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Integrated dual wavelength lasers for millimeter wave generation

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We have designed integrated dual-wavelength lasers in which an array waveguide grating is used as intra-cavity filter to allow lasing on two wavelengths within a common arm of the device. The devices have been designed with the purpose to exploit the beating of the two wavelengths on a photodiode in order to generate a 70GHz carrier wave. The use of a common SOA to amplify both wavelengths is promising for reducing the variations in frequency difference between the two operating laser modes. Both linear and ring configurations have been explored.

Introduction

The market potential for systems that can provide short range communications with data rates above 1 Gbp/s is increasing [1]. To achieve this, the carrier frequency has to increase into the range of mm waves (30 GHz – 300 GHz) [2]. In this region of the spectrum, ranges are available where e.g. fog, rain and smoke can be penetrated and a sufficiently large distances can be covered. However millimeter waves can be used in applications other than communication technology. Waves in these frequency ranges can also be exploited for surveillance aims [2] and recently these frequencies have been used in imaging systems for microcrack detection in concrete structures to detect potential damage [4].

The traditional electronic approach to sub-terahertz generation is based on frequency multiplying chains of microwave oscillators [5]. Unfortunately this results on a high level of noise that makes electronic devices unsuitable for millimeter wave generation for high speed communication which requires a low phase noise. As a matter of fact, when multiplication stages are used to increase the frequency of the carrier waves, the single side band (SSB) phase noise degrades 20 dB/decade [2].

In the European Union FP7 iPHOS project, the goal is to use optical techniques to generate a 70 GHz or 120 GHz carrier wave through mixing of two low noise optical data modulated carrier frequencies on a fast photodiode coupled to an antenna. The work described in this paper concerns the development of a single semiconductor chip containing a laser source, that produces the two optical carrier waves with a stabilized frequency difference that is tunable around 70 GHz, and a data modulator system.

Dual wavelength AWG-based laser

The requirements on the two wavelength sources depend on the exact value of the communication speeds and modulation formats, however the main points can be identified as follows. The source needs to produce two wavelengths separated by a frequency that can be tuned around 70 GHz (68-74 GHz e-band). Power in both wavelengths should be equal with a total output power of 10mW. The phase noise in the frequency difference signal of < 90 dBc/Hz at 100 kHz would be suitable for a communication speed filling the whole band. This can be realized by using lasers with a free running laser linewidth of several hundreds of kilohertz and then stabilizing them actively to e.g. a reference etalon with a feedback loop time of approximately 5 ns.

The aim of our work is to design and fabricate an integrated dual wavelength laser in which an intracavity Arrayed-Waveguide Grating (AWG) is used to select two cavity modes. In such a device, the AWG is combined on a single chip with SOAs which provide the required gain. Our InP integration technology allows us to integrate on the same chip also electro-optic phase modulators (PHMs) and monitoring photodiodes (PDs) in order to stabilize and fine tune the frequencies. An AWG-based laser (AWGL) has several advantages over other multi-wavelength lasers and discrete tunable lasers (e.g. DFB lasers). Firstly, it has the ability to deliver light at the available wavelengths simultaneously and efficiently into the same output waveguide. Secondly the fine tuning of the wavelength can be done through a PHM which is voltage controlled. Since the current through this type of PHM is typically in the nA to μA range, low power (in the order of μW) is needed to control it. As a consequence, the heat dissipation in the PHM is negligible and only a minor effect occurs on the amplification required in the cavity. Thirdly, the coarse tuning of the two wavelengths is determined by the same filter (AWG). When the temperature of the AWG filter changes, the frequency difference between its transmission channels will not change in first order. In fourth place, the layout of the laser can be made such that both wavelengths are amplified by the same optical amplifier. In this way many sources of the frequency noise of the laser output are shared. Consequently, the noise level of the difference frequency between the two wavelengths supported will be considerably lower than that one which would result from the beating between two wavelengths amplified by two independent SOAs.

Design choices

In order to integrate active and passive components on the same chip, layerstacks with different-bandgap materials have to be combined on the same wafer. For the fabrication of the wafers, the butt-joint integration approach was used. The active-passive scheme allows the integration of SOAs, PHMs, monitoring photodiodes and optics for wavelength stabilization. Three different type of wafers are being used for fabrication. These wafers differ in the gain material structure: 4-Quantum-Well, 2-QW and single-QW. 4-QW active-layer devices will provide higher power whereas single-QW devices are expected to perform with a lower noise level due to the lower ASE intensity (at the same length).

We have designed three types of integrated dual-wavelength lasers in which an AWG is used as intra-cavity filter to allow lasing on two wavelengths within a common arm of the device: two devices are linear lasers and the third one is a ring laser. In the following we will focus on one of the linear laser designs.

The schematic of a linear AWGL configuration is depicted in Figure 1. The cavity contains, from right to left, an SOA which amplifies both wavelengths and an AWG with 70 GHz channel spacing and a free spectral range (FSR) of 8.96 nm. Two of the AWG channels are connected, through a waveguide, to a balanced Michelson interferometer (MI) containing a PHM in each arm. Photodiodes are connected to a higher order output of the AWG. These can monitor the power in each of the two wavelengths.

