Monolithic 2µm GaSb-based passively mode-locked laser

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Abstract. A double-section passive mode-locked GaSb-based laser emitting more than 10mW average power is presented. The device emits optical pulses at 18.76 GHz repetition rate and estimated pulse width of 1.3 ps. An optical spectrum as wide as 3.2 nm is recorded which spans over more than 10 longitudinal modes.

Introduction

High-frequency ultrashort optical pulses emitting in the eye-safe 2 µm range are desirable for numerous applications in advanced telecommunication and sensing applications[1], [2]. Due to their compactness, high efficiency, and low cost, passive mode-locked integrated semiconductor lasers are attractive sources for the above applications. The majority of the past research concerning monolithic passively mode-locked semiconductor lasers has been focused at 1.3 µm and 1.55 µm communication windows, utilizing GaAs[3] and InP[4] material systems. Moving to the longer wavelength at 2 µm and beyond requires the use of GaSb-based heterostructures. While there is a large variety of results concerning the development of the continuous wave (CW) laser diodes (LDs) in the 2-3 µm range, but there are only a few recent publications describing passive mode-locking in GaSb LDs[5]–[7]. This is largely because this material system and related technology is much less spread compared to major InP and GaAs platforms used in optical communication. On the other hand, GaSb has emerged as a very appealing platform for sensing, in combination with Silicon-photonics (SiPh)[8],[9]. For example, we have recently demonstrated a widely tuneable hybrid laser employing GaSb gain chip and SiPh external tuneable mirror at 2.6 µm[10]. In fact, this development of monolithic mode-locked lasers at 2 um is triggered by the opportunity to combine such chips with SiPh circuitry for more advanced circuit functionality, such as mid-IR on-chip frequency combs[11].

In this work, we report a high power and high repetition-rate InGaSb/AlGaAsSb double quantum well (QW) passive mode-locked laser operating around 2 µm. We demonstrated the fabrication process and characterization of the mode-locked laser. Laser under mode-locked condition emits more than 10 mW average power, which is higher than other mode-locked lasers at same wavelength utilizing GaSb material system

Design and fabrication

The epitaxial structure was grown on an n-GaSb substrate by solid-source molecular beam epitaxy. The structure comprised two 10 nm thick compressively strained $Ga_{0.75}In_{0.25}Sb$ QWs separated by a 20 nm thick $Al_{0.30}Ga_{0.70}As_{0.027}Sb_{0.97}$ barrier. A 130 nm thick $Al_{0.30}Ga_{0.70}As_{0.027}Sb_{0.97}$ waveguide surrounds the active region on both sides. The upper and lower cladding layers consist of 2000 nm thick p- and 2700 nm thick n- $Al_{0.9}Ga_{0.1}As_{0.07}Sb_{0.93}$ layers, respectively. The epitaxial structure is capped with 200 nm of highly p-doped GaSb.

The wafer was processed into 5 µm wide ridge waveguide (RWG) Fabry-Pérot lasers to ensure a single transverse mode operation. The RWG was defined by photolithography and etched 1.9 µm deep by inductively coupled reactive ion etch system. In order to electrically separate the saturable absorber section from the laser section, a 12 µm wide and 1.5 µm deep isolation trench was etched into the upper cladding. A schematic of two section mode-locked laser is shown in Fig.1a). The RWGs were passivated with a 100 nm thick SiN-layer. The SiN-layer was removed from the top of the waveguide in order to open a path to inject the current and the p-side contact was deposited on the SiN and on the opened

Fig.1: Schematic diagram of a two section GaSb mode-locked laser, b) microscopic image of a processed GaSb mode-locked laser

