Ga0.35In0.65 N0.02As0.08/GaAs bidirectional light-emitting and light-absorbing heterojunction operating at 1.3 μm

Faten Adel Ismael Chaqmaqchee1* and Naci Balkan2

Abstract
The Top-Hat hot electron light emission and lasing in semiconductor heterostructure (HELLISH)-vertical-cavity semiconductor optical amplifier (THH-VCSOA) is a bidirectional light-emitting and light-absorbing heterojunction device. The device contains 11 Ga0.35In0.65 N0.02As0.08/GaAs MQWs in its intrinsic active region which is enclosed between six pairs of AlAs/GaAs top distributed Bragg reflectors (DBRs) and 20.5 pairs of AlAs/GaAs bottom DBR mirrors. The THH-VCSOA is fabricated using a four-contact configuration. The wavelength conversion with amplification is achieved by the appropriate biasing of the absorption and emission regions within the device. Absorption and emission regions may be reversed by changing the polarity of the applied voltage. Emission wavelength is about 1,300 nm and a maximum gain at this wavelength is around 5 dB at $T = 300$ K.

Keywords: THH-VCSOA; Bidirectional; GaInNAs; Amplification

Background
Vertical-cavity semiconductor optical amplifiers (VCSOAs) at 1.3 μm are key photonic components in optical communication systems [1-4]. Dilute nitride III-V alloy semiconductors and in particular GaInNAs/GaAs quantum well (QW)-based VCSOAs were originally proposed as replacements for GaInAsP/InP QWs due to its reduced temperature sensitivity and inherent polarization insensitivity [5,6]. In addition, their growth on GaAs and their integrability with GaAs/Al(Ga)As distributed Bragg reflectors (DBRs) allowed them to be considered as the active region in 1.3-μm vertical-cavity devices. In this article, a novel VCSOA based on the hot electron light emission and lasing in semiconductor heterostructure (HELLISH) as an alternative to conventional VCSOAs is investigated [7]. Spontaneous emission of ultra bright HELLISH has been previously reported and demonstrated by us [8,9]. The simple bar HELLISH-VCSOA [10] and Top-Hat HELLISH-VCSOA [11] structures with GaInNAs/GaAs quantum wells in the active region are designed to operate in the 1.3-μm wavelength region.

In this work, we demonstrate for the first time, optical amplification at wavelength $\lambda \approx 1.3$ μm in electrically pumped THH-VCSOA devices. We measured the photoluminescence (PL) and electroluminescence (EL). By combining the two measurements, we obtained the electrophotoluminescence (EPL) signal from which the light amplification is obtained. At a temperature of $T = 300$ K, maximum gains were achieved when voltages of 40, 60, and 80 V were applied.

Methods
The device of THH-VCSOA with the code VN1520 was grown by molecular beam epitaxy (MBE) on a semi-insulating GaAs substrate. Figure 1a shows the sample structure. Eleven Ga0.35In0.65 N0.02As0.08/GaAs QWs were used in the active region to supply enough gain at a wavelength of around 1.28 μm. The active region is within a micro-cavity which was formed by growing DBRs below and above the active region. Top and bottom DBRs have 6 and 20.5 pairs of AlAs/GaAs, with mirrors yielding calculated reflectivities of 0.6 and 0.99, respectively. The device was fabricated by selective etching to have a p-channel of...
Figure 1 Schematic diagram of (a) THH-VCSOA structure and its contact configuration and (b) potential distributions along p-channel and n-channel. In the region of $V_p > V_n$, the device is forward biased, while in the region of $V_n > V_p$, the device is reverse biased.

Figure 2 Integrated electroluminescence intensity of bidirectional field effect light-emitting and light-absorbing heterojunction device (for both voltage polarities). Temperatures of $T = 100$ and $300$ K.

Figure 3 EL spectra of bidirectional THH-VCSOA-based GaInNAs/GaAs structures at different temperatures. The inset shows the temperature dependence of the peak energy (filled squares) compared with the Varshni equation (dotted lines).
length 0.6 mm and an n-channel of length 1 mm. Under normal operational conditions, contacts 1 and 2 are biased with either positive polarity (+V) or negative polarity (−V) while contacts 3 and 4 are both connected to the ground.

When the device is biased with (+V), as shown in Figure 1b, the potential near contact 2 \( (I_2) \) is higher in the p-channel than in the n-channel \( (V_p > V_n) \). This forward-biased region operates as a light emitter. In contrast, near contact 3 \( (I_3) \), \( V_p < V_n \) and this region is effectively reverse biased, which forms the absorption section. Thus, the device can absorb light with photon energies of \( h\nu_0 \) where \( h\nu_0 > E_g \) and emit light with photon energies of \( h\nu_1 \sim E_g \). The polarity of the applied bias can be interchanged leading to the reversing of the absorption and emission regions.

