Integrated dual-wavelength AWG laser for sub-terahertz wave generation

A. Corradi[1], G. Carpintero[2], M. K. Smit[1] and E.A.J.M. Bente[1]

[1] COBRA Research Institute, Eindhoven University of Technology, PhI Group, Eindhoven, The Netherlands
[2] UC3M, Universidad Carlos III de Madrid, Spain

We present a monolithically integrated ring dual-wavelength semiconductor laser in which both wavelengths (λ_1 and λ_2) are generated and amplified by the same semiconductor optical amplifier (SOA). An arrayed waveguide grating (AWG) is used as intra-cavity filter to combine the two wavelengths. The use of a Mach-Zehnder construction allows equalizing actively the power of λ_1 and λ_2 and tuning their frequencies. An analytical model is exploited to investigate the influence of crosstalk on the functioning of the device and to identify a calibration strategy. The device has been fabricated using active/passive integration technology on a standardized photonic integration platform.

Introduction

The development of new applications of millimeter waves (mmWs) and terahertz (THz) radiation faces a lack of sources: this frequency range is known in literature as the "terahertz gap" [1]. In this paper we report on research into the development of an integrated dual wavelength laser that can be part of a millimeter wave transmitter. The design and fabrication of the device are done using existing standardized optical semiconductor device design platform and fabrication process based on InP [2].

Photonic-based millimeter wave generation

Several techniques based on photonics to generate millimeter waves have been reported in literature [3]. These methods are all based on generating an optical carrier wave with an amplitude modulation at the required millimeter wave frequency. In most systems this light is then modulated with the data to be transmitted and directed towards a high speed photodiode (Fig. 1). The photodiode rectifies the optical signal and the resulting millimeter wave signal can then be amplified electronically and coupled to a transmitting antenna [1].
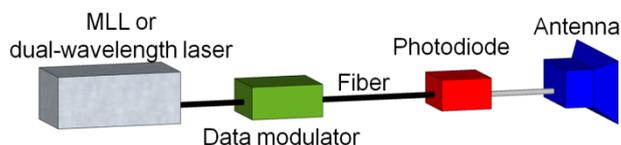
Fig. 1. Block scheme of an optical millimeter wave generator.

The main techniques for generating the modulated optical carrier are based on mode-locked lasers or optical mixing of two single frequency laser sources. The basic idea behind the work presented here is to investigate photonic integrated dual-wavelength lasers based on optical mixing in which the frequency fluctuations of the two wavelengths λ_1 and λ_2 are correlated. This can be obtained using a dual-wavelength laser in which both wavelengths are generated and amplified by one common semiconductor optical amplifier (SOA). Being amplified by the same SOA, λ_1 and λ_2 share the same variations caused by changes in refractive

index due to changes in temperature and variations in carrier concentration. As a consequence, the instantaneous deviations in frequency of λ_1 and λ_2 can be close to identical if the laser cavity length for both laser modes is similar.

Ring dual-wavelength AWG-based laser

The schematic of the presented ring dual-wavelength laser is depicted in Fig. 2. In order to achieve lasing action simultaneously on two different wavelengths supported by a single SOA, accurate control of the roundtrip loss in the cavity is required to balance the power of λ_1 and λ_2. As a consequence, part of the cavity of λ_1 must be separated from the cavity of λ_2. A control system must be added to the parts of the cavities which are not shared in order to be able to control independently the losses. The requirement on the power ratio between the two wavelengths is not particularly strict though. A power ratio of 2 for $P_{\lambda_1} / P_{\lambda_2}$ leads to a reduction in difference frequency modulation depth to 0.94 compared the ideal power ratio of 1. Balanced Mach-Zehnder interferometers (MZIs) provided with voltage controlled electro-optic phase modulators (PHMs) are used to adjust the losses in each individual channel.