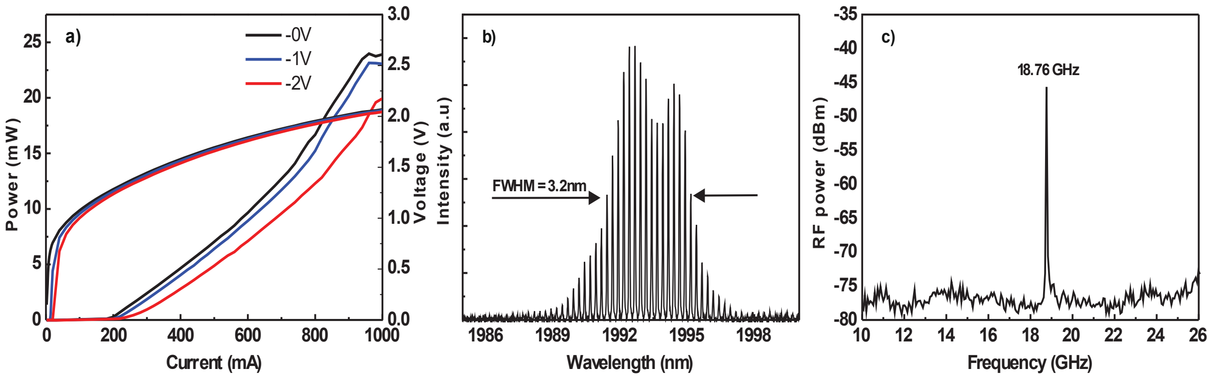

Fig.2: a) *L-I-V* curve of the laser at room temperature with different V_{abs}. b) Optical spectrum of the mode-locked laser (I_g = 700 mA, V_{abs} = -2 V*)*. c) RF spectrum of the mode-locked laser (I_g = 700 mA, V_{abs} = -2 V*)*.

area. The p-side contact consisted of Ti/Pt/Au-layer structure. To allow subsequent cleaving of high-quality facets, the substrate was thinned down to 140 µm thickness and the n-side of the sample was metallized to produce the n-contact. For this step, we used an annealed Ni/Au/Ge/Au layer stack. Prior to testing, the chips were mounted on AlN-submounts with an epoxy-adhesive containing silver particles. A microscopic image of two section mode-locked laser is shown in Fig.1b).

Characterization

The lasers were tested under the CW current injection, at RT. The gain section was forward-biased while the absorber section was reverse-biased to act as a saturable absorber for passive mode-locking. In this work, we studied a laser with a total length of 2.2 mm and the absorber section length of 0.10 mm. The bias voltage applied to the absorber section (V_{abs}) was varied, and forward current applied to gain section (I_g) was increased from 0 to 1500 mA at each V_{abs}.

Fig.2 a) shows the light-current-voltage (*L-I-V*) characteristic of a laser at different V_{abs}. Laser operates under mode-locked condition when V_{abs} is -2 V. High resolution optical spectrum, measured with Yokogawa AQ6375 optical spectrum analyzer, shows full width at half maximum (FWHM) of ~3.25 nm, and more than 10 logitudinal modes spaced by ~0.25 nm, as shown in Fig.2 b). From this we can determine the group index to be 3.61. Spectrum was measured under the mode-locked conditions where I_g = 700 mA and V_{abs} = -2 V. The width of light pulses can be estimated from the width of optical spectra. Pulse width of ~ 1.29 ps is estimated if sech^2 pulse shape is assumbed[12]. Optical pulse signal was measured by a high speed photodetector (ET-5000) and RF signal was amplified by UA0L65VM amplifier, followed by a RF spectrum anlyzer. RF signal shows a clear beating frequency around 18.76 GHz, which corresponds to the round trip cavity length of 2.2 mm and group index of 3.61.

Conclusions

We demonstrated a passively mode-locked GaSb-based double quantum well laser emitting around 2 µm with more than 10mW optical power. A 3.2 nm broad optical spectrum with more than 10 modes in the entire bandwidth is recorded under -2 V bias voltage across the absorber section. The RF spectrum of the signal measured under the mode-locking condition showed a clear beat note frequency around 18.76 GHz. Optical pulse width was estimated to be 1.29 ps. Further work is aimed at integration of mode-locked laser in extending cavity configuration with SiPh circuitry for wavelength tuning and repetition rate control.

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