Multi-wavelength transmitter employing a filtered-feedback laser

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In this paper, we present a monolithically integrated filtered-feedback multi-wavelength transmitter. This transmitter is formed by four channels of filtered-feedback laser integrated with four Mach-Zehnder modulators (MZMs). The multi-wavelength laser simultaneously lases at wavelengths spaced at 200 GHz, where more than 40 dB side mode suppression ratio and less than −35 dB optical crosstalk are measured. The transmitter chip is mounted on a specially designed sub-mount, and characterized with the modulators driven in an electrical push-pull manner. The transmitter system is evaluated in terms of optical link gain and crosstalk.

I. Introduction

Progress in wavelength-division-multiplexing (WDM) technologies for broadband telecommunication systems has raised the demands for integrated laser-modulator transmitters, especially multi-wavelength transmitters, due to their efficiency in increasing the flexibility and reducing the cost of WDM systems. Different integrated transmitters have been reported, such as tunable distributed feedback (DFB) lasers with Mach-Zehnder modulators on InP [1], tunable distributed Bragg reflector (DBR) laser arrays with electro-absorption modulators (EAMs) on InP [2], and multi-section hybrid III-V/silicon DBR lasers integrated with electro-absorption modulators [3].

Here we present a monolithically integrated photonic multi-wavelength transmitter[4] employing a filtered-feedback laser[5], and concentrate on the simultaneous operation of the different transmitter channels. The transmitter and its sub-mount are designed to be used as WDM source to achieve a multi-signal-path optical beam forming network [6] for application in a 3~5 GHz smart antenna system.

This paper describes the characterization of the multi-wavelength laser, the properties of the modulator, as well as the analog optical link created by one channel of the transmitter formed by the integrated laser and the modulator. Subsequently, the crosstalk between different channels during simultaneous operation is investigated.

II. Transmitter Device

The multi-wavelength transmitter circuit consists of mainly two parts, a filtered-feedback multi-wavelength laser (FFMWL)[5] and the four identical Mach-Zehnder modulators that are connected to the laser. Fig.1 shows the schematic layout and a microscope photograph of multi-wavelength transmitter device. The design and working concept of this transmitter have been described in [4]. The FFMWL part is formed by four Fabry-Pérot (FP) lasers which each use two multimode interference reflectors (MIRs)[7] as on-chip cavity mirrors. The FP lasers are wavelength-locked through a feedback section with a common arrayed waveguide grating (AWG) and a common reflector. Each of the four channels thus emits a single wavelength which is determined by AWG channel. At the left side of each FP laser, the light is routed to a Mach-Zehnder modulator for which the waveguides contain multiple InGaAsP quantum wells (MQW) which employ the quantum confined Stark effect for enhanced electro-optic effect. The transmitter has a separate output for each channel.

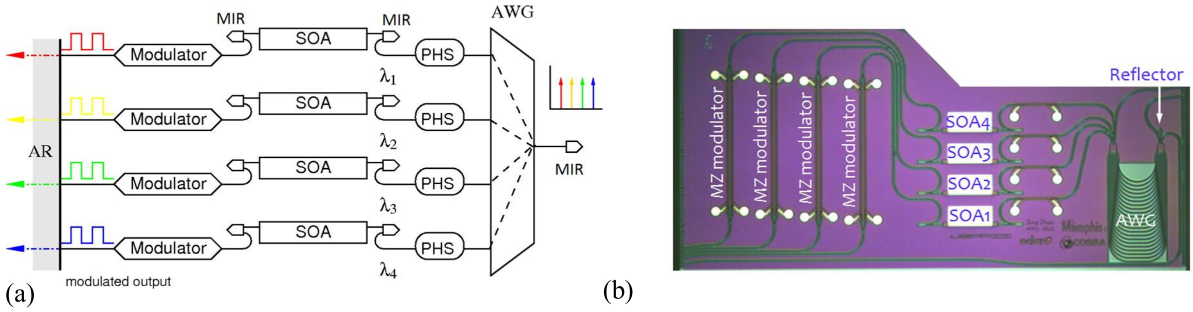

Fig. 1. (a) Schematic of the 4-channel transmitter device and (b) Microscope photograph of the realized device. The chip dimension is 2×4 mm^2.

III. Device Characterization

The transmitter chip and a thermistor are mounted on a dedicated copper cold finger platform as shown in Fig. 2a. A Peltier element placed underneath the copper platform is used to stabilize the chip temperature at 28°C. All the electrodes on the chip have been wire-bonded to their corresponding tracks on a custom-designed printed circuit board (PCB) which is surrounding the copper platform (Fig. 2a). Lasers and phase shifters are connected to laser current drivers and voltage controllers, respectively, from the connectors on the PCB. For the MZ modulators, the push-pull operation is realized electrically, where the two arms of the modulator are driven by RF signals with opposite phase. A pair of 180° phase difference RF signals is connected to the modulator input electrodes from a rat-race coupler [8] on the PCB, which behaves like a 3-dB splitter dividing the input signal to two branches with a phase inverter in one branch. A rat-race coupler operates in a specific frequency range. In the following measurement, the coupler with a centre frequency 4.5 GHz with ~30% bandwidth is used. The electrodes on the output side are terminated with 50 Ω impedances. The modulators are wired-bonded to the PCB as shown schematically in Fig. 2b. The light emits from the output wavelength of MZ modulators, and is collected by a lensed fibre that is positioned at the output waveguide of the chip with a 3-axes alignment stage.

