Performance characteristics of a continuous-wave compact widely tunable external cavity interband cascade lasers

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Abstract: We present the design and performance of a novel broadly tunable continuous-wave external-cavity interband cascade laser (ECicL). The ICL die growth and fabrication, as well as the external cavity geometry are described. Tuning across the 3.2-3.35 μm wavelength range, limited by the gain width of the ICL active medium, is achieved at a maximum power level of 4 mW.

OCIS codes: (140.5960) Semiconductor lasers; (140.3570) Lasers, single-mode.

References and links

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1. Introduction

Lasers and laser-based instruments are finding numerous applications in analytical instrumentation, remote sensing, imaging, and illumination for the industrial, medical, and security instrumentation markets. Broadband IR sources and visible-to-NIR lasers are employed in a myriad of applications, and recent progress by external cavity quantum cascade laser (ECqcL) technology has led to the first commercial tunable laser sources for the 4-12 μm spectral range [1,2]. However, the spectral gap between 3 and 4 μm has lacked viable room temperature semiconductor laser sources. This wavelength range is especially important for vibration spectroscopy, since it is a fingerprint region for the fundamental N-H, C-H and O-H stretching vibrational modes that are present in all organic molecules.

The interband cascade laser (ICL) is a novel semiconductor emitter [3] that now offers room temperature continuous wave (CW) operation for wavelength spanning 2.9-4.2 μm [4,5]. This report will describe the laser fabrication, along with design of the broadly-tunable external-cavity ICL (ECicL) package and performance results.

2. Growth and characterization of uncoated Fabry-Perot ICL chips

The ICL wafer was grown by molecular-beam epitaxy on an *n*-GaSb (100) substrate. The active region designs were generally similar to those described in Refs [4]. and [5], except for minor differences such as the GaInSb hole well composition and thickness.

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The 3-mm-long ICL chip with 12 µm ridge width and Au electroplating was mounted epitaxial-side-up on a copper heatsink and initially characterized in Fabry-Perot mode with uncoated facets. Figure 1 shows the optical power *vs*. current (*P-I*) curve for CW operation at 15°C heatsink temperature. The threshold for lasing was 180 mA, and an optical power in excess of 20 mW per facet was achieved at 700 mA where the compliance voltage was 3.2 V. The sub-threshold amplified spontaneous emission (ASE) spectrum, recorded by an FTIR spectrometer at 125 mA, indicated a gain center at 3130 cm^{-1} (3.19 µm) as shown in Fig. 2.

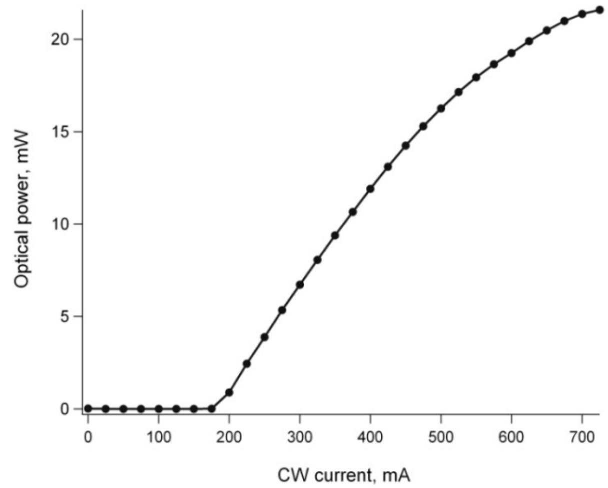

Fig. 1. CW *P-I* curve for the uncoated ICL chip at 15°C.

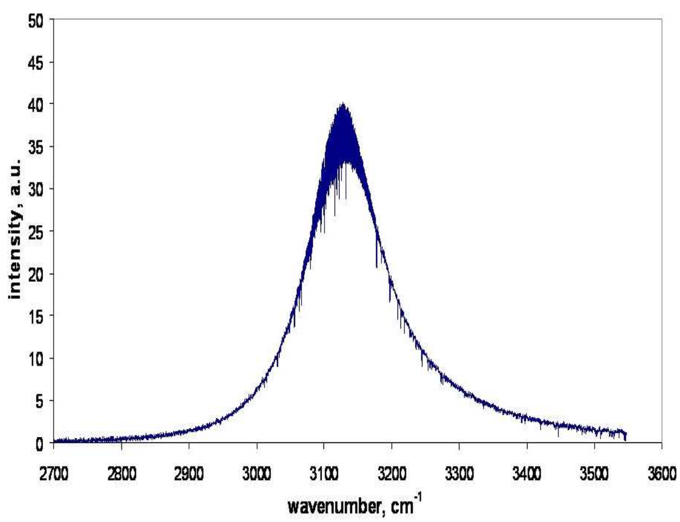

Fig. 2. FTIR spectrum of ASE from the Fabry-Perot ICL at 125 mA and 15°C.

