Monolithic tunable GaSb-based lasers at 3.3 μm

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Widely-tunable monolithic two-section lasers emitting at around 3.3 μm have been developed. The devices are based on GaInAsSb quantum wells with quinary AlGaInAsSb barrier layers. Tuning is achieved by adjusting the currents injected into two segments with lateral binary superimposed gratings. Counter-directional current-tuning of the segments resulted in wavelength channel switching, co-directional current-tuning in wavelength tuning of a channel. The typical tuning range of the devices is around 23 nm. High-sensitivity measurements indicate that sidemode suppression ratios are usually around 45 dB.

Introduction: High-speed, high-sensitivity gas analysis (e.g. in industrial processes) is a major field of application for monomode semiconductor lasers. The wavelength selection in such devices is usually achieved by a grating that provides distributed feedback (DFB). Recent progress has extended the emission range of GaSb-based lasers beyond 3.0 μm [1, 2], enabling for example tunable diode laser spectroscopy (TDLS) applications for hydrocarbons [3]. While the current-induced tuning range of DFB lasers is usually limited to a few nanometres, there are a number of applications which will benefit from lasers with wider tunability (>10 nm). A widely-tunable laser allows sensing of multiple gas absorption lines in a gas mixture or separating spectral features of overlapping absorption lines. It can also be used to determine the base line of a measurement by sampling a spectral region far away from the broad spectral features that arise from collision broadening or large molecules. Multiplexing combinations of selected DFB lasers [4] is an option, but quickly becomes complex and costly. Using external cavity setups [5] can become problematic in an industrial environment owing to the mechanical parts involved. In addition, transmission variations due to fluctuations of the gas composition or particles crossing the laser beam (e.g. in combustion processes) require tuning frequencies in the kilohertz range. A monolithic solution that is compact, robust and provides a high tuning speed is given by a multi-segment laser. Corresponding designs with a multitude of segments and rather complex current control [6] as well as simpler designs with as few as two segments have been demonstrated [7]. Gas-sensing application of such lasers has been performed in lower wavelength ranges (e.g. 1.8 μm [8]). Operation of multi-segment lasers based on GaSb was achieved up to a maximum wavelength of 2.8 μm [9, 10].

We present two-segment devices fabricated on quinary barrier GaSb type-I material around 3.3 μm. Using individual current control of both segments, spectral mapping of the emission wavelength was performed. Wide tuning with sidemode suppression ratios (SMSR) > 25 dB (limited by the sensitivity of the setup) is demonstrated.

Fabrication: The epitaxial laser layers used for device fabrication are based on the GaSb material system and have GaInAsSb quantum wells with a direct (type I) transition and AlGaInAsSb quinary barriers. The gratings consist of metal lines patterned laterally to the ridge waveguide of the laser [11]. A more detailed description of the epitaxial material and the processing of DFB lasers can be found in [12]. A main difference here was the electrical separation of the 975 μm-long ridges by a ~50 μm-wide region into two equally long segments by reactive ion etching into the highly doped cap layer. The resistance between the segments was in the order of 1.5 kΩ, effectively avoiding crosstalk. Another key difference from DFB device processing was the structure of the grating, which was designed by transfer-matrix simulations, as described in [9]. Using the principle of binary superimposed gratings (BSG) [13], aperiodic and slightly differing lateral metal patterns were applied to the two segments. The different individual periods included in a BSG were chosen to be coinciding after the length of one segment and weighted to result in equal losses for each DFB wavelength. The effective refractive index used was $n \simeq 3.42$, as determined in [12]. Overall grating lengths were below 500 μm and could be defined within a single e-beam lithography pattern, avoiding stitching errors. Lasers were cleaved close to the defined gratings for similar phase conditions of the BSG modes at the position of the facets. Devices were mounted epitaxial-side up on TO headers with integrated Peltier coolers and hermetically sealed.

Characterisation: Characterisation was performed using an automated setup for continuous-wave current control of the two segments in combination with a Fourier transform infrared (FTIR) spectrometer. 2D maps of the emission wavelength of the devices for fixed temperatures were generated. Currents were varied in steps of 5 mA, the spectral resolution was 0.125 cm^{-1}. Output powers of the lasers were typically in the order of a few multiwatts.

Fig. 1 shows a false-colour plot of a device with a highly reflective backside coating on a TO3 header at a chip temperature of +3°C. Monomode emission wavelengths with SMSR > 25 dB are colour coded for the variation of currents through both segments. The wavelengths of three designated tuning areas ('channels') close in on one another, resulting in a quasi-continuous tuning of around 14 nm in the range 3350.3–3364.1 nm. Wavelength tuning within the channels occurs along diagonal stripes (lower left → upper right), switching of channels is performed by counter-directional current-tuning (lower right → upper left).

