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# Ga<sub>0.35</sub>In<sub>0.65</sub>N<sub>0.02</sub>As<sub>0.08</sub>/GaAs bidirectional light-emitting and light-absorbing heterojunction operating at 1.3 μm

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## 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 Ga<sub>0.35</sub>In<sub>0.65</sub>N<sub>0.02</sub>As<sub>0.08</sub>/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.

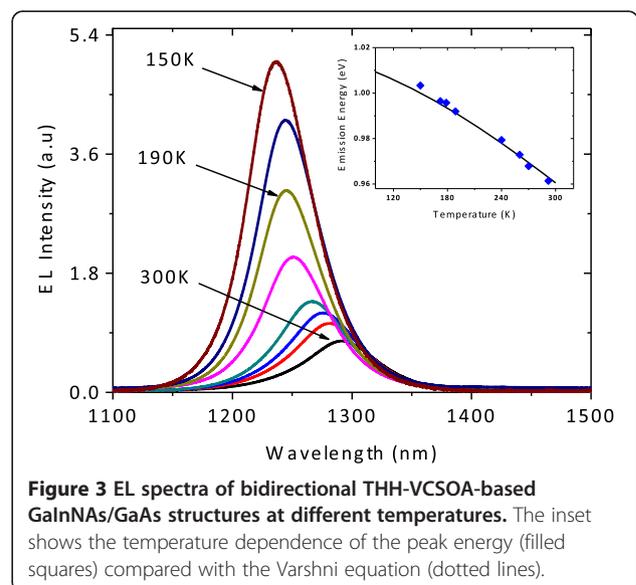
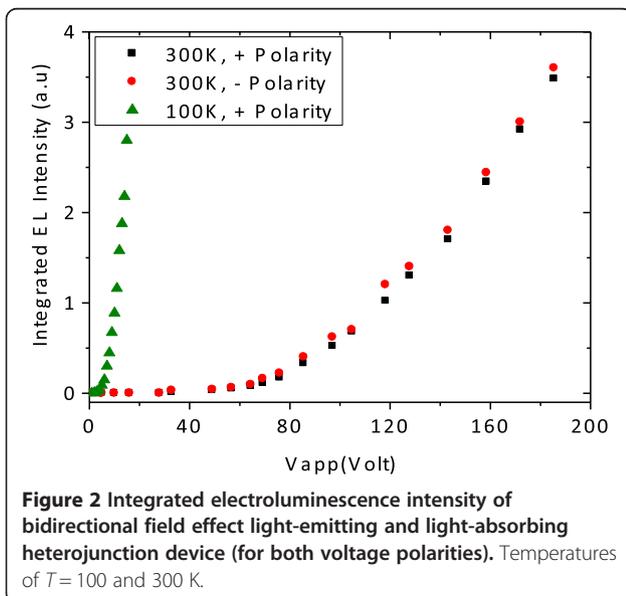
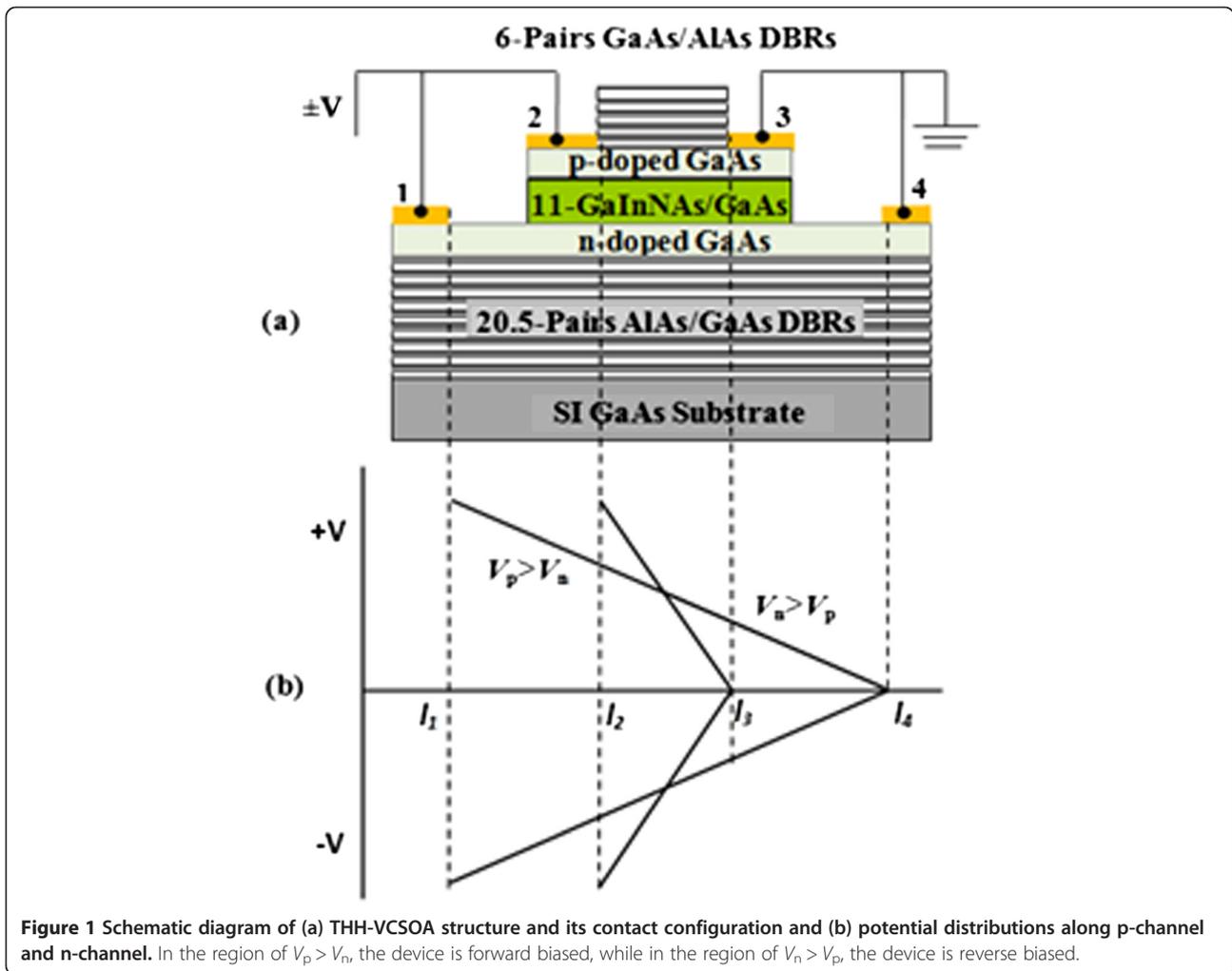
## Methods