3. External cavity arrangement

The basic Fabry-Perot ICL is unsuitable for spectroscopic applications, because its emission spectrum lacks both the desired narrowness and tunability. A wavelength selector such as a diffraction grating must therefore be incorporated, for example, as an end mirror to an "external cavity" laser. The wavelength selector leads to narrow-linewidth ECicL output that

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can be tuned across the entire bandwidth of the active semiconductor gain medium (~100 cm^{-1}) via rotation of the diffraction grating.

The mounted ICL die was integrated into the Daylight Solutions external cavity assembly that was originally developed for quantum cascade lasers and described previously [2]. Figure 3 shows a schematic diagram of an external-cavity ICL in the Littrow configuration.

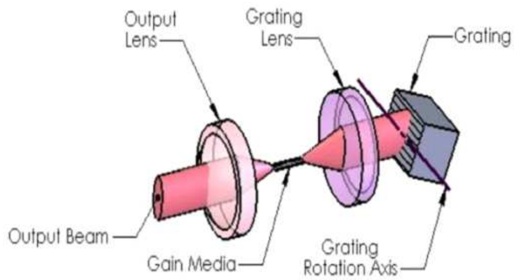

Fig. 3. Schematic representation of the main components of an external cavity interband cascade laser.

The external cavity is characterized by a 25 mm long optical cavity length, miniature grating tuning mechanism, and integrated current and temperature controls. Figure 4 shows a photograph of the laser head. To realize the external cavity arrangement, the chip facet facing the grating was anti-reflection (AR) coated using a two-layer film design, while the output facet was left uncoated. The AR coating increased the Fabry-Perot lasing threshold at 15°C from 180 mA to 260 mA, and resulted in an optical output power ratio of 7.5 between the AR-coated and uncoated sides. The change in threshold current upon AR coating was small due to relatively-high waveguide optical losses in the ICL chip. The light emitted from both facets was collimated with a pair of identical AR coated aspheric NA = 0.78 ZnSe lenses. This produced a near-Gaussian highly-elliptical beam in the presence of a diffraction grating or mirror feedback, as compared to multi-spatial-mode output in the Fabry-Perot configuration.

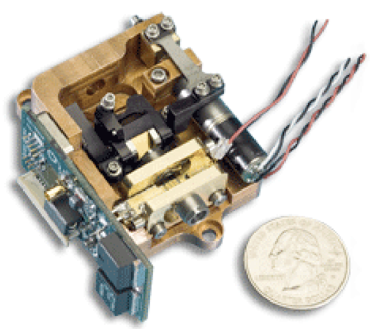

Fig. 4. Photograph of the Daylight Solutions external-cavity broadly tunable interband-cascade laser source.

The Au-coated 300 g/mm replica grating on a glass substrate had ~90% diffraction efficiency in the first diffraction order. The Littrow grating angle and, consequently, the output wavelength, were controlled via the combination of a stepper motor and an integrated absolute encoder operating in a closed loop controlled by a microprocessor. The driving current and temperature were set and controlled to 0.1 mA and 0.02°C via digital PID.

4. External-cavity laser characterization

The laser could be operated in both pulsed and CW modes. In pulsed mode, the spectral linewidth, averaged over a single pulse, was of order 1 cm^{-1} full width at full maximum (FWFM) due to thermal transient chirp as the laser gain medium heated. For CW operation,

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the thermal chirping vanished and stable single-mode output was achieved at all grating angles. However, the tuning via simple grating rotation was complicated by wavelength discontinuities, in the form of mode hops that resulted from a lack of coordination between the optical roundtrip length and the grating angle. While Daylight Solutions has developed mode-hop-free tuning in the modified Littrow configuration, the present work did not aim to develop this mode of operation. Rather, it was limited to demonstrating wavelength narrowing and coarse control of the ICL output in an external cavity using simple grating rotation. Because room-temperature CW operation is more challenging and desirable than low-duty-cycle pulsed operation, we focused on CW characterization of the ECicL at multiple grating angles, operating currents, and heatsink temperatures.

The present study limited the injection current to 260 mA, to prevent self-lasing of the chip. The optical output power from the ECicL was measured with a pyroelectric-based power meter, and output spectra were recorded by a tunable monochromator employing a LN_2-cooled MCT detector. The laser temperature, measured by a thermistor mounted on top of the heatsink a few mm away from the chip, was used in the temperature control loop. The laser driver and measurement instruments were controlled via a PC, with all data acquisition fully automated.

