Single-mode heterogeneous III-V/Si_3N_4 laser

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Abstract: We demonstrate a single-mode laser based on a III-V semiconductor optical amplifier, heterogeneously integrated on a silicon nitride chip by micro-transfer printing, and adiabatically coupled to a silicon nitride waveguide cavity through an intermediate layer of hydrogenated amorphous silicon. Single-mode lasing with an on-chip power of 0.6 mW at 1569 nm is achieved using the combination of a microring resonator and a distributed Bragg reflector.

1 Introduction

In recent years, external cavity lasers using integrated silicon nitride waveguide feedback circuits have been demonstrated with fundamental linewidths down to less than 1 kHz [1]. The use of high-Q resonators and long optical delay lines in these integrated external cavities are enabled by the ultra-low waveguide losses of the order of 10 dB/m or less, that can be achieved on silicon nitride integrated circuits nowadays [2]. Initial device demonstrations using silicon nitride cavities used external III-V reflective semiconductor optical amplifiers (RSOAs), interfaced with the silicon nitride feedback circuit through edge coupling [3]. Recently, techniques are being explored for a more intimate integration of the active III-V components on the silicon nitride circuits. This includes hybrid techniques such as flip-chip integration [4] as well as heterogeneous integration schemes based on wafer bonding [5] and micro-transfer printing [6]. Lasers exhibiting a low fundamental phase noise are an important component for coherent communications with high data rates, as well as for the optical generation of low-noise microwave and mm-wave signals for radio-over fiber applications. In this work, we demonstrate a heterogeneously integrated laser comprising of a III-V semiconductor optical amplifier which is adiabatically coupled to a silicon nitride waveguide circuit. The laser is designed as a component for the optical generation of mm-wave signals up to 500 GHz for future wireless applications.

2. Laser design and measurement

A laser cavity was designed for single-mode lasing with cavity mirrors, optical delay and spectral filters in the Si_3N_4 layer. The fabrication procedure is the same as in [6]. A 1348-µm-long optical amplifier with a 900-µm-long central section provides the gain. A schematic layout of the laser is shown in Fig. 1. On one side, the amplifier is connected to a broadband distributed Bragg reflector (DBR) grating by a 5-mm-long single-mode Si_3N_4 waveguide. The DBR mirror is designed to have a reflection band of 4 nm wide around a central wavelength of 1570 nm, which corresponds to around 500 GHz. On the other side of the amplifier, a microring resonator (MRR) acts as a spectral filter, reflecting only narrow frequency bands. The MRR is designed to have a free spectral range (FSR) of 4.1 nm, such that only one of its resonances lies within the reflection band of the DBR. Furthermore, the width of the resonance has to be sufficiently narrow to avoid two longitudinal modes to start lasing. The longitudinal mode spacing in the cavity is estimated to be 76 pm or 9.3 GHz at 1570 nm. The gap between the bus waveguide and the ring is chosen to target a power coupling coefficient of 3%. Assuming losses of 1.1 dB/cm, the ring is undercoupled, which will result in narrow resonance bandwidths, facilitating single-mode operation at the cost of a lower mirror reflectivity. A directional coupler between the ring resonator mirror and the amplifier extracts 20 % of the optical power. In this first demonstration, heaters for tuning were not added yet. However this design which uses only one MRR, would allow to tune the lasing wavelength across the 500 GHz reflection range of the DBR using only two heaters: one on the MRR and one on the optical delay line. Beating the output of two such lasers would allow to generate microwave signals between 0 GHz and 500 GHz.

3. Results and discussion

The laser is characterized by measuring the optical output power and spectrum as a function of bias current at 20°C. The measured voltage and on-chip optical output power are plotted against the bias current in Fig. 2, as well as the recorded lasing wavelengths. An on-chip output power of 0.6 mW was achieved at a wavelength of 1569 nm. Mode-hopping takes place every 7-14 mA, mainly due to refractive index changes in the amplifier. The modes hop maximally 60 ± 10 pm, which confirms our estimation of the FSR of the cavity. Just above threshold, the slope efficiency is 0.021 W/A. A lasing spectrum showing single-mode operation for a bias current of 158 mA at 20°C is shown in Fig. 3. The inset shows the RF spectrum of the beat note of our device with an external laser. If multiple adjacent longitudinal modes would be able to start lasing, extra peaks would be expected with a spacing of around 9 GHz. Only one peak is visible in the spectrum with a signal-to-noise ratio of >30 dB, confirming the single-mode behaviour of our device. The reflection band of the DBR, spanning from 1565 nm to 1569 nm, can be discerned in the ASE background on the optical spectrum. From the ratio between the two outputs, it is clear that the losses in the MRR are higher than expected. Measurement of the separate test structure confirms that the waveguide loss in the ring is around 8 dB/cm. This is due to the 50 μm bending radius of the ring, which appears to cause radiative losses.

