Integrated dual-wavelength AWG-lasers for millimeter wave generation

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Abstract— **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. Both linear and ring laser configurations have been designed.**

Keywords- millimeter waves; sub-terahertz; dual-wavelength;

I. Introduction

Millimeter wave frequencies (30 GHz - 300 GHz) are of great interest in the development of broadband wireless communication systems because they can provide short range communications with data rates above 1 Gbp/s [1, 2]. Furthermore, millimeter waves can be exploited for surveillance aims [3] and for microcrack detection in concrete structures [4].

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 and a data modulator system.

II. Dual wavelength AWG-based laser

The source has to provide 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 realised 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. 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 into the same output waveguide. Secondly, the fine tuning of the wavelength can be done through a electro-optic phase modulator (PHM) which is voltage controlled. Since the current passing 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 semiconductor optical amplifier (SOA). 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.

III. Design choices

Active-passive technology allows the integration of SOAs, PHMs and monitoring photodiodes (PDs) on the same chip. Three different type of wafers have been 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 amplified spontaneous emission (ASE) intensity (at the same length).

A. Linear dual-wavelength laser

The schematic of the 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. Two of the AWG channels are connected, through a waveguide, to a balanced Michelson interferometer (MI) containing a PHM in each arm. PDs are connected to a higher order output of the AWG: they monitor the power in each of the two wavelengths.

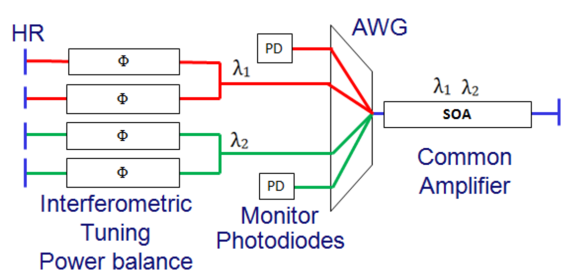

Fig.1. Schematic of the linear AWG-based laser.

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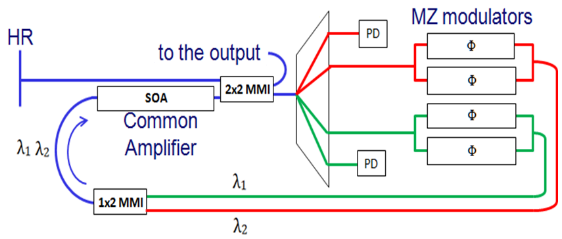

Fig.2. Schematic of the ring AWG-based laser.

The wavelength selection results from the combination between the transmission of the AWG and the cavity modes. The fact that we have two wavelengths being amplified in the same SOA means that we have to equalise 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. Although this stabilisation 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 region).

B. *Ring dual-wavelength laser*

Several versions of ring AWG-based lasers with slightly different design characteristics have been included in the mask-set. The ring devices will be used to investigate and to exploit the predisposition for single-mode lasing of ring cavities. The schematic of one of these lasers is depicted in Figure 2. An AWG is used as intra-cavity filter. Two of the AWG channels are connected to a balanced Mach-Zehnder interferometer (MZ) containing a PHM in each arm. This MZ construction is used for the fine tuning and to balance the power in the two arms. The MZs are connected, through a waveguide, to a "2 by 1" Multi-Mode Interferometer (2x1 MMI). An SOA connected to the common arm of the AWG amplifies both wavelengths. A 2x2 MMI is inserted between the common SOA and the AWG in order to extract the signal from the ring cavity. One of the output waveguides is connected to a high-reflective coated facet that acts as a mirror. The feedback signal from the facet forces the ring cavity to work in the clockwise direction. This is required in order to have light onto the photodiodes which are connected to higher order outputs of the AWG and that are monitoring the power at the two wavelengths.

IV. Device Layout

A picture of the linear laser during fabrication is presented in figure 3. 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 to choose 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 optimal wavelength with respect to the gain peak in the amplifier can be selected.

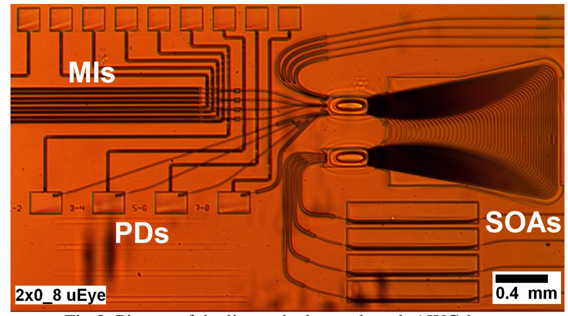

Fig.3. Picture of the linear dual-wavelength AWG-laser.

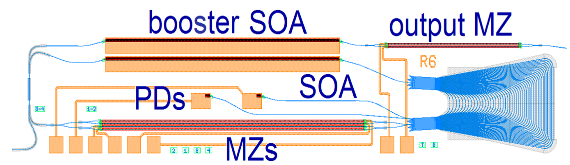

Fig.4. Mask layout of the linear AWG-based laser.

The mask layout of the ring laser is depicted in figure 4. Also in this case an extension can be noticed. The actual output waveguide is connected to a booster SOA in order to amplify the signal and then to a MZ that will be used as data modulator.

In both configurations the free spectral range (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 (ring) AWGLs is 9-10 mm (13-14 mm) thus, for these devices a mode spacing of approximately 4 GHz (5.5 GHz) is predicted. The channel width (Full-Width Half-Maximum, 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 (MZs). The length of the PHMs has been chosen equal to 2 mm for the linear device and equal to 3.3 mm for the ring laser 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 [5].

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