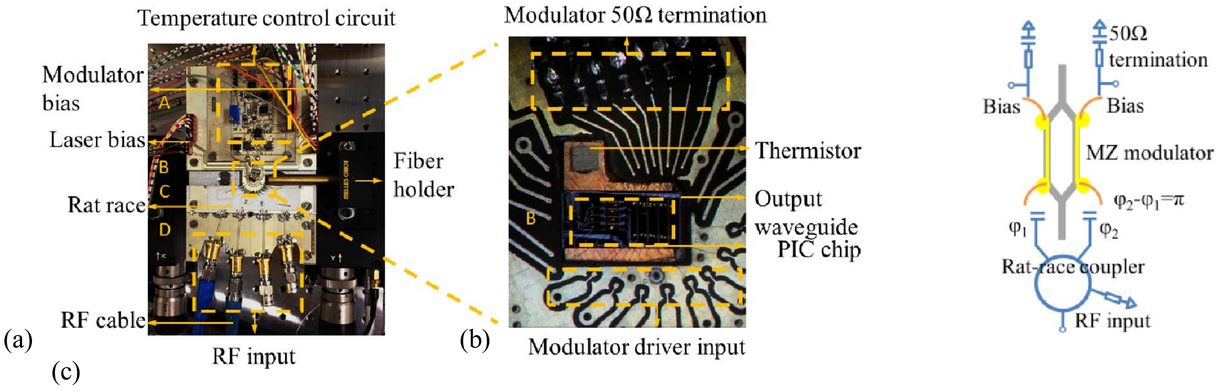

Fig. 2. (a) Microscope photograph top view of the transmitter chip on the sub-mount system. PCB A is temperature control system, B is the PCB to which the chip is wire-bonded, C is the rat-race PCB to split the input RF signal in to two branches with opposite phase, D is the board with SMA RF connectors; (b) Zoom in on part B: the transmitter chip mounted and wire-bonded to the testing board; (c) Schematic drawing of the connection of each MZ modulator driven in a push-pull manner through a rat-race coupler on the PCB. All the components on the PCB are indicated in blue colour.

Firstly we measure the spectra of the multi-wavelength laser. All the four channels are operated simultaneously, and the modulators are unbiased. The light spectrum from each channel is recorded, and superimposed in Fig. 3a, where the pumping currents are indicated. The fibre-coupled power for each channel is around −1.5 dBm. The wavelength channel spacing is defined by the AWG spacing of 200 GHz. The highest side mode has a suppression ratio (SMSR) of more than 40 dB, and the optical cross talk into the other laser channels is less than −35 dB (see the inset of Fig. 3), which will be suppressed by more than 20 dB when multiplexed by another AWG, in a multiplexed output transmitter. Fig. 3b presents the normalized light transmission as a function of the reverse bias voltage for each of the two modulator arms for channel 1. All the modulators have a Vπ of ~ 4 V and 18 dB extinction ratio. As the modulators are based on MQW waveguides, where the refractive index change is induced by the quantum confined Stark effect, a non-linear electro-optic phase shifting is obtained[9]. Due to the reverse bias dependent electro-absorption in the phase shifters, the peak value as well as the extinction ratio decrease at a higher reverse bias voltage.