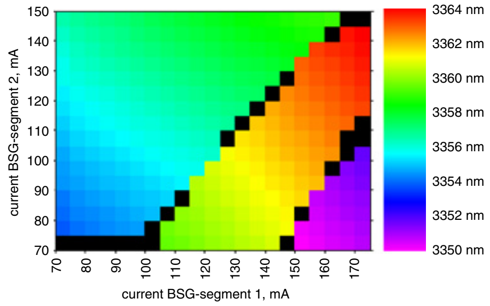

Fig. 1 *False-colour plot of emission wavelengths of two-segment tunable device mounted on TO3 operated at +3°C*

Quasi-continuous tuning from 3350.3–3364.1 nm is achieved. Black areas < 25 dB; Other areas have SMSR > 25 dB

Besides wide tuning around a specific wavelength, the device principle can also be used to cover discrete wavelength ranges separated by several nanometres. This is especially useful when targeting several absorption lines of different gases in a mixture or for baseline sampling. Fig. 2 shows the spectral tuning of an uncoated device at −3°C, mounted on a TO8. Four distinct monomode channels can be addressed by choosing different current combinations for the segments. Simultaneous current tuning covers 3320.7–3322.1 nm, 3329.3–3330.6 nm, 3334.0–3337.9 nm and 3342.2–3343-7 nm, resulting in an overall tuning range of 23 nm.

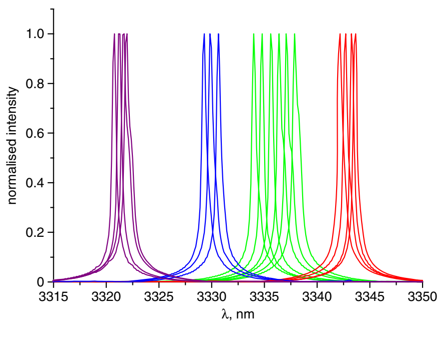

Fig. 2 *Spectral intensities against wavelength for four discrete monomode wavelength channels in two-segment tunable device mounted on TO8 operated at −3°C; overall tuning range of 23 nm is covered*

The dynamic range of the fast automated setup used for these measurements is about 25 dB, limiting the measured SMSR. For some wavelengths, high-sensitivity measurements with a dynamic range above 55 dB were performed using a 1150 mm-long grating spectrometer and lock-in technique in step-scan mode. The spectral resolution was below the laser resonator mode distance, making it possible to reveal the Fabry-Pérot mode comb and determining a real SMSR. The spectrum of a tunable laser, operated at −5°C with segment currents 110 mA/100 mA, emitting at 3333 nm is shown in Fig. 3. A SMSR of

45 dB is observed, indicating very effective suppression of competing sidemodes. High-quality TDLS, comparable to DFB-applications, is thus very feasible with this concept.

Finally, it should be mentioned that this concept is limited mainly by the width of the gain spectrum of the laser material. Stable tuning ranges with high SMSRs in the order of 100 nm should therefore be possible.

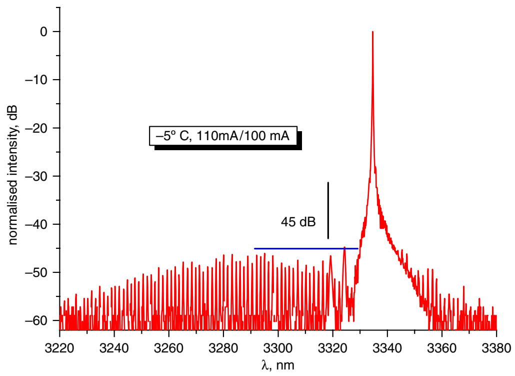

Fig. 3 *High-sensitivity spectrum of two-segment tunable device mounted on TO3 in monomode operation at* $-5^{\circ}C$

Currents through segments 1 and 2 are 110 and 100 mA, respectively. SMSR of 45 dB is obtained

Conclusions: Two-segment table BSG lasers have been fabricated on GaSb-based type-I transition material with quinary barriers around 3.3 μm. Automated 2D measurements show ideal current tuning behaviour in diagonal, monomode wavelength channels. Stable quasi-continuous tuning (∼14 nm) and tuning in distinct channels (23 nm) are possible. SMSRs up to 45 dB promise excellent feasibility for a variety of applications, e.g. multi-gas-species analysis.

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