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Optical mm-Wave Synthesizer Using Semiconductor Ring Laser (a Review)

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Millimeter wave (mm-wave) technology is significant for military needs and applications due to its numerous advantages, such as huge bandwidth, deploying small antenna and high radar resolution. Due to atmospheric influence, mm-wave is important in short-range applications such as fire control radar. Similarly for the next-generation communication and military applications, high-speed radio over fiber networks are very crucial. In this paper, a review of the generation and modulation of millimeter-wave signal optically using semiconductor ring laser (SRL) has been done. The phenomena of optical injection locking and four-wave mixing are exploited in SRL to generate radio frequency (RF) optical signals. The signals with huge data rate can be transferred directly from an intensity modulated optical signal onto a RF optical signal with RF frequency tunable in steps of the free spectrum range (FSR) of SRL. They can be converted with flexible RF modulation formats over the optical carrier.

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1. Introduction

Huge bandwidth and high data rate are the hot demands of next generation wireless communication systems due to increase in usage of smart phone devices. High-speed communication is also vital in military applications including radar communication. Thus converting high-speed data signal onto the mm-wave carrier is one of the biggest challenges in the research. Four-wave mixing is an important technique, which is being used to create RF carriers optically. It is a non-linear phenomenon in which two or three signals beat together and produce fourth signal. Optical fibers, semiconductor optical amplifiers and semiconductor lasers are considered as robust candidates for producing FWM. However, in SRL, a very strong cavity enhanced FWM (CE-FWM) are produced [1, 2].

A very strong FWM process can be generated when an external optical light is injected into a non-lasing cavity mode. As a result several modes are enhanced in power and locked in phase. These enhanced FWM modes are mirrored around the main lasing mode of SRL at fixed period in the wavelength. This type of FWM is named as cavity enhanced FWM (CE-FWM) and is first reported in SRLs by Furst and Sorel [1]. We have previously reported the conversion of 4 Gbits/sec data onto a 60 GHz tunable mm-wave optical carrier.

In this paper we have reviewed the mm-wave generation and modulation in semiconductor ring lasers. This paper provides overview of the tunable mm-wave synthesizer using SRL.

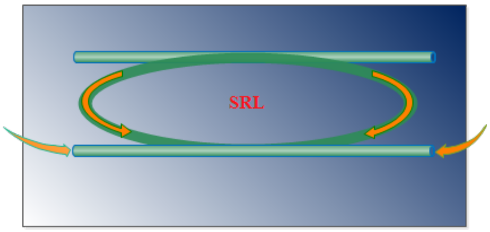

Fig. 1. Illustration of SRL racetrack device.

2. Semiconductor ring lasers

The SRL is a potential device for future optical communication systems due to its key characteristic of very strong directional bistability. This feature enables SRL to switch in terms of pico-seconds between two states. SRL is a potential candidate for all optical signal processing [3, 4]. SRL is being used for variety of applications such as optical logic [5, 6, 9], label swapping [7], all-optical memory [8], and optical regeneration [9], all-optical multicast [10], all-optical logic gates [11] and millimeter wave (mm-wave) generation and modulation [2].

SRLs are suitable for monolithic integration because they do not require cleaved facets or gratings for optical feedback [12]. That was the reason they were considered as the best lasers for photonic integrated circuits (PICs). Conversely, the desired linear plot of optical output power L as a function of biased current I ($L-I$ curve) was not found, instead it had a non-linear $L-I$ response.

Besides, simple and integrated SRLs with different dimensions and designs are reported. A number of different kinds of SRL on the basis of cavity geometry, including rectangular [13], circular [14], racetrack [10], triangular [15] and diamond [16], have been reported. Regardless of different geometries, SRLs are capable to accomplish optical feedback without reflection between a pair of facets. Light travels as standing waves in the SRL

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when it is operated in the bidirectional regime, and in this regime it is difficult to achieve the single mode operation. However when the SRL is made to operate in the unidirectional region, light in the cavity travels in the form of traveling waves around the loop. Due to this reason, it is easier to achieve single mode operation in SRL, as compared to the FP lasers that carry light in the form of standing waves.

