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Integrated dual-wavelength semiconductor laser systems for millimeter wave generation

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Abstract- We have designed and fabricated 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 amplifier of the device.

I. INTRODUCTION

Millimeter-wave frequencies (30 GHz - 300 GHz) have attracted great interest from industries involved 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].

The devices presented in this paper will be used within the European Union FP7 iPHOS project to implement an optical technique to generate millimeter waves. The idea is to create a 70 GHz carrier wave through mixing of two low noise optical carrier frequencies with data modulation 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 produce two wavelengths separated by a frequency that can be tuned around 70 GHz (68-74 GHz e-band). 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 intra-cavity 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) [5].

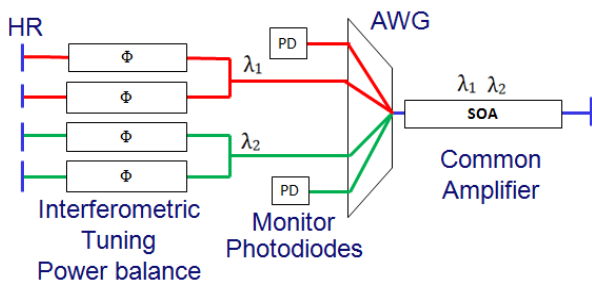


Figure 1: Schematic of the linear AWG-based laser.

III. LINEAR AND RING LASER DESIGNS

The schematic of the linear AWGL configuration is depicted in Figure 1. The cavity contains, from right to left, a semiconductor optical amplifier (SOA) which amplifies both wavelengths and an AWG with 70 GHz channel spacing and a free spectral range (FSR) equal to 1120 GHz. Two of the AWG channels are connected, through a waveguide, to a balanced Michelson interferometer (MI) containing an electro-optical phase modulator (PHM) in each arm. Monitoring photodiodes (PDs) are connected to a higher order output of the AWG: they 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 (mode spacing \approx 4 GHz since the cavity length is 9-10 mm). The channel width (Full-Width Half-Maximum, FWHM) of the AWG is designed to be 36 GHz. Only small loss differences (\sim 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 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 setting a transmission loss for each wavelength channel. The MIs will be actively controlled by signals derived from the monitor photodiodes using a specific electronic circuit. 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 ratio (SMSR) required in the output of each channel.

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 amplified spontaneous emission (ASE) for both wavelengths (the wavelengths separation is so small that they can be considered to be inside a homogeneous gain region). In this way 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.

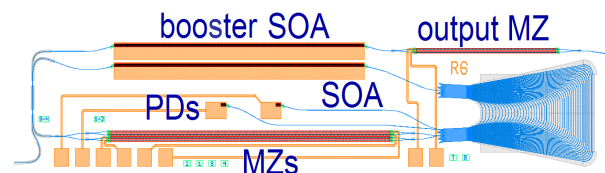


Figure 2: Mask layout of the ring AWG-based laser.

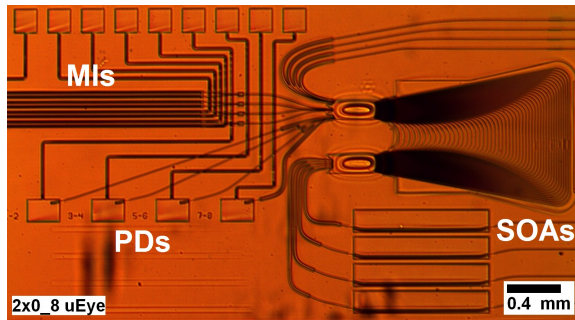


Figure 3: Picture of the linear dual-wavelength AWG-laser.

Figure 2 shows a design corresponding to the “equivalent ring configuration” of the linear AWGL. The ring lasers are provided with booster SOA and data modulator (output Mach-Zehnder modulator) and will be used to investigate and to exploit the predisposition for single-mode lasing of ring cavities.

