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Spectral characterisation of monolithic modelocked lasers for mm-wave generation and signal processing

P. Acedo, H. Lamela, S. Garidel, C. Roda, J.P. Vilcot, G. Carpintero, I.H. White, K.A. Williams, M. Thompson, W. Li, M. Pessa, M. Dumitrescu and S. Hansmann

The study of a monolithic multisection modelocked laser for millimetre (mm)-wave radio-over-fibre (RoF) links is reported. The longitudinal mode spectrum is studied, as is the evolution of the mode distribution with the injected current in the different sections. A stable dual-mode operation regime is identified and used to demonstrate the possibility of using this device as a compact transmitter in RoF systems incorporating optoelectronic upconversion through the injection of an intermediate frequency signal in the absorber section, while the 40 GHz mm-wave carrier is injected in the gain section. Characterisation of the modelocked laser in an analogue transmission experiment shows a spurious free dynamic range of 65 dB-Hz$^{2/3}$.

Introduction: Photonic millimetre (mm)-wave generation and all-optical upconversion are key techniques in future radio-over-fibre (RoF) systems where frequencies above 30 GHz are to be used due to spectral congestion [1]. Conventional mm-wave optical links use external modulators of both electroabsortion (EAM) and Mach-Zehnder types [2], and all-optical upconversion is usually incorporated in up- and down-optical links to obtain lower cost and compact control stations and base stations [3]. Nevertheless these schemes present low modulation efficiency, high insertion losses and the necessity of at least two photonic components in the transmitter [3].

A more compact system can be obtained using multisection semiconductor modelocked lasers where a mm-wave signal is used to stabilise the multisection laser (optical carrier generation) and data is introduced separately in another section of the device [4]. In these devices the mm-wave carrier frequency is fixed by the longitudinal mode separation of the laser cavity (around 40 GHz for a 1 mm-long cavity). A further advance is the use of dual-modelocked semiconductor structures where only two laser modes oscillate in the cavity separated by the desired mm-wave frequency [5]. This dual-mode operation is preferred in terms of RF conversion efficiency (higher modulation depth) when optical generation of mm-wave is targeted, compared to the RF carriers generated using short pulses from multimode modelocking lasers, as modulation depths of 100% are possible [6].

In this Letter we present a multisection monolithic modelocked laser for mm-wave signal generation and processing. Spectral characterisation of the output light from the laser has allowed us to identify different regimes and operation with only two longitudinal modes of equal power can be obtained for specific injection currents in the different sections. Demonstration of mm-wave generation and optoelectronic upconversion has been carried out and a spurious free dynamic range (SFDR) of 65 dB-Hz$^{2/3}$ obtained, proving the possibility of using such a monolithic device for compact, low power consumption and low-cost base stations for mm-wave RoF links.

Characterisation of monolithic multisection modelocked laser: The devices used for this work have been developed in the framework of the European IST Project MONOPLA [7] and consist of a GaInAsP/InP multiple quantum well (MQW) structure, emitting at approximately 1550 nm, and are dimensioned (length of the cavity) to achieve repetition rates of 40 GHz [8]. The device has four sections grown on the same structure: gain, extended cavity (or phase), grating, and absorber, where the active layer is all along the total length of the laser device. Each section, that can be independently biased, is active, and can participate in the light amplification. In the experiments that follow we have used the device labelled S04, which has a geometry of 300 µm gain section length, 370 µm phase section length, 200 µm grating section length, and 150 µm absorber section length.

Fig. 1 shows the optical spectrum of the device for different bias conditions using an YVON-JOBIN TRIAX 550 monochromator with 0.05 nm of resolution. In all cases the absorber section was short-circuited ($V_{abs} = 0$ V) while the other sections were biased independently. When the laser is above the threshold condition, several modes around 1565 nm wavelength appear. Separation between adjacent modes was calculated to be $f_{sep} = 39.5$ GHz, that corresponds to the designed parameters for which the device was fabricated. In Figs. 1*a–d* the current in the grating section is changed while keeping the rest of the parameters constant (see subcaption of Fig. 1). We can appreciate in Fig. 1 two differentiated groups of modes, and how the modes in the group in the lower part of the spectrum are more relevant when we increase the current in the grating section. Control of the total number of modes oscillating is obtained by changing the current in the gain section, while centre frequency can be also be varied by changing the phase section bias current.

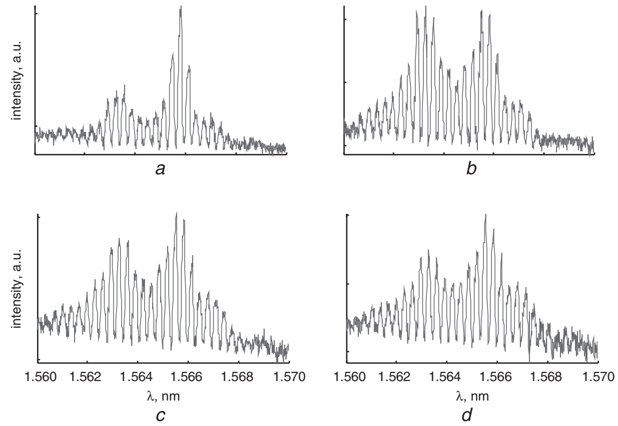

Fig. 1 *Optical spectrum for device*

Biasing conditions: $V_{abs} = 0$ V, $I_{gain} = 30$ mA, $I_{phase} = 30$ mA, and $I_{grating} = 16$ mA (Fig. 1*a*), $I_{grating} = 18$ mA (Fig. 1*b*), $I_{grating} = 20$ mA (Fig. 1*c*), $I_{grating} = 22$ mA (Fig. 1*d*)

Under certain bias conditions (lowering the current in the grating section to obtain only one group of longitudinal modes), these modelocked semiconductor lasers present a stable, dual-mode behaviour as shown in Fig. 2, where the biasing conditions are also described. In Fig. 2 we can see only two adjacent longitudinal modes with the same amplitude, centred at 1565.5 nm, and separated by 39.5 GHz (other longitudinal modes remain 20 dB below). With this modal structure, high efficiency mm-wave generation can be obtained through injection of a 39.5 GHz signal in the gain section of the device [6].

