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Microwave signal generation using a dual-beam optically injected 1550 nm VCSEL

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ABSTRACT:

We report microwave signal generation using a 1550 nm single-mode VCSEL subject to two-frequency optical injection. Double injection locking is achieved. It is found that this generation system is independent of the master lasers polarization.

Key words: Vertical-cavity surface-emitting lasers, microwaves, injection locking.

1.- Introduction

Photonic microwave signal generation has the advantages of high speed, low power consumption, low cost and high reliability. Photonic microwave sources are interesting for applications ranging from broadband wireless access networks to emerging broadband photonics-based phased-arrays antennas and radars [1]. Period-one nonlinear dynamics of optically injected semiconductor lasers has been used for microwave signal generation. This approach allows widely tunable, optically controlled and single sideband generation of microwave signals [1]. The generated frequency range far exceeds the intrinsic relaxation oscillation frequency of the semiconductor laser. Tunable narrow-linewidth microwave signals have been generated by using a single-beam optical injection scheme [1].

Interest in two-frequency optical injection in semiconductor lasers has also recently appeared [2-6]. In particular, microwave generation using dual-beam optical injection in semiconductor lasers has been investigated [2]. ‘Double injection locking’ is observed when the slave laser (SL) is subject to strong optical injection by both master lasers (ML). In this approach microwave signal frequency corresponds to the frequency difference between the two ML. A very high frequency microwave signal has been generated by using a dual-beam optically injected DFB laser [2]. Comparison of the performance with a similar microwave signal generated with single optical injection shows that a significant reduction of the linewidth is achieved when using the ‘double injection locking’ scheme. Similar photonic microwave generation using VCSELs instead a DFB laser has also been recently proposed. Numerical simulations have shown that single and multi-transverse mode VCSELs subject to two-frequency optical injection can generate high-frequency microwave signals [3,4].

In this work we report high-frequency microwave signal generation using a 1550 nm single-mode VCSEL subject to two-frequency optical injection. It is found that this microwave signal generation system is independent of the ML polarization. ‘Double injection locking’ is observed and the

VCSEL emits in the two ML frequencies. The frequency of the generated microwave signal corresponds to the frequency difference between the two ML.

2.- Experimental set-up

The all-fibre experimental set-up (see Fig. 1) includes two ML (Tunics Plus CL) and a single-mode VCSEL (Raycan) with a threshold current of 1.5 mA. The VCSEL is biased at 4 mA and it emits in a stable linear polarization state with a power of 0.32 mW. The optical spectrum of the free-running (FR) VCSEL has two peaks (see Fig. 2a) that correspond to two orthogonal polarizations.

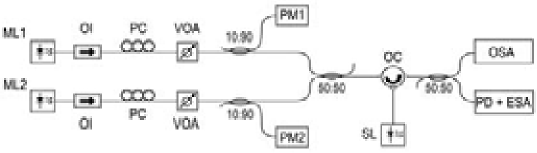

Fig. 1: All-fiber experimental setup: (OI) optical isolator, (PC) polarization controller, (VOA) variable optical attenuator, (PM) power meter, (OC) optical circulator, (OSA) optical spectrum analyzer, and (ESA) electrical spectrum analyzer.

The lasing mode is located at a wavelength of 1537.93 nm and has a direction that we will call parallel. The subsidiary mode has orthogonal polarization and its wavelength, 1538.17 nm, is shifted 0.24 nm (30 GHz) to the long-wavelength side of the lasing mode.

3.- Results for high injected power

Polarization controllers are first adjusted in such a way that the direction of the polarization of the injected light is the parallel one. Injected powers from ML1 and ML2 measured in front of the VCSEL are P_{ML1} = 0.84 mW and P_{ML2} = 1.91 mW, respectively. The optical spectrum under double frequency injection consists of two well defined peaks at the emission wavelengths of ML1 and ML2. These peaks are clearly larger than the peaks that correspond to the reflected light of ML1 and ML2 at the VCSEL's mirror (see Fig. 2a). This indicates that the VCSEL is emitting in the two ML frequencies ('double injection locking'). A Radio Frequency (RF) signal is generated at ν_{RF}=16.4 GHz (Fig. 2b), corresponding to the frequency separation between ML1 and ML2, $\Delta\nu_{12}$. Similar results were obtained by tuning the ML2 frequency with a maximum value for ν_{RF} of 18 GHz, that corresponds to the stable locking range that can be obtained in the single-beam optical injection scheme for the injection power used in this section.