The emitted light from the sample surface was collected and dispersed using a cooled photo multiplier and monochromator assembly. The output signal was filtered using an EG&G 162 boxcar averager with gated integrator. An Argon laser of wavelength \( \lambda = 488 \text{ nm} \), using variable powers, is used as the light source in the absorption experiments. External bias was applied in a pulsed mode between contacts 1 and 4, and 2 and 3 of the top-hat-shaped device. The device resistance depends on the device dimensions and can be as high as 1.0 KΩ in devices with long channel lengths. The applied voltage pulses were 50-μs wide with a repetition time of 10 ms defining a duty cycle of \( 5 \times 10^3 \).

**Results and discussion**

Figure 2 shows integrated EL intensity as a function of applied voltage for both voltage polarities. The EL was measured using voltage pulses of widths and repetition times of about 50 μs and 9 ms, respectively, to avoid excessive Joule heating. It is clear that the light intensity is

![Figure 1](image1.png)  
**Figure 1** Temperature-dependent amplified signal of bidirectional THH-VCSOA structure.

![Figure 2](image2.png)  
**Figure 2** Amplified intensity as a function of applied voltages between 30 and 200 V at \( T = 300 \text{ K} \).

![Figure 3](image3.png)  
**Figure 3** PL, EL, and EPL spectra of THH-VCSOA at \( T = 300 \text{ K} \).

![Figure 4](image4.png)  
**Figure 4** Gain versus incident power using various applied voltages at \( T = 300 \text{ K} \).
independent of the polarity. The threshold voltages \( V_{th} \) of the bidirectional device are \( V_{th} \) approximately 50 V at \( T = 300 \) K and \( V_{th} \) approximately 4 V at \( T = 100 \) K.

Figure 3 shows the EL emission spectra as a function of temperature. The peak wavelengths at \( T = 150 \) and 300 K are around \( \lambda = 1,236 \) and 1,288 nm, respectively. Theoretically, a red shift of the active material peak wavelength with temperature at a rate of 0.38 nm/K is predicted. We compare the experimental peak emission energy versus the temperature plot with the Varshni equation:

\[
E_g(T) = E_0 - \alpha T^2 / (T + \beta),
\]

where \( E_0 \) and \( E_g(T) \) are the bandgaps at \( T = 0 \) K and at a finite temperature of \( T \), respectively and \( \alpha \) and \( \beta \) are around \( 4.8 \times 10^{-4} \) eV·K\(^{-2}\) and 284 ± 167 K, respectively [12,13].

The device was mounted on a temperature-controlled holder at varied temperatures. External voltage pulses up to 110 V were applied between the diffused contacts and the integrated EPL intensities of the THH-VCSOA are measured as a function of bias voltage with the photoexcitation power was kept constant at around 17 mW. In Figure 4, we show the peak intensities of EPL signals for both positive and negative polarities at \( T = 14^\circ\)C and for positive polarity at temperatures of \( T = 30 \) and 44\(^\circ\)C.

Amplified spectra are plotted as a function of applied voltages in Figure 5. It is clear from the figure that as the applied voltage increases, the integrated intensity increases with the emission peak at around 1,280 nm.

The spectra of EL, PL, and the combined EPL of bidirectional THH-VCSOA device at 1,280 nm are shown in Figure 6. The spectra have a broad bandwidth due to the fact that light was collected from the whole forward-rectangular THH-VCSOA device at 1,280 nm. The input signal of 488 nm is absorbed by the THH device, causing a modulation of the 1,280-nm biased area. The input signal of 488 nm is absorbed by the THH device, causing a modulation of the 1,280-nm biased area. The input signal of 488 nm is absorbed by the THH device, causing a modulation of the 1,280-nm biased area.

Conclusions

The operation of bidirectional THH-VCSOA-based Ga\(_{0.35}\)In\(_{0.65}\)N\(_{0.02}\)As\(_{0.08}\) at a wavelength of 1,280 nm has been demonstrated. Maximum optical gain of about 5 dB is observed at \( V_{app} = 80 \) V and at \( T = 300 \) K. Therefore, we conclude that the THH-VCSOA device is a bidirectional field-effect light-emitting and light-absorbing heterojunction and can work as an optical amplifier and wavelength converter in the 1.3-\( \mu \)m wavelength regime. The performance of the device can be improved by reducing the dimensions of the device, so that high electrical fields can be reached by the application of small voltages.