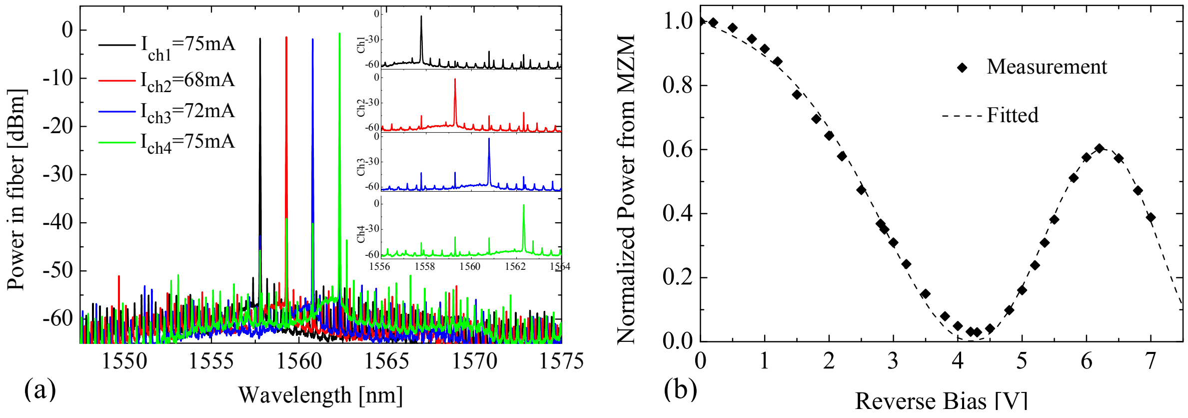

Fig. 3 (a) Superimposed lasing spectra of the four simultaneously operating laser channels; (b) Normalized modulator output power versus reverse bias at wavelength of 1560nm with fitted curve.

For the optical link measurement and the following crosstalk measurement, all laser channels of the FFMWL are operating simultaneously with the setting and wavelength as shown in Fig. 3, and the continuous wave signals are fed into each MZ modulator. Two arms are DC-biased at the quadrature point of the modulator. For each channel, the modulated optical output is coupled out from the chip and routed to a high-speed photodiode (R2560A), where the detected signal is sent to input port of the Electrical Network Analyser (ENA), and the output of the ENA is connect to MZ modulator. Thus a microwave analog optical link (AOL) is built [10]. The result obtained in Fig.5 is measured optical link gain. At the quadrature bias of the modulator, the optical output power in-fibre is −4.5 dBm. With this optical power, the link gain is constant at −43±1 dB (including the loss on PCB) in the measured frequency range.

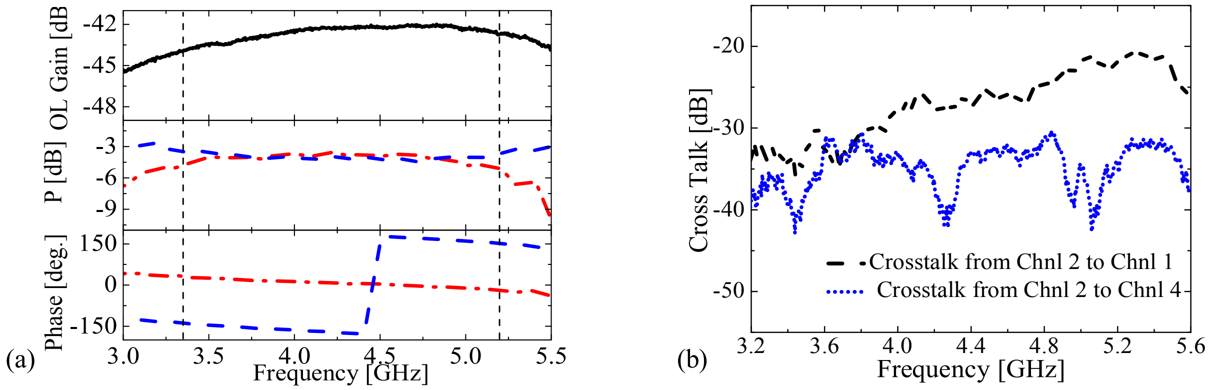

Fig. 4 (a) From top to bottom there are the intrinsic optical link gain, the rat-race two arms power coupling and phase coupling versus frequency, for coupler PCB at central frequency of 4.5 GHz. The vertical dotted lines indicate 1-dB bandwidth of the rat-race coupler. The loss for this 4.5 GHz rate-race coupler is 0.9 dB; (b) The EO transmission cross talk from channel 2 to channel 1 and 4 are plotted in dashed line and dotted line, for PCBs at central frequency of 4.5 GHz.

The crosstalk performance for all the channels is measured, which is quite comparable for different channels. The crosstalk to an adjacent channel reaches −20 dB for the adjacent channel, and −30 dB for the 2nd adjacent channel at 5.5 GHz (e.g. Channel 2 Fig. 4b). Furthermore, the crosstalk is also verified by applying two different frequency signals on two adjacent modulators. The light from one channel is detected by the ESA, where the RF signals at both frequencies can be observed with the power difference corresponding to EO transmission crosstalk measurement.

IV. Conclusion

Successful multi-channel operation of a monolithically integrated multi-wavelength transmitter based on filtered feedback is reported for the first time. Compared with the commonly used optical transmitter formed by discrete components, here we not only integrated the transmitter laser and modulator in a single chip, but also integrated the multi-channel version of transmitter. The four channels of the filtered-feedback laser operate simultaneously with a good side-mode suppression ratio of 40 dB. The optical link formed by this transmitter has an intrinsic gain around −43 dB. The bandwidth of the transmitter is above 5 GHz. The system crosstalk from adjacent channels is less than −20 dB for a frequency below 5 GHz. In terms of link performance, the link gain quadratically increases with the optical power, which can be significantly improved by adding a booster amplifier in the integrated circuit.

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