An AWG is used as intra-cavity filter to combine the two channels and consequently λ_1 and λ_2. The advantages of using an AWG for this purpose and more details about the design parameters are presented in [4].
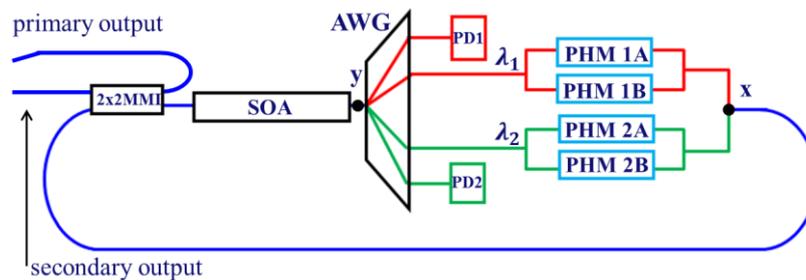

Fig. 2. Schematic of the ring dual-wavelength laser. An SOA provides gain for both wavelengths. An AWG is used as intracavity filter to combine λ_1 and λ_2. MZIs are used to compensate losses in the individual channels. A 2x2 multimode interferometer (MMI) couples the light out of the ring cavity.

In order to monitor the power balance between λ_1 and λ_2, photodiodes (PDs) are integrated and connected to the higher order outputs of the AWG. A 2x2 multi-mode interferometer (MMI) couples the light out from the ring cavity. The first output waveguides reaches the edge of the chip with a 7-degree angle in order to reduce back-reflections inside the cavity. The second output of the 2x2 MMI, instead, is connected through a straight waveguide to the edge of the chip in order to provide a considerable feedback inside the cavity and force the laser to work in clockwise direction. The reason for this design choice is to increase the signal power received by the PDs.

Calibration method and influence of crosstalk

In the ideal situation in which the AWG has no crosstalk between adjacent channels, the MZI are perfectly balanced and the PHMs have exactly the same length (and as a consequence the same voltage-to-phase relation), the control of the different signals applied to the device would be rather simple. The MZI configuration would simply allow setting a transmission loss for each channel. Furthermore an offset applied to both PHMs of the same channel would simply shift the cavity modes.

In reality, there is an optical length difference between the different PHMs and as a consequence they have different efficiency. Furthermore, a small imbalance between the two arms of the same MZI makes it is necessary to apply a difference between the two PHMs in order to achieve the maximum in the transmission function of the MZI.

The crosstalk between the two adjacent channels of the AWG also plays an important role in the functioning of the device. The crosstalk complicates the control of the laser because the two channels are not independent from each other. While adjusting losses and tuning of λ_1, also the transmission of λ_2 is affected.

Fig. 3 shows simulations of the transmission function of the filter composed of the AWG and the MZI construction (power transmission from point x to point y in Fig. 2). Two corner cases are compared. The red line refers to the following settings: $V_{1A}=V_{1B}=V_{2A}=V_{2B}= 0$ V. The blue line corresponds to $V_{1A}=V_{1B} = 0$ V, $V_{2A}=V_{2B} = V_\pi$.
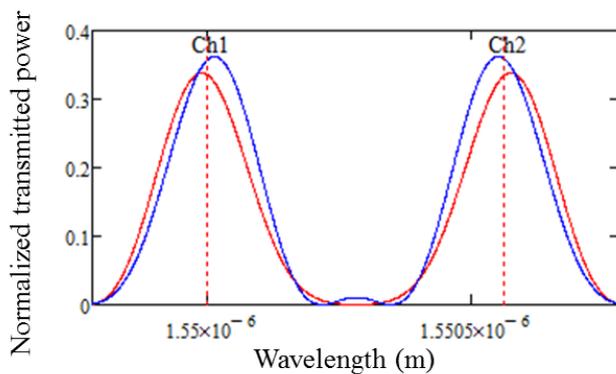

Fig. 3. Transmission function of the filter composed of the AWG and the MZI construction. The two lines represent two different voltage settings applied to PHMs.

The dash lines indicate the center of the channels of the AWG. The simulation does not take into account any imbalance among PHMs and between MZI arms.

Fig. 3 demonstrates that the settings applied to PHMs affect the transmission of the filter and in particular change the difference in frequency between the maxima of the two channels. Being the channel spacing of the AWG equal to 70 GHz, the difference in frequency between the maxima of the transmission function is 73 GHz while $V_{1A}=V_{1B}=V_{2A}=V_{2B}= 0$ V. If $V_{1A}=V_{1B} = 0$ V, $V_{2A}=V_{2B} = V_\pi$, the difference in frequency becomes 67 GHz. Above threshold, the wavelength selection of the lasing modes results from the combination between the transmission of the filter and the cavity modes.

