Narrow Linewidth Single-mode Semiconductor Laser Development for Coherent Detection Lidar

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ABSTRACT

High power, tunable, single mode, narrow linewidth semiconductor lasers in the 2.05-μm wavelength region are needed to develop semiconductor laser reference oscillators for optical remote sensing from Earth orbit. 2.05-μm narrow linewidth monolithic distributed feedback (DFB) and distributed Bragg reflector (DBR) with the external grating ridge waveguide lasers fabricated from epitaxially grown InGaAs/InGaAsP/InP and InGaAsSb/AlGaAsSb/GaSb hetero-structures are reported.

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Introduction

The coherent Doppler lidar approach for acquiring global profilometry of tropospheric winds from Earth orbit is reliant on off-nadir beam scanning geometry for retrieval of vector winds by Doppler analysis of laser radiation backscattered by entrained aerosols and cloud particles [1]. The off-nadir scan pattern induces large platform-induced Doppler components that may be compensated by scan-synchronous tuning of a frequency-agile local oscillator (LO) laser. Frequency-agile LO technology development has thus far implicitly assumed the same laser material as the transmitter laser. (The currently favored spectral region for conducting Doppler lidar wind sounding is ~2.05 μm, the operating wavelength of Tm,Ho:YLF.)

This approach has been under development for a number of years and has demonstrated functionality in a breadboard system close to that required for the space-based implementation [2-7]. However, compared to diode laser technology such devices are mechanically complex, with tuning stability and reproducibility being critically dependent on the maintenance of stringent alignment tolerances. An alternative monolithic semiconductor laser reference oscillator would offer superior resistance to environmentally induced alignment degradation and generally longer lifetime. In addition, the semiconductor laser option has the potential for considerably more rapid tuning capability, rendering feasible a wider variety of lidar pointing/scanning strategies.

The fabrication and validation of prototype novel architecture semiconductor lasers is presently under way at the Jet Propulsion Laboratory (JPL) with the express goal of addressing the power and spectral purity requirements of spacebased coherent Doppler lidar wind measurement and laser absorption spectrometry for global CO_2 mapping [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 Device

Although the linewidth of Fabry-Perot (FP) multimode semiconductor lasers has typically been on the order of 20 - 100 MHz., different approaches discussed in literature such as Distributed Bragg Reflector (DBR) and Distributed Feedback (DFB) lasers have been utilized in facilitating single mode selection and reducing linewidth to near 1 MHz. Unfortunately, linewidth rebroadening at relatively low optical power levels limits the use of these types of lasers in many applications. These lasers exhibit several gain non-linearities that contribute to gain and refractive index, change causing power dependent, single mode instability and linewidth rebroadening. To realize high single mode output power and narrow spectral linewidth <1 MHz, it is necessary to suppress longitudinal spatial hole burning. (LSHB) and to optimize the optical and electrical confinement properties of carriers in a relatively long 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 1.

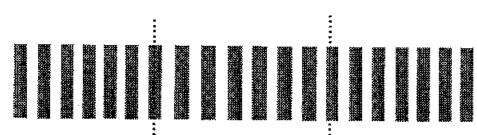

Fig. 1. Diagrammatic representation of the CPM-DFB grating concept.

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]. The single mode operation and linewidth of CPM-DFB lasers fabricated in the 2-μm spectral region has yet to be determined, but promising results have been obtained for CPM devices in InGaAsP/InP material produced at JPL operating at 1.54 μm. The single mode spectral characteristic along with measured linewidth of a 1.5 mm long CPM-DFB using delay self -heterodyne system is shown in Fig.2.