The ECicL characterization was performed at two heat-sink temperatures: 10°C and 15°C. At each temperature, the diffraction grating was scanned across the entire tuning range at several current values, and the optical output power and spectra were recorded at each of several discrete grating angles and current settings. Visual inspection confirmed that every recorded spectrum featured a single narrow line corresponding to single-mode output. Each emission wavelength was evaluated by fitting the sharp recorded feature to a Gaussian shape. Because the monochromator resolution was intentionally coarsened to minimize the time required to acquire a full data set, the reported wavelengths (optical frequencies) are accurate to ± 0.003 nm (± 1 cm^{-1}). Figures 5 and 6 summarize the results for heatsink temperatures of 10°C and 15°C, respectively. Both optical power *vs*. wavelength at several fixed current settings and optical power *vs*. current (*P-I*) at several fixed wavelength settings are given. For all of the reported testing conditions, the input power required for operation is < 0.8 W. The data show the ECicL to be capable of tuning across 3090-3200 cm^{-1} (3.13-3.24 μm) at both temperatures. At 10°C and the highest current of 260 mA, the maximum output power at the center of the tuning curve reaches ≈4 mW, while powers exceeding 1.5 mW are obtained over the entire tuning range.

The kinks in the *P-I* curves and irregularities in the power *vs*. wavelength curves are mode-hops caused by a competition between different cavity modes in the presence of both grating feedback and the parasitic etalon associated with non-zero reflectivity of the AR coating. Such irregularities occur generally in external cavity lasers rather than being specific to the gain medium. As expected, the tuning range, maximum output power, and threshold currents are all affected adversely by increasing temperature. However, for many laboratory setups and field applications, the considered 10-15°C operational temperatures and sub-Watt power dissipation levels are readily achievable with an off-the-shelf single-stage thermoelectric cooler. Thus, for practical purposes the presented data qualify the ECicL for room-temperature CW operation.

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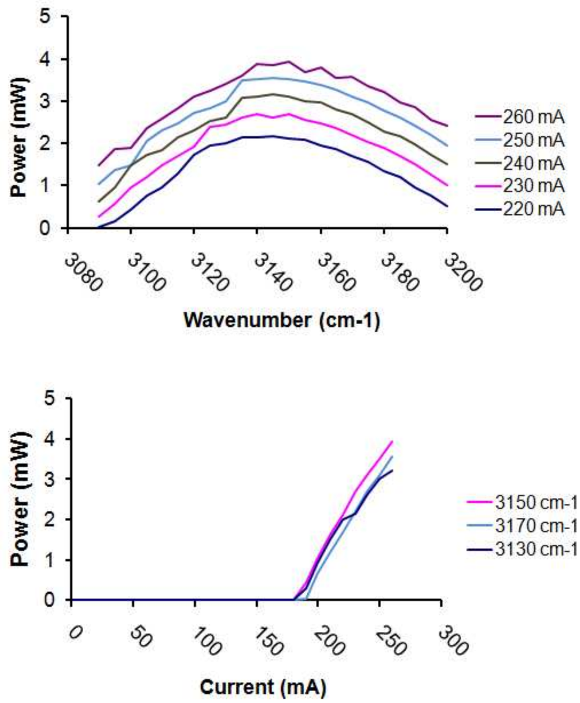

Fig. 5. Power vs. wavelength (top panel) and powe vs. injection current (bottom panel) for ECicL at 10°C.

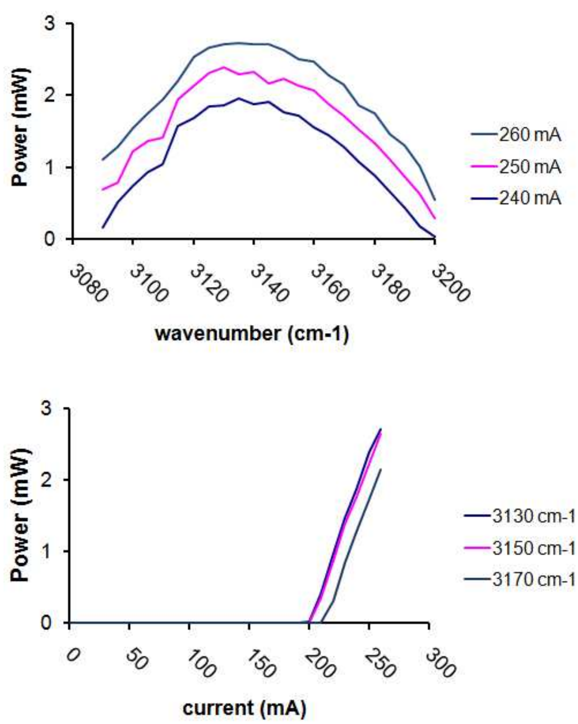

Fig. 6. Power vs. wavelength (top panel) and powe vs. injection current (bottom panel) for ECicL at 15°C.

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5. Conclusions

In summary, this letter reports the first demonstration of a tunable room-temperature ECicL, with a tuning range of ~110 cm^{-1} (0.11 μm) around the 3.2 μm central wavelength, mW-level output powers over the entire tuning range, and maximum input power < 1 W. Work is in progress to develop pulsed ECicLs suitable for moderate-resolution spectroscopic applications as well as continuously tunable ECicLs for high-resolution applications. Concurrent are ongoing improvements to the laser design and fabrication, as well as expanded spectral coverage to fully span the 3-4 μm band.

Acknowledgments

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