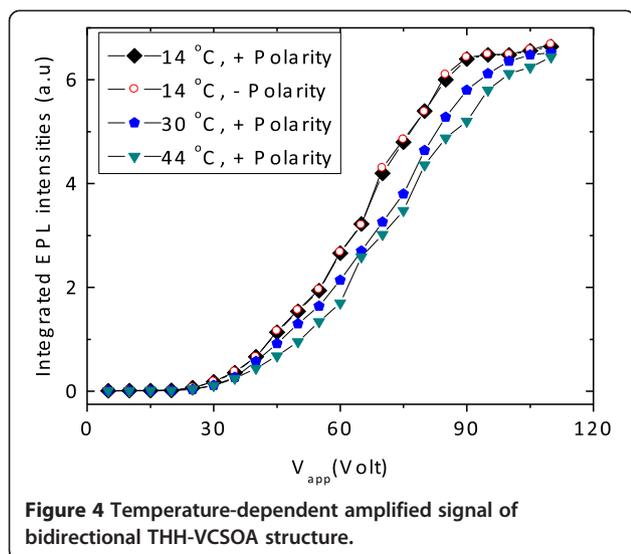
The device of THH-VCSOA with the code VN1520 was grown by molecular beam epitaxy (MBE) on a semi-insulating GaAs substrate. Figure 1a shows the sample structure. Eleven Ga<sub>0.35</sub>In<sub>0.65</sub>N<sub>0.02</sub>As<sub>0.08</sub>/GaAs QWs were used in the active region to supply enough gain at 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