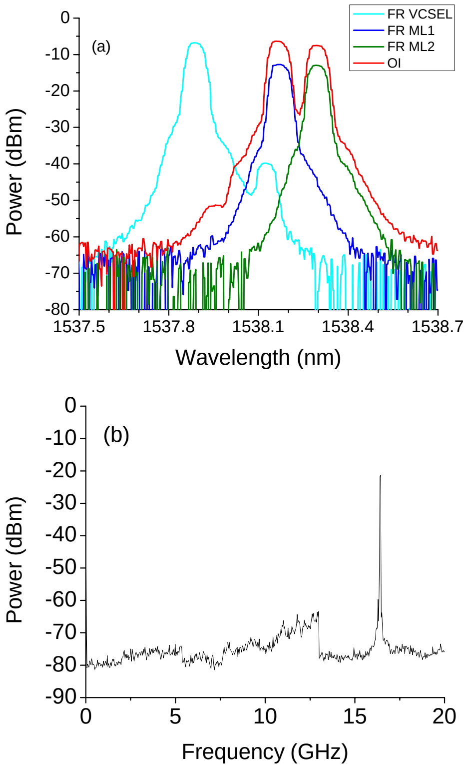

Fig. 2: (a) Optical spectrum of the free-running ML1, ML2 (reflected at VCSEL's mirror) with parallel polarization and VCSEL and of the two frequency injected VCSEL (red), with λ_{ML1}= 1538.16 nm and λ_{ML2}= 1538.29 nm. (b) RF spectrum obtained from the two frequency injected VCSEL.

Polarization controllers are now adjusted in such a way that the direction of the polarization of the ML is the orthogonal one. Polarization switching (PS) is observed in the VCSEL because ML wavelengths are close to the orthogonal polarization wavelength of the device (see Fig. 3a). As in the case of parallel injection, the VCSEL is emitting in the two ML frequencies. A RF signal is generated at 10 GHz that corresponds to $\Delta\nu_{12}$ (Fig. 3b). A maximum value for ν_{RF} of 18 GHz was obtained by tuning the ML2 frequency, that corresponds to the stable locking range that can be obtained in the single-beam optical injection scheme. We have found that this range increases when an EDFA is used to amplify the injected power.

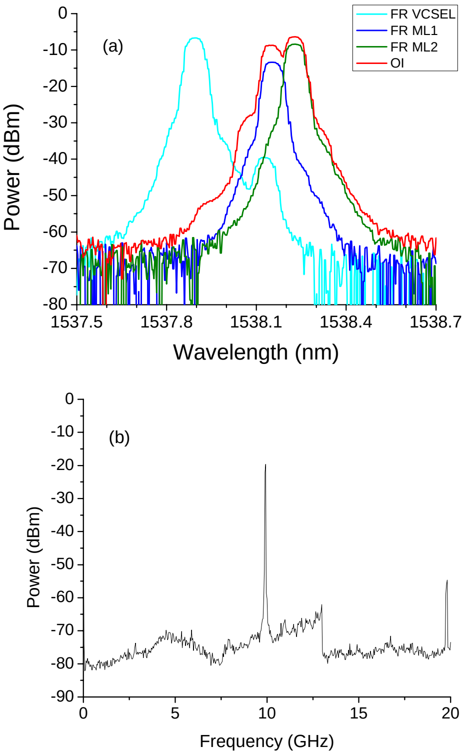

Fig. 3: (a) Optical spectrum of the free-running ML1, ML2 (reflected at VCSEL's mirror) with othogonal polarization and VCSEL and of the two frequency injected VCSEL (red), with λ_{ML1}= 1538.15 nm and λ_{ML2}= 1538.23 nm. (b) RF spectrum obtained from the two frequency injected VCSEL.

