at these output power levels.

Acknowledgment

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