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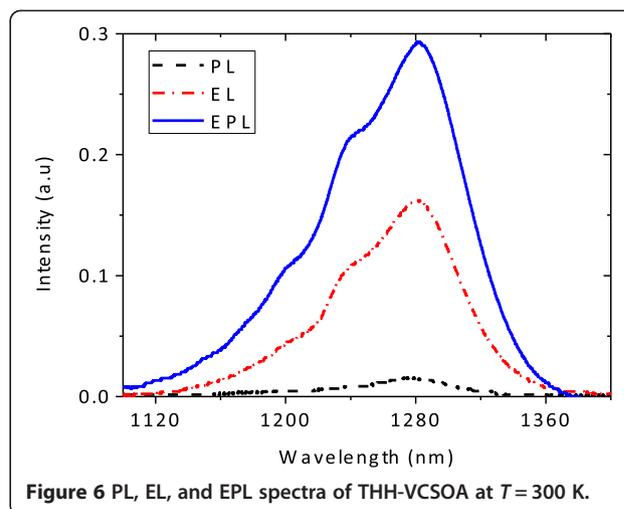
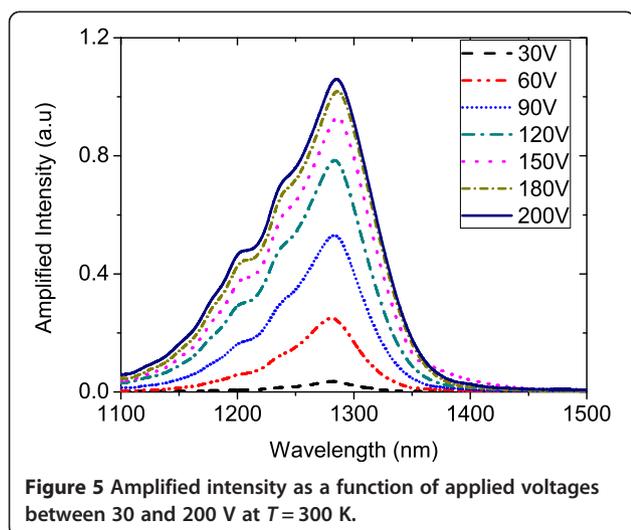




length 0.6 mm and an n-channel of length 1 mm. Under normal operational conditions, contacts 1 and 2 are biased with either positive polarity (+V) or negative polarity (-V) while contacts 3 and 4 are both connected to the ground.

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.

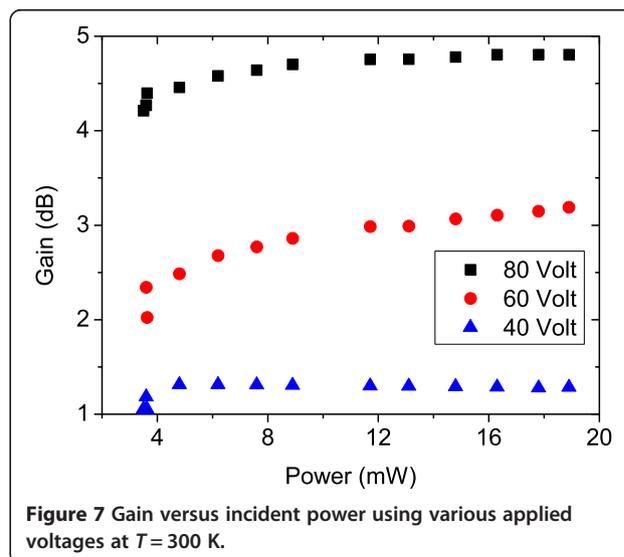
The emitted light from the sample surface was collected and dispersed using a cooled photo multiplier and



monochromator assembly. The output signal was filtered using an EG&G 162 boxcar averager with gated integrator. An Argon laser of wavelength  $\lambda = 488$  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 K $\Omega$  in devices with long channel lengths. The applied voltage pulses were 50- $\mu$ s 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  $\mu$ s and 9 ms, respectively, to avoid excessive Joule heating. It is clear that the light intensity is



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  $\cdot$  K $^{-2}$  and  $284 \pm 167$  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-VCSSOA are measured as a function of bias voltage with the photo-excitation 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  $T = 14^\circ\text{C}$  and for positive polarity at temperatures of  $T = 30$  and  $44^\circ\text{C}$ .

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-VCSSOA 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-biased area. The input signal of 488 nm is absorbed by the THH device, causing a modulation of the 1,280-nm light, thus acting as a wavelength converter. In EPL, the device is optically but also electrically pumped, with  $V_{app} = 80$  V in amplitude. The EL spectrum alone was also measured with  $V_{app} = 80$  V and the difference between EL + PL and EPL intensities is accountable for the gain from the device. Optical gains versus incident powers at various applied voltages are depicted in Figure 7. At  $T = 300$  K, maximum gains of around 1.3, 3.3, and 5 dB at  $V_{app} = 40, 60,$  and  $80$  V, respectively, are observed.

## Conclusions

The operation of bidirectional THH-VCSSOA-based  $\text{Ga}_{0.35}\text{In}_{0.65}\text{N}_{0.02}\text{As}_{0.08}$  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-VCSSOA 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- $\mu\text{m}$  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; VCSSOA: 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 Action MP0805 for the collaborative research.

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Received: 17 September 2013 Accepted: 3 January 2014

Published: 17 January 2014

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doi:10.1186/1556-276X-9-37

**Cite this article as:** Chaqmaqchee and Balkan: **Ga<sub>0.35</sub>In<sub>0.65</sub>N<sub>0.02</sub>As<sub>0.08</sub>/GaAs bidirectional light-emitting and light-absorbing heterojunction operating at 1.3 μm.** *Nanoscale Research Letters* 2014 **9**:37.

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