In order to calibrate the different components of the device and be able to control the laser, the following strategy is proposed. The idea is to maximize the transmission of the two channels, one at a time, and record the settings of the PHMs. Operating sub-threshold, while three PHMs are grounded, the voltage applied to V_{1A}, for example, is scanned. Once that a maximum in the transmission of channel 1 has been found, V_{1A} is kept fixed and V_{1B} is scanned. Afterwards, also the settings of PHM 2A and 2B are controlled and the transmission through channel 1 is optimized. The same procedure has to be applied to channel 2.

This method allows finding possible imbalances in the MZIs, differences in the efficiency of the PHMs and the value of V_π for each PHM.

Preliminary results

All the results reported in this section have been obtained at a temperature of 14°C of the actively cooled aluminum chuck on which the chip is mounted. The SOA, the PHMs and the PDs on the chip are wire bonded to a simple circuit board from which connections to the current and voltage suppliers are made. The threshold current of the

laser is 130 mA. As expected, while biasing the common SOA without balancing the losses in the different channels using the MZIs, the device lases in a single mode; the modes in the other channel are suppressed. The mode spacing matches the expected value of 6.0 GHz being the cavity length 14 mm long.

The output power collected from the actual output waveguides is considerably higher than the output power collected from the secondary output (power difference higher than 30dB while biasing at 180 mA), demonstrating that the asymmetric output configuration successfully forces the laser to work in clockwise direction.

Fig. 4a shows that, adjusting the voltage values applied to the PHMs, the losses in the two channels can be balanced and dual-mode operation can be achieved. However, a power difference of 5 dB is still present between λ_1 and λ_2 meaning that the settings are not optimized. The frequency difference between the two lasing wavelengths is 61.8 GHz, considerably smaller than the designed channel spacing of the AWG. This is due to the influence of the crosstalk as explained in the previous paragraph but also to the fact that the actual channel spacing of the AWG is smaller than the designed value (65 GHz instead of 70 GHz).

Fig. 4b shows the power at a specific wavelength (1532.9 nm) as a function of the V_{1A} when the device is biased sub-threshold at I = 125 mA. This explains how the voltage applied to the PHM influences the transmission through the channels. A value of V_π equal to 3.9 V is measured.
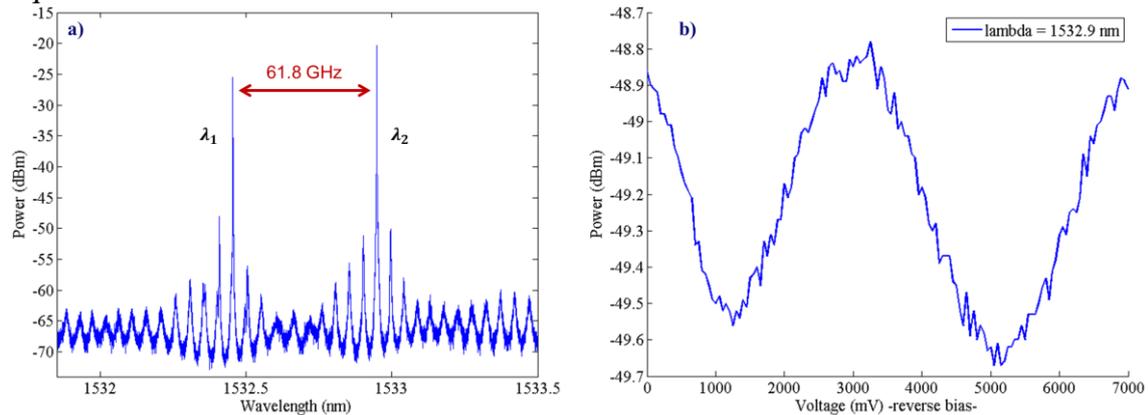

Fig. 4. a) Output spectra of the ring laser while operating in dual-mode. b) Power at λ=1532.9 nm as a function of V_{1A} while biasing at I = 125 mA.

Acknowledgements

References

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