

## Characterisation of monolithically integrated dual wavelength AWG-lasers for mm-wave generation

A. Corradi<sup>1</sup>, G. Carpintero<sup>2</sup>, E. Smalbrugge<sup>1</sup>, M. K. Smit<sup>1</sup> and E.A.J.M. Bente<sup>1</sup>

<sup>1</sup> COBRA Research Institute, Eindhoven University of Technology, OED Group, Eindhoven, The Netherlands

<sup>2</sup> UC3M, Universidad Carlos III de Madrid, Spain

*In this paper we present characterisation results of monolithically integrated InP based quantum well dual wavelength lasers in which an Array Waveguide Grating (AWG) is used as intra-cavity filter to allow lasing on two wavelengths within a common optical amplifier of the device. The devices require accurate control of the optical loss of each wavelength which is achieved through the use of Michelson interferometers (MIs) in the cavity. The results show that reasonably stable dual wavelength operation is possible with a side mode suppression ratio better than 20dB for each of the two wavelengths without fast active feedback control.*

### Introduction

Millimeter-wave (mmW) 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 micro-crack detection in concrete structures [4].

The traditional electronic approach to sub-terahertz generation is based on frequency multiplying chains of microwave oscillators. 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 [5].

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 (Figure 1). The work described in this paper concerns the development of a single semiconductor chip containing a laser source and a data modulator system.

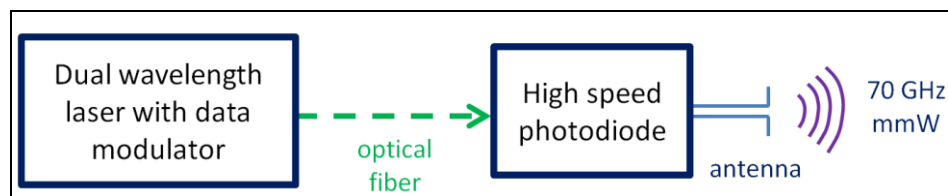


Figure 1: Block scheme of an optical mmW generator system.

### 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) [6].

### Linear and ring laser designs

The schematic of the linear AWGL configuration is depicted in Figure 2. 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. This value of the FSR should be large enough to keep output power at higher orders of the AWG sufficiently low [7]. 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 = 4.1 GHz since the cavity length is 9.8 mm). 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.

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.

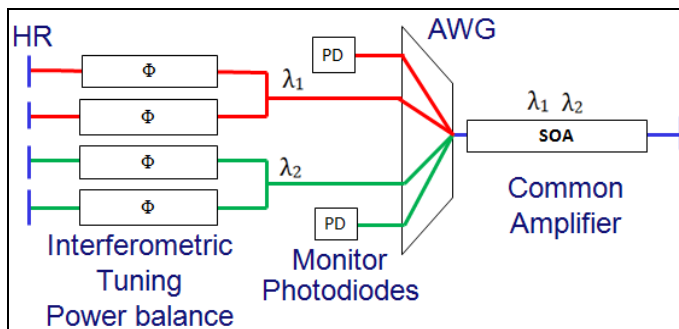


Figure 2: Schematic of the linear AWG-based laser.

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.

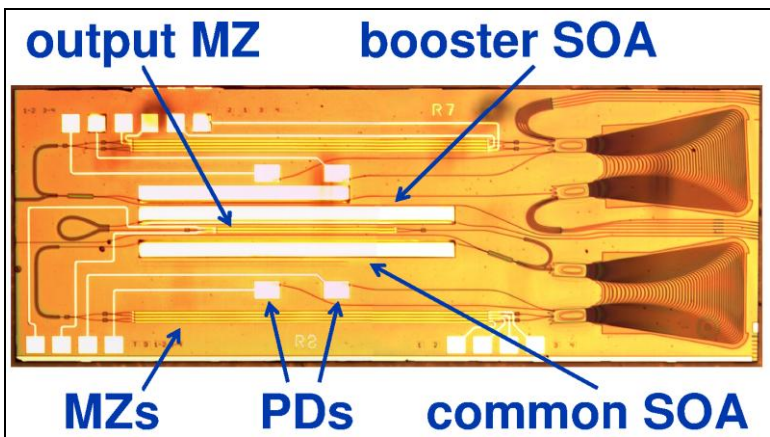


Figure 3: Picture of ring AWG-based laser chip. Two devices are present on this chip. The ring laser in the bottom part is provided with a booster SOA and an output modulator.

the predisposition for single-mode lasing of ring cavities.

### 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-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).

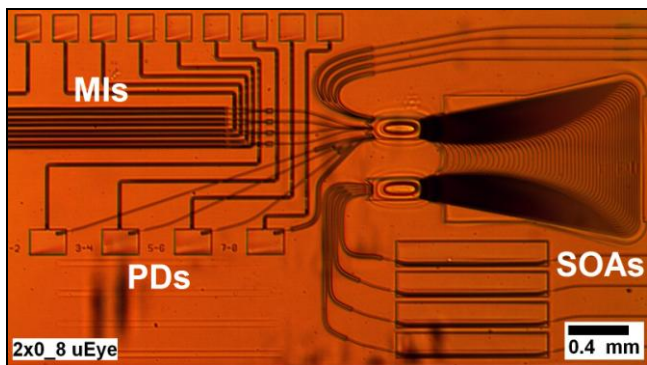


Figure 4: Picture of a linear dual-wavelength AWG-laser during fabrication.