3. Tunable millimeter wave synthesizer

Our approach exploits cavity enhanced four-wave mixing (CE-FWM). Figure 2 illustrates the experimental setup of mm-wave synthesizer using SRL. A holding beam (HB) is provided using tunable laser (TL1) to injection lock the SRL at one of its cavity modes (say m_0) in the CCW direction. Tunable laser (TL2) is modulated using an optical modulator such as Mach-Zehnder Modulator (MZM), by signals from a pulse pattern generator (PPG). Both HB from TL1 and the data modulated signal from TL2 are coupled together using a 3-dB coupler and fed into the SRL with their polarization adjusted to maintain TE input.

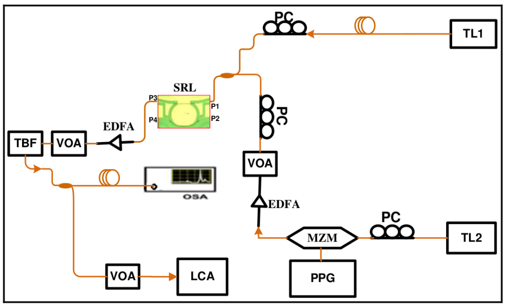

Fig. 2. Illustration of mm-wave synthesizer.

When the TL2 input is injected into a side mode m_{-3} of SRL, CE-FWM is generated as illustrated in Fig. 3. Due to CE-FWM, the cavity modes (m_{-3}, m_{-6}, m_3 and m_6) are locked in phase and are periodically enhanced in the amplitude. According to the standard mode-locking (ML) theory, the beating between the cavity modes results in a periodical modulation of the optical signal with a frequency equal to the frequency spacing between the modes, as demonstrated in [1], and produces a tremendous RF tone purity. As fig. 2 illustrates, the generated RF frequency is 3× of the SRL free spectrum range (FSR). FSR defines the frequency difference between two adjacent modes. Additionally, as one of the injected signals is modulated by a data pattern, this RF optical carrier is also modulated by the same data pattern.

A pair of modes (m_3 and m_6 in Fig. 3) is isolated by adjusting a very narrow band tunable band-pass filter (TBF) in such a way that both modes have the same power level as illustrated in Fig. 4a, creating an optical carrier that is single-side band-modulated by the mm-wave, with the mm-wave in turn amplitude modulated by the data. In similar fashion m_{-3} and m_{-6} can also be separated as shown in Fig. 4b. These mm-wave signals can be separated using mixers and other RF components.

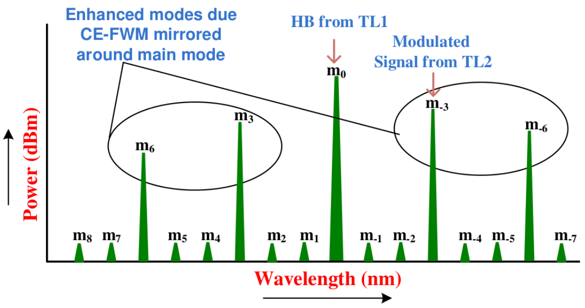

Fig. 3. Cavity enhanced FWM in SRL using data modulated signal.

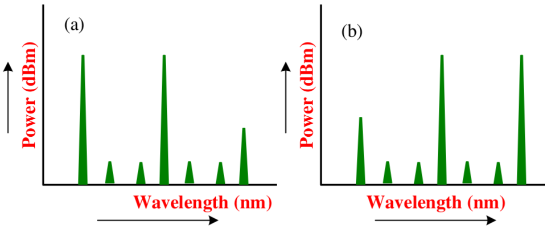

Fig. 4. Millimeter wave generation using SRL.

4. Conclusions

The paper provides a brief review of the tunable mm-wave synthesizer, which uses a semiconductor ring laser. Cavity enhanced four-wave mixing is exploited to generate and modulate mm-wave carrier. This concept can be very important for next generation communication system. It can lead to a prototype of tunable mm-wave synthesizer. However it is suggested to explore the concept both theoretically and experimentally.

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