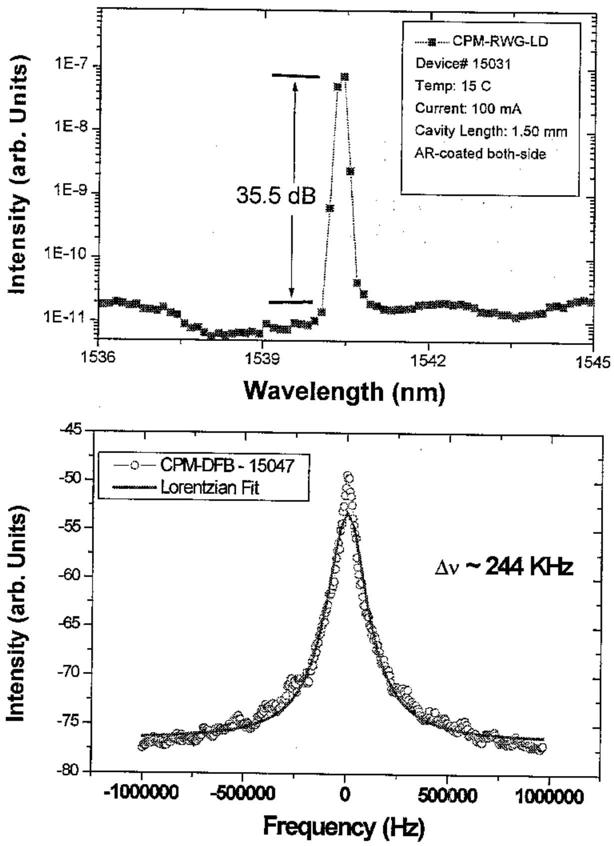

Fig. 2. Emission spectrum of 1500 μm long cavity 1.54 μm CPM-DFB lasers and its corresponding linewidth

It can be seen from Fig. 2 that the CPM architecture effectively reduce the linewidth below 1MHz as evident in <300 KHz beat note spectrum measured for 1.5 mm long cavity using delay self heterodyne technique with 5km fiber optical delay. A typical measured light-current characteristic of 1.54 μm CPM-DFB laser is shown in Fig.3.

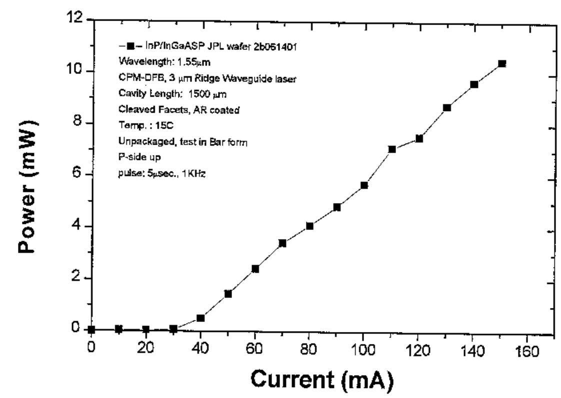

Fig. 3. Current-power characteristic of InGaAsP/InP CPM-DFB ridge waveguide laser operating at 1.54-μm.

III. Sb-BASED HYBRID DEVICES

Significant progress has been made toward fabrication of single mode hybrid DBR lasers with the external Bragg grating defined on SiN waveguide deposited on a micromachined silicon bench and InGaAsSb/GaSb based ridge waveguide gain chips operation in the 2-μm spectral region. Fabry-Pérot ridge waveguide lasers (gain chips) have been fabricated in material wafers epitaxially grown at the MIT Lincoln Laboratory. Optical output powers in excess of 30-mW multimode at 1-kHz PRF have been achieved with the devices produced thus far. Fig. 4 shows the output spectrum of a device with a 5-μm, 750 μm long ridge waveguide cavity along with measured pulsed mode light-current characteristic.

For efficient coupling the external waveguide is designed to have a mode similar to the Sb-based gain chip. In addition, the gain chip must be precisely aligned to the external Bragg grating waveguide. To that end, a micromachined bench provides the features facilitating vertical alignment. The lateral alignment is accomplished with a precision flip chip bonder. The top view and cross section of the micromachined bench is provided in Fig. 5. The main feature of the bench is the precise definition of the vertical distance between stand-offs and the waveguide core. Using this technology we recently have demonstrated single mode DBR lasers operating at 650-nm [11].