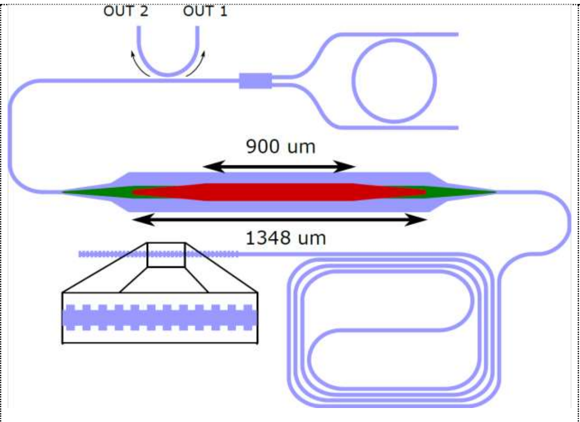

Figure 1: Schematic layout of the laser cavity design. Red = III-V SOA; green = intermediate hydrogenated amorphous silicon; blue = silicon nitride.

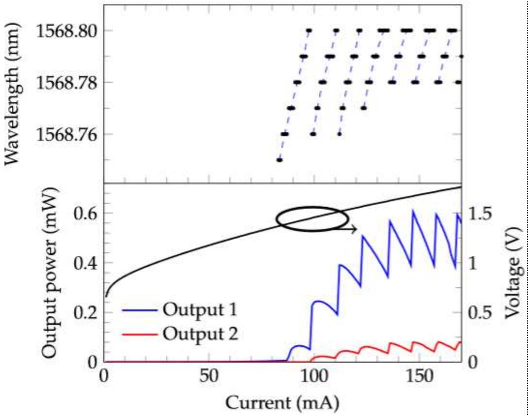

Figure 2: Power-current and voltage-current curves of the device and the corresponding lasing wavelengths. The dashed blue lines serve as a guide to the eye.

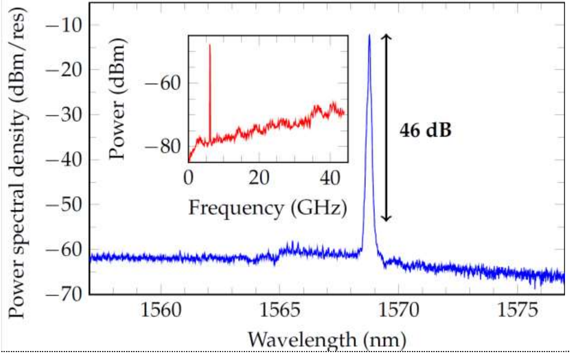

Figure 3: Lasing spectrum for a bias current of 158 mA at 20°C, recorded with a resolution of 50 pm. The side-mode suppression ratio is 46 dB. The reflection band of the DBR mirror is clearly visible in the noise floor. The inset shows the electrical spectrum of the beat note of the device's output with an external laser.

4. Conclusion

A design of a heterogeneously integrated laser on silicon nitride for the generation of microwave signals up to 500 GHz was demonstrated. Single-mode lasing is achieved using only one MRR, allowing for easier tuning of the output wavelength. Reducing the losses in the ring resonator could lead simultaneously to higher output powers and more narrow spectral filtering, which would allow for longer optical delay lines in the laser cavity and hence a better phase noise performance.

5. References

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Session 2: Chair: Geert Morthier moderator: Tasfia Kabir

11:00-11:15 Introduction to the International Semiconductor Laser conference 2021, Potsdam
Paul Crump
Ferdinand Braun Institute - Berlin

11:15-11:30 Material interfaces as performance-limiting factors in high power GaAs-based diode lasers
P. Crump and G. Tränkle
Ferdinand Braun Institute - Berlin

11:30-11:45 Single-Mode-Heterogeneous-III-V-Si3N4-Laser
Camiel Op-de-Beeck, Gunther Roelkens, Bart Kuyken
Photonics Research Group, Department of Information Technology - Ghent University - imec, Center for Nano- and Biophotonics - Ghent University

11:45-12:00 23.5 nm wavelength tuning of a 1550 nm VCSEL in CW operation based on the liquid crystal micro-cells technology
C. Levallois, C. Paranthoen, B. Boisnard, T. Camps, B. Sadani, K. Tavernier, S. Bouchoule, L. Dupont, M. Alouini, P. Debernardi and V. Bardinal
Univ Rennes - INSA Rennes – CNRS - Institut FOTON – UMR 6082, Univ Toulouse – CNRS - LAAS, C2N – CNRS - Université Paris-Sud, IMT Atlantique - Optics Department - Plouzané, Consiglio Nazionale delle Ricerche (CNR), IEIIT

12:00-12:30 Hybrid integrated diode lasers for the infrared and visible based on silicon nitride waveguide feedback circuits - Invited Talk
Klaus Boller
University of Twente

12:30- 13:30 Lunch break – Meet the presenters

Paul Crump

Camiel Op-de-Beeck

C. Levallois

Klaus Boller