IV. FABRICATION AND PRELIMINARY RESULTS

A first set of devices has been fabricated in our COBRA cleanroom. Our InP integration technology allow us to integrate on the same chip passive waveguides, SOAs, PHMs and PDs. Three different types of wafers with pre-defined active-passive layout have been used for fabrication. These wafers differ in the gain material structure: 4-Quantum-Well, 2-QW and single 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).

A picture of a 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 connecting four waveguides with optical amplifiers to one end of the AWG. In this way four independent device configurations are available.

A second set of linear lasers has been fabricated at OCLARO Technology Ltd. in the framework of the Paradigm FP7 EU project. These devices have a threshold current equal to 30 mA (SOA length = 500 μm). Figure 4 shows that the channel spacing of the AWG matches nicely the designed value of 0.56 nm (70 GHz). The level of power is low due to

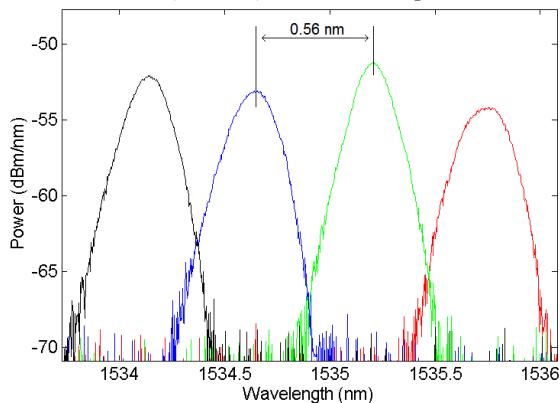


Figure 4: Spectrum of the 4 different channels of the AWG.

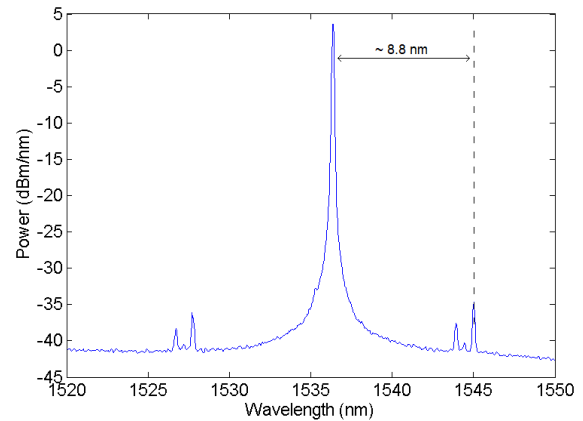


Figure 5: Spectrum from the output waveguide of the common arm of the AWGL. The MIs were not controlled.

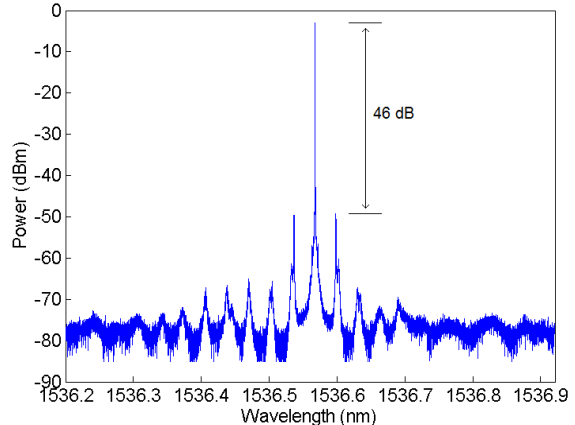


Figure 6: High resolution spectrum from the output waveguide of the common arm of the AWGL. A 46 dB SMR has been demonstrated.

the high-reflective coating of the facet corresponding to the left side of Figure 1.

Figure 5 and 6 present the spectra measured from the output waveguide of the common arm of the device while the common SOA is biased with a current equal to 60 mA. Since during this measurements the MIs were not controlled, the device was lasing through the cavity created by the channel with lower losses. Figure 5 demonstrates that the FSR of the AWG is close to the designed value (8.96 nm). The value of the FSR is large enough to keep output power at higher orders of the AWG sufficiently low. Figure 6 shows that the mode spacing corresponds to the total cavity length (4.0 GHz). Furthermore a SMR higher equal to 46 dB is demonstrated.

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