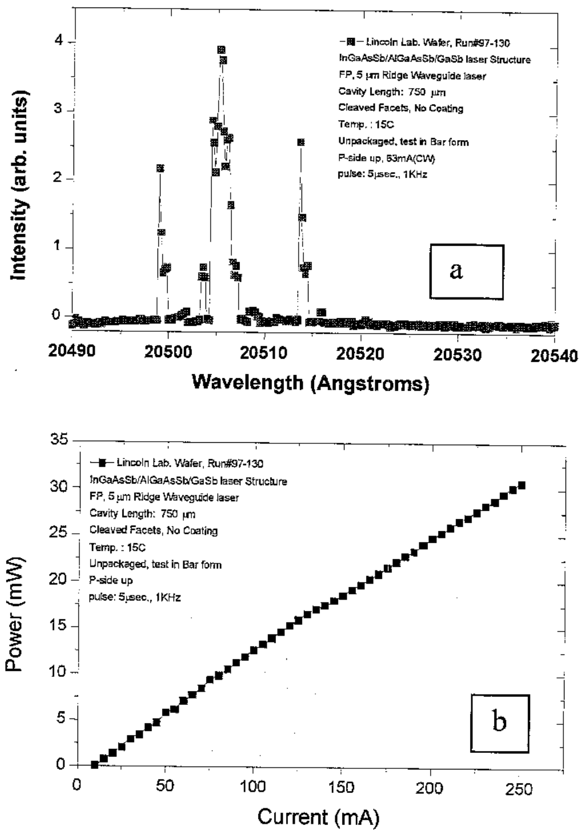

Fig. 4. (a) Emission spectrum, (b).Pulsed current-power characteristics of 5-µm ridge waveguide,Fabry-Pérot lasers in InGaAsSb/AlGaAsSb/GaSb.

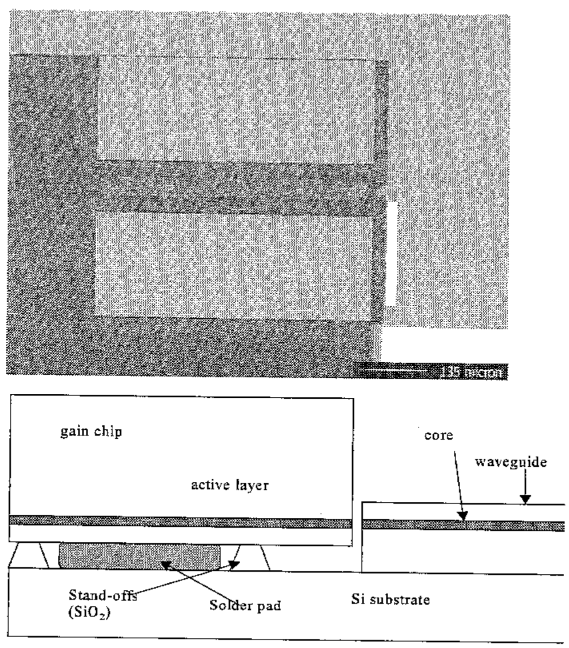

Fig. 5. The top view and cross section of the external grating waveguide micromachined bench.

IV-CONCLUSION

Corrugation Pitch-Modulation Distributed Feedback (CPM-DFB) and external grating Distributed Bragg Reflector (DBR) laser architectures are being developed to enable narrow linewidth (<500 kHz) operation of semiconductor lasers in 2-µm spectral region in laser material systems: InGaAsP/InP and AlGaAsSb/InGaAsSb/GaSb.

ACKNOWLEDGMENT

This work was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Kamjou Mansour greatly acknowledges the effort of Y. Qiu for epitaxial regrowth on InGaAs-based wafers.

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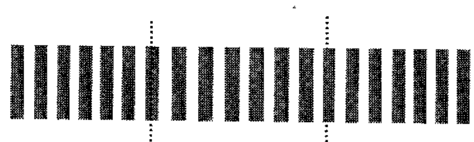

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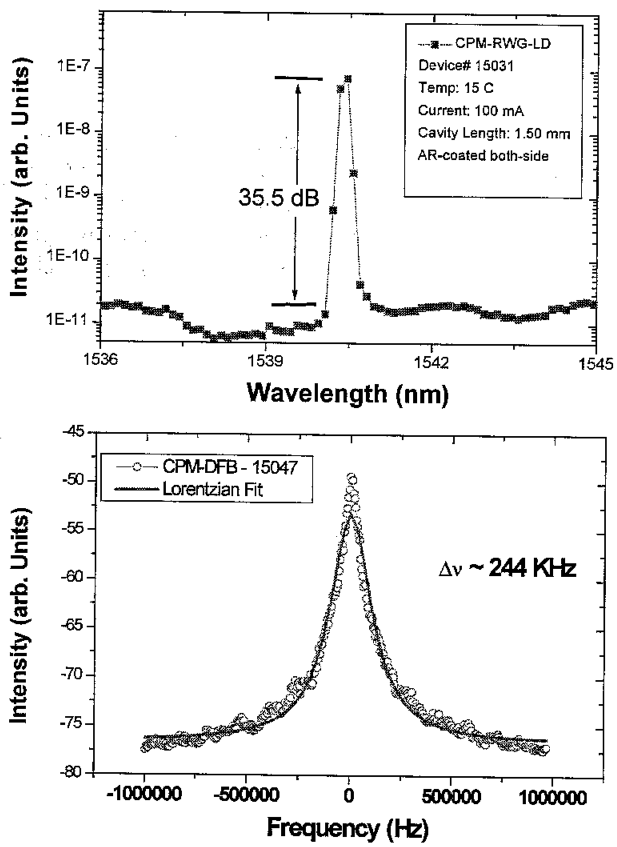

