Gain characteristics of 1.3µm GaInNAs/GaAs quantum wells monolithically integrated on Ge

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ABSTRACT

Gain characteristics of quantum-well laser diodes monolithically integrated on Ge substrate are reported. The gain is provided by two GaInNAsSb/GaAs quantum-wells with emission at 1.2 µm–1.3 µm. The diode exhibits continuous-wave operation with mW-level output power at room temperature.

Keywords: Monolithic integration, laser diode, gain, GaInNAs quantum well

1. INTRODUCTION

Silicon photonics offers the most advanced and versatile, integration of a large variety of passive optical components. On the other hand, Si lacks the ability to generate light requiring integration with III–V optoelectronics emitter. Amongst various platforms targeting for Si/III–V convergence, monolithic integration enables highest level of scalability. The main issues preventing developments in this direction are related to the large lattice mismatch between Si and III–V compounds, and formation of antiphase domains at the interface between group IV and III–V layers. An interesting possibility to mitigate the lattice mismatch issue has emerged recently owing to developments of Ge/SiGe/Si epitaxy. In turn, this allows integration of GaAs optoelectronics components on artificial Si/Ge substrates, since Ge and GaAs-based compounds have similar lattice constants. This approach has been recently pursued in demonstration of 1.3 µm InAs/GaAs QD lasers on Ge/Si [1], [2]. On the other hand, attempts to integrate InGaAs/GaAs quantum-well (QW) emitters have been limited to a wavelength range below 1.1 µm due to the strain associated with In [3].

Recently, we proposed a new approach for the fabrication of gain structures at 1.2 – 1.3 µm monolithically integrated on an artificial Ge substrate (i.e. incorporating a GaAs-based buffer) [4], which takes advantage of recent progress in epitaxy of GaInNAs/GaAs compounds [5], [6]. Compared with QD gain structures monolithically integrated on Ge/Si, QW technology should provide higher single-pass gain increasing the density of integration, the operation speed, and reducing the power consumption. Here we report the gain characteristics of GaInNAs/GaAs/Ge quantum well laser diodes operating at 1.3 µm.

2. EPTAXIAL STRUCTURE

The general structure is depicted in Figure 1. The laser was grown by plasma-assisted molecular beam epitaxy (MBE) onto a 4” artificial Ge substrate. The epitaxial growth was started with a GaAs buffer layer followed by a thick n-GaAs contact layer. Then we grew the laser structure that consisted of two dilute-nitride QWs embedded within a 250 nm GaAs waveguide and surrounded by 1 µm AlGaAs claddings. Finally, a p++ contact GaAs layer was deposited on top. Following the epitaxy we assessed the photoluminescence (PL) emission of the laser diode grown on the Ge substrate and compared it with the signal obtained from a similar structure grown on n-GaAs (100) substrate. As shown in Figure 1, the two type of structures provide similar level of PL, with slight difference in the peak wavelength, possibly due to a difference in composition. The difference in the background signal is due to different types of substrates. Moreover, the morphology of the structure was assessed by microscopy (both optical and atomic force). Again, we did not observe significant changes in quality besides an increase in roughness of a structure grown on Ge.

![Diagram of laser structure]

*Figure 1. Left: General schematics of the laser structure. Right: PL signal for GaInNAsSb QWs on Ge and GaAs [4].*
3. LASER DIODE PROCESSING AND PERFORMANCE

Laser diodes with a ridge waveguide (RWG) geometry were fabricated with both p- and n- contacts on the top. Finally, laser bars were cleaved and some of the bars were HR/HR coated to allow operation with reduced current. The coatings consisted of two pairs of SiO$_2$/TiO$_2$ for the front mirror and 6 pairs for the back mirror, ensuring 75% and 99.5% nominal reflection, respectively. The devices were glued epi-side up on AlN-submounts. Room temperature cw operation with mW-level output power for a component as short as 250-µm is shown in Figure 2 (left). Temperature dependent LI-characterization (not shown) reveals a characteristic temperature above 125 K and continuous wave lasing up to 120 °C.

![Figure 2](image)

*Figure 2. Left: Room temperature output characteristics of the GaInNAs/GaAs/Ge 1.3 µm laser. Results are shown for 250µm long transversely single mode LDs at room temperature. Right: Modal gain vs wavelength at different current densities from 2 kA/cm$^2$ to 10 kA/cm$^2$ with 1kA intervals.*

Gain characteristics were determined using Hakki-Paoli method [7] for AR/AR-coated and as cleaved devices. Figure 2 (right) shows the spectral gain curve under different levels of injection for 2 µm wide and 250 µm long waveguide. The device exhibited a modal gain of up to 68 cm$^{-1}$ at a current density of 10 kA/cm$^2$. At moderate injection level of 5 kA/cm$^2$ full width half maximum of modal gain curve is around 70 nm.

4. CONCLUSIONS

We report gain characteristics of a 1.3 µm dilute-nitride QW laser integrated on Ge substrate. Laser diode demonstration reveal excellent output and temperature characteristics, wide gain spectrum capable to support multiple channels and high gain. Compared to InAs/GaAs QD lasers at similar wavelength range grown on Ge, our approach enables higher gain and hence efficient operation of short components (potentially below 200µm chip length). This is an advantageous feature for higher density of integration, higher speed, and lower power consumption.

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REFERENCES