The wavelength selection results from the combination between the transmission of the AWG and the cavity modes. In principle, the fine tuning of the cavity resonance of each of the two wavelengths can be done using a single PHM in the cavity. However, the fact that we have two wavelengths being amplified in the same SOA means that we have to equalize the power in the two wavelengths actively. This is achieved using the MI configuration which allows to set a transmission loss for each wavelength channel. The MIs will be actively controlled by signals derived from the monitor photodiodes. Each MI can also be used to tune the optical length of the cavity by applying an offset voltage to both PHMs. This tuning is limited by the side-mode suppression required in the output of each channel. The tuning range will depend on the channel width of the AWG and the cavity length. Although this stabilization technique results in a more complex design, using the same amplifier for two wavelengths gives the advantage to have the same carrier densities and the same variations in ASE for both wavelengths (the wavelengths separation is so small that they can be considered to be inside a homogeneous gain range). In principle, also short amplifier sections could be used in the wavelength separated arms of the dual wavelength laser. The disadvantage is that they would introduce noise in the optical path length of the arms and thus noise in the cavity frequencies. Furthermore they would require more power.

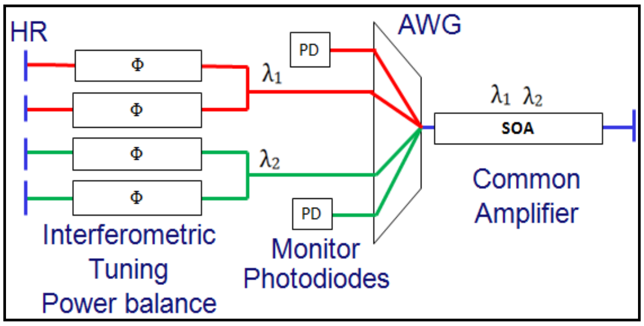

Figure 1: schematic of the linear AWG-based laser.

Device layout

In the device layout the AWG is dominant since it has a relatively small channel spacing. Furthermore, the active gain regions are in predefined positions. The mask layout for the linear laser described above is presented in figure 2 together with a picture of the device during fabrication. Two extensions can be noticed in this layout. The first is that in total four independent wavelength channels are available each at 70 GHz distance (0.56 nm). This allows for choosing the wavelengths nearest the gain maximum or to choose two wavelengths 140 GHz apart. The unwanted channels can be excluded using the MI settings.

The second extension is that this design allows to connect four waveguides with optical amplifiers to one end of the AWG. In this way four independent device configurations are available. By activating only one of these amplifiers, the absolute wavelength can be selected with one FSR and the optimal wavelength with respect to the gain peak in the amplifier can be selected.

The FSR of the AWG has been designed equal to 1120 GHz (8.96 nm) which is sufficiently large to avoid lasing effects at higher orders of the AWG. The cavity length of the linear AWGLs is 9-10 mm, thus for these devices a mode spacing of approximately 4 GHz is predicted. The channel width FWHM of the AWG is designed to be 36 GHz. Only small loss differences (~0.1 dB) are needed to suppress other modes. Laser simulations show that such a channel width provides sufficient suppression of the longitudinal side modes of the cavity. These simulations are also used to demonstrate the tuning and loss control using the MIs. The length of the PHMs has been chosen around 2 mm in order to make sure that a 2π phase shift can be obtained with reverse voltage lower than 6 V (a linear phase shift efficiency around 0.33rad/V·mm single path is expected). Since both wavelengths are tunable over at least half the cavity-FSR, the frequency difference between the two wavelengths generated can be tuned over a significant portion of the relevant mm-wave frequency band and probably over the full band. Furthermore the switching speed of the PHMs in reverse bias can be up to several tens of GHz [6].

The use of control elements as data modulators will be investigated. Integrated MIs have been used as data modulators in [7].

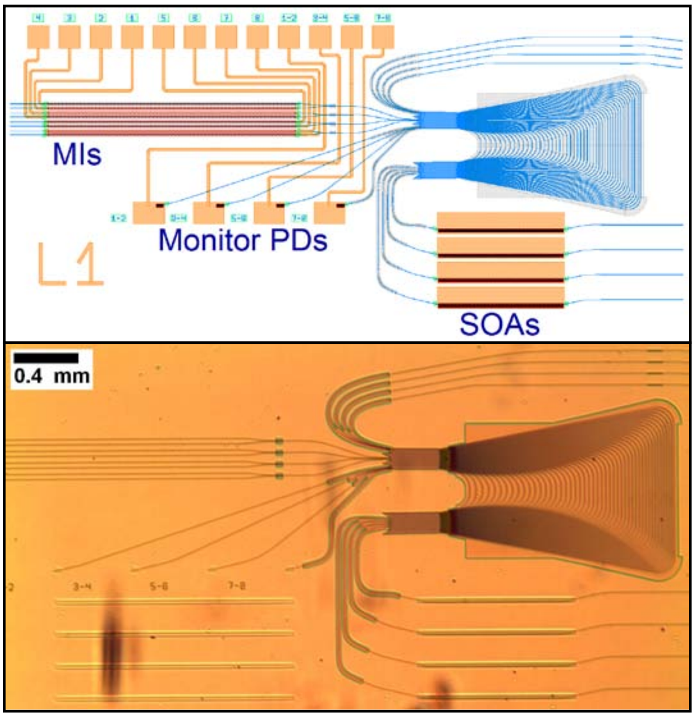

Figure 2: mask layout of a linear AWG-based laser (top) and picture of the devices during fabrication (bottom). Active regions, waveguide pattern and deeply-etched areas can be noticed.

On the same mask-set, a design corresponding to the “equivalent ring configuration” of the linear AWG-based laser has also been included. The ring laser will be used to investigate and to exploit the predisposition for single-mode lasing of ring cavities. The cavity of the ring AWG-based laser is 13-14 mm which leads to a mode spacing around 5.5 GHz. Several versions of ring AWG-based laser with slightly different design characteristics have been included in the mask-set, in particular some of them are provided with SOA and Mach-Zehnder data modulator in the output arm.

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