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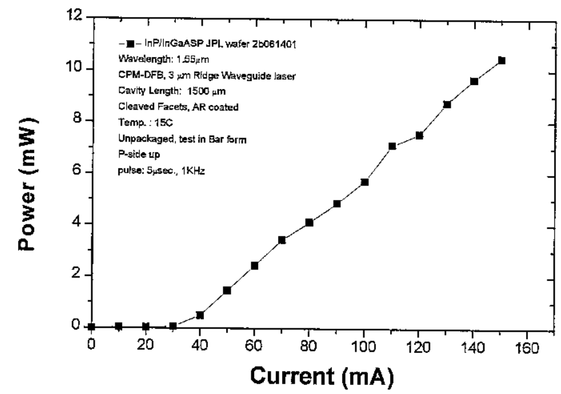

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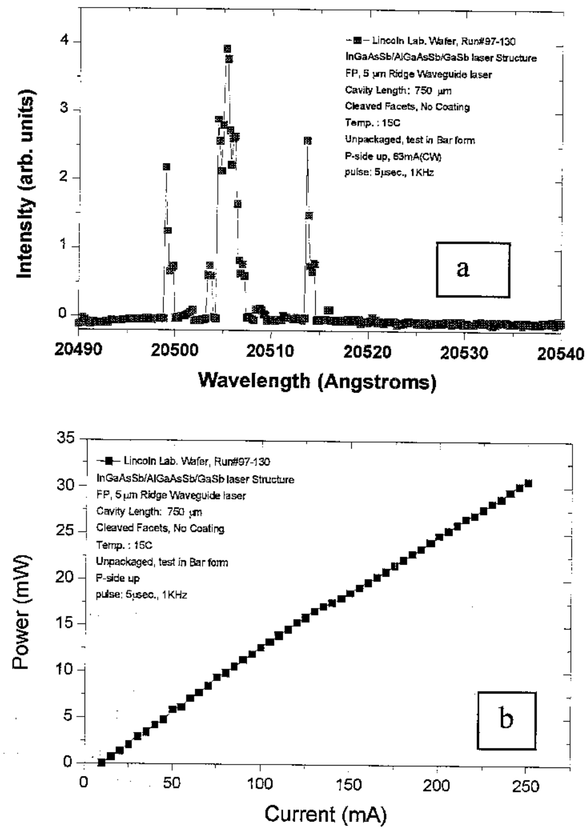

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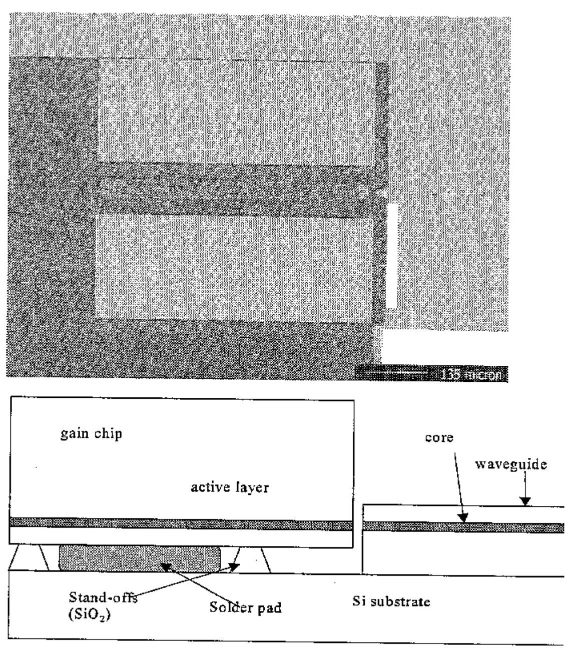

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