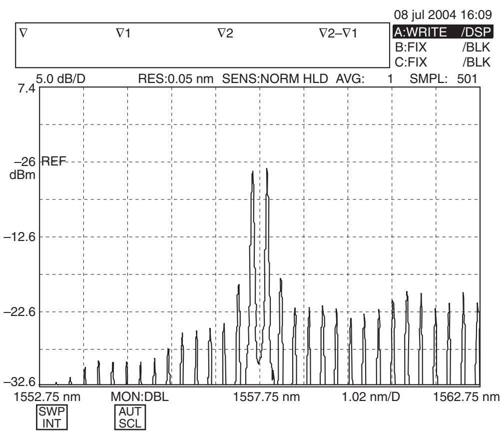

Fig. 2 *Longitudinal mode spectrum in dual-mode operation*

Biasing condition: $V_{abs} = 0$ V, $I_{gain} = 22.7$ mA, $I_{phase} = 40.2$ mA, $I_{grating} = 3.8$ mA
Note reduction in bias current in grating and gain sections

It is important to note that with this control of the optical spectrum through the biasing conditions it would be possible in principle to select one longitudinal mode for each of the 'groups' shown in Fig. 1. Such modes will be several times 39.5 GHz apart, and optical generation of mm-wave above 100 GHz would be possible. A similar approach (selection of two longitudinal modes from a modelocked laser several orders apart) has been demonstrated using an external arrayed waveguide grating (AWG) for the longitudinal mode selection [9]. In this case a simple monolithic device will be responsible for the generation of the two optical modes more than 100 GHz apart.

Millimetre-wave signal generation and upconversion: To demonstrate the possibility of using such a device for compact and low-cost mm-wave RoF links we have demonstrated optoelectronic upconversion with this device. For this experiment the modelocked laser is kept at the stable dual-mode operation (Fig. 2) and a 39.5 GHz carrier signal is introduced in the gain section while a 32 Mbit/s NRZ pseudorandom binary sequence (PRBS) signal is injected in the absorber section. Fig. 3 shows the detected electrical spectrum of the upconverted signal using a high speed (50 GHz 3 dB bandwidth) photodiode. As we can appreciate the electrical spectrum corresponds to the upconverted PRBS signal, centred at the carrier frequency (39.5 GHz).

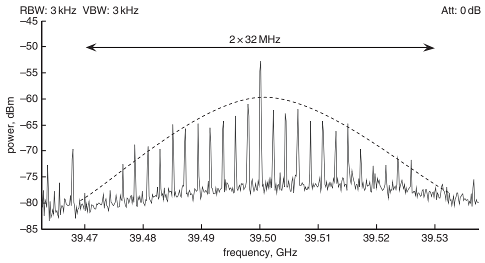

Fig. 3 *Electrical spectrum of upconverted NRZ 32 Mbits PRBS signal with 2^8 bits word length*

The linearity of the transmitter based on such device has been studied, injecting in the absorber section two tones centred at 10 MHz and separated 1 MHz. With such configuration we have measured the SFDR shown in Fig. 4. An SFDR of 65 dBc-Hz$^{2/3}$ has been obtained.

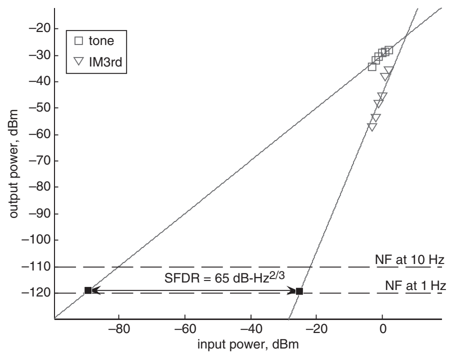

Fig. 4 *SFDR obtained for upconversion process in dual-mode operation*

Conclusion: We present a monolithic multisection modelocked laser for compact and low-cost mm-wave RoF links since it avoids use of external modulators for signal upconversion. Carefully study of the spectrum has allowed us to identify dual-mode operation for certain current scenarios for mm-wave RoF links around 40 GHz. Optoelectronic upconversion with this device has been demonstrated through the introduction of the LO signal (39.5 GHz) at the gain section and the IF signal in the absorber section. The dynamic range of the device has been measured and an SFDR of 65 dBc-Hz$^{2/3}$ observed.

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P. Acedo, H. Lamela, C. Roda and G. Carpintero (*Optoelectronics and Laser Technology Group, Universidad Carlos III de Madrid, Avenida de la Universidad 30, 28911 Leganés, Madrid, Spain*)

S. Garidel and J.P. Vilcot (*IEMN-CNRS, Avenue Poincare BP69, Villeneuve d'Ascq F-59652, France*)

I.H. White, K.A. Williams, and M. Thompson (*Cambridge University Engineering Department, Cambridge CB3 0FB, United Kingdom*)

W. Li, M. Pessa, and M. Dumitrescu (*Optoelectronics Research Centre, Tampere University of Technology, FIN-33101, Finland*)

S. Hansmann (*Am Kavalleriesand 3, D-64295 Darmstadt, Germany*)

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