Abbreviations

DBRs: distributed Bragg reflectors; EL: electroluminescence; EPL: electrophotoluminescence; HELLISH: hot electron light-emitting and lasing in semiconductor heterostructure; MBE: molecular beam epitaxy; PL: photoluminescence; THH: Top-Hat HELLISH; QWs: quantum wells; VCSOA: vertical-cavity semiconductor optical amplifier.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

NB and FAIC designed the structure. FAIC fabricated the devices and carried out the experimental work and wrote the article. NB is the inventor of the original device and the overall supervisor of the project. Both authors read and approved the final manuscript.

Acknowledgements

FAI Chaqmaqchee is grateful to the Ministry of Higher Education and Scientific Research of IRAQ for their financial support during her study at the University of Essex. We are grateful to the Institute for Systems Based on Optoelectronics and Microtechnology in Madrid for their assistance with the device fabrication. The authors are also grateful to Professor Mark Hopkinson and Dr. Maxim Hughes for growing the structures. Finally, we would like to thank the COST MP0805 for the collaborative research.

Author details

1. University of Koya, Faculty of Science and Health, Kurdistan Region, Koya
KOY45, IRAQ. 2. School of Computer Science and Electronic Engineering, University of Essex, Colchester CO43SQ, UK.

Received: 17 September 2013 Accepted: 3 January 2014

References

1. Björnlin ES, Geske J, Bowers JE: Optically preamplified receiver at 10 Gbit/s using vertical-cavity SOA. Elect Lett 2001, 37:1474–1475.
2. Suzuki N, Chashi M, Nakamura M: A proposed vertical-cavity optical repeater for optical inter-board connections. IEEE Photon Technol Lett 1997, 9:1149–1151.
3. Bouche N, Corbett B, Kuszelewicz R, Raj R: Vertical-cavity amplifying photonic switch at 1.5 \( \mu \)m. Photon Technol Lett 1996, 8:1035–1037.
4. Björnlin ES, Dahl A, Pirkjek J, Abraham P, Chiu Y-J, Bowers JE: Vertical-cavity amplifying modulator at 1.3 \( \mu \)m. Photo Technol Lett 2001, 13:1271–1273.
5. Alexandropoulos D, Adams NJ: GainNAs-based vertical cavity semiconductor optical amplifiers. J Phys Condens Matter 2004, 16:53345–53354.
6. Pirkjek J, Björnlin S, Bowers JE: Design and analysis of vertical-cavity semiconductor optical amplifiers. IEEE J Quantum Electron 2001, 37:127–134.
7. Wahl JY, Balkan N: Low field operation of hot electron light emitting devices: quasi-flat-band model. IEE Proc Optoelectron 2004, 151:482–485.
8. O’Brien A, Balkan N: Ultra bright surface emission from a distributed Bragg reflector hot electron light emitter. Appl Phys Lett 1997, 70:266.
9. Sceats R, Balkan N: Hot electron light emission at 1.3 \( \mu \)m from a GainAs/InP structure with distributed Bragg reflectors. Phys Stat Sol 2003, 198:495–502.
10. Chaqmaqchee FAI, Mazzucato S, Oduncuoglu M, Balkan N, Sun Y, Gunes M, Hopkinson M: GainNAs-based HELLISH vertical cavity semiconductor optical amplifier for 1.3 \( \mu \)m operation. Nanoscale Res Lett 2011, 6:1–7.
11. Chaqmaqchee FAI, Balkan N, Herrero JM: Top-Hat HELLISH-VCSOA for optical amplification and wavelength conversion for 0.85 to 1.3 \( \mu \)m operation. Nanoscale Res Lett 2012, 7:1–6.
12. Wah JY, Loubet N, Potter RJ, Mazzucato S, Arnoult A, Carrere H, Bedel E, Marie X, Balkan N: Bi-directional field effect light emitting and absorbing heterojunction with Ga0.8In0.2N0.015As0.985 at 1250 nm. IEE Proc Optoelectron 2003, 150:72–74.

13. Varshni YP: Temperature dependence of the energy gap in semiconductors. Physica 1967, 34:149–154.

doi:10.1186/1556-276X-9-37
Cite this article as: Chaqmaqchee and Balkan: Ga0.35In0.65N0.02As0.08/GaAs bidirectional light-emitting and light-absorbing heterojunction operating at 1.3 μm. Nanoscale Research Letters 2014 9:37.