The first extension 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 e.g. 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 Memphis FP7 EU project. These devices have a threshold current equal to 30 mA (SOA length = 500 μm). Figure 5 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 the high-reflective coating of the facet corresponding to the left side of Figure 1.

In figure 3 a picture of a two ring AWG-based lasers on one chip is shown. The design of these devices corresponds to the “equivalent ring configuration” of the linear AWGL. The ring laser in the bottom part of the picture is provided with a booster SOA and an output Mach-Zehnder data modulator. These devices will be used to investigate and to exploit

A picture of a linear laser during fabrication is presented in figure 4. 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 e.g. 140 GHz apart. The unwanted channels can be excluded using the MI

# Characterisation of monolithically integrated dual wavelength AWG-lasers for mm-wave generation

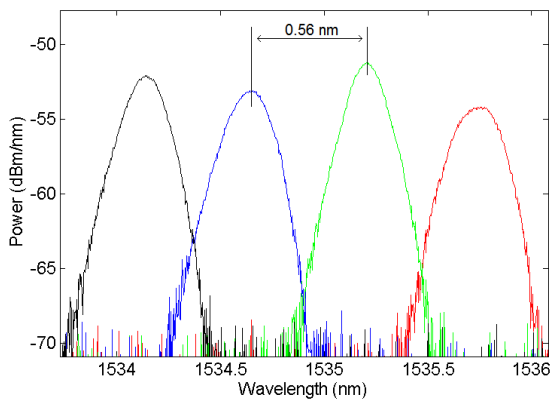


Figure 5: Spectrum of the 4 different channels of the AWG.

Manually setting the values of voltage applied to the PHMs of the MIs in each individual channel of the device, we have been able to adjust the optical losses in each channel in order to balance the power between two lasing wavelength of two different channels. Stable dual wavelength operation has been achieved not only between two neighbours channels (figure 7) but also between channels which are separated in frequency by two time and three time the channel spacing of the AWG.

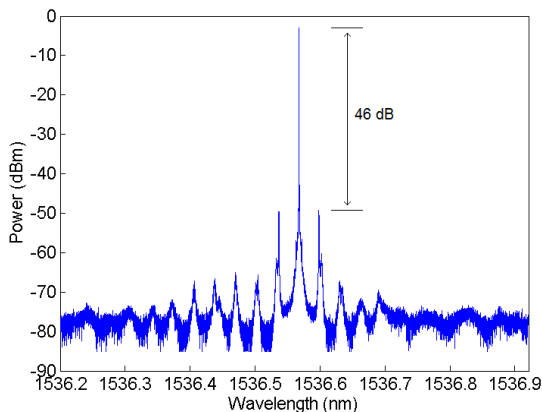


Figure 6: Optical spectrum from the output waveguide of the common arm of the AWGL. A 46dB SMSR has been demonstrated.

Figure 6 presents 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 6 shows that the mode spacing corresponds to the total cavity length (4.1 GHz). Furthermore a SMSR higher equal to 46 dB is demonstrated.

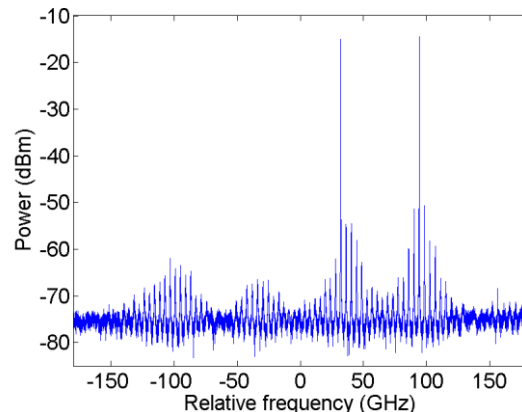


Figure 7: Optical spectrum of the laser obtained adjusting the losses in each individual channel. Dual wavelength operation has been achieved.

## References

- [1] G. Fettweis, "WIGWAM: System concept for 1Gbit/s and beyond", in IEEE 802 plenary meeting, November 2005.
- [2] C.C. Chong *et al.*, "Millimeter-wave wireless communication systems: theory and applications", in EURASIP Journal on Wireless Communications and Networking, 2007.
- [3] R. Appleby and R.N. Anderton, "Millimeter-Wave and Submillimeter-Wave Imaging for Security and Surveillance", in Proceedings of the IEEE, 95(8) pp.1683 – 1690, 2007.
- [4] S. Oka *et al.*, "Latest trends in millimeter-wave imaging technology", in Progress In Electromagnetics Research Letters, Vol. 1, 197–204, 2008.
- [5] European Union FP7 iPHOS project website [www.iphos-project.eu](http://www.iphos-project.eu).
- [6] A. Corradi *et al.*, "Integrated dual-wavelength AWG-lasers for millimeter wave generation", in Proceedings of the 16th ECIO, 2012.
- [7] G. Carpintero *et al.*, "95 GHz millimeter wave signal generation using an arrayed waveguide grating dual wavelength semiconductor laser", in Opt. Lett., vol. 37, issue 17, pp. 3657-3659 2012.