4.- Results for low injected power

In this section we present results obtained when decreasing P_{ML1} to 0.11 mW. ML1 is now a VCSEL similar to the slave laser. The value of P_{ML2} and the orthogonal direction of the injected polarization are maintained. Results obtained with an optical spectrum analyzer (BOSA) with much better frequency resolution (10 MHz) are shown in Fig. 4(a). Like in the previous section, P_{ML1} and λ_{ML1} are such that there is injection-locking with PS under single optical injection. Again two main peaks at λ_{ML1} and λ_{ML2} can be seen in Fig. 4(a). A third peak that appears at $2\lambda_{ML2}$ - λ_{ML1} shows that optical injection affects the dynamics of the slave VCSEL in such a way that the RF signal (see Fig. 4(b)) is not just due to a beating in the detector of beams reflected at the VCSEL mirror.

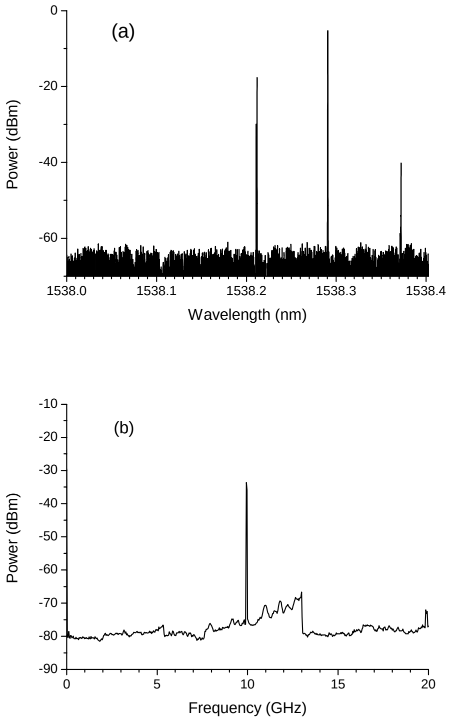

Fig. 4: (a) Optical spectrum of the two frequency injected VCSEL, with λ_{ML1}= 1538.21 nm and λ_{ML2}= 1538.29 nm. (b) RF spectrum obtained from the two frequency injected VCSEL. ML1 is a VCSEL similar to the SL.

Comparison of the spectrum shown in Fig. 4(a) with the spectrum that corresponds to the reflected light of ML1 and ML2 at the VCSEL's mirror (that is, with the slave VCSEL off) indicates that the slave VCSEL is emitting at λ_{ML2} wavelength. The situation changes when λ_{ML2} is increased as it is shown in Fig. 5. Now most of the light emitted by the slave VCSEL appears at λ_{ML1} wavelength. As λ_{ML2} increases beyond 1538.37 nm the emitted power at λ_{ML2} quickly decreases. The 1538.37 nm value corresponds to the wavelength below which there is injection locking under ML2 single optical injection. The λ_{ML2} wavelength range in which the slave VCSEL emits at λ_{ML1} and λ_{ML2} is smaller than that obtained in the previous section. That indicates that the wavelength range in which 'double injection locking' appears decreases as the injected power is decreased.

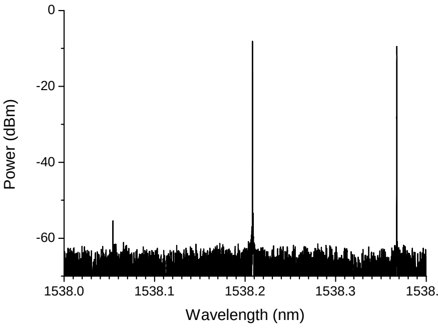

Fig. 5: (a) Optical spectrum of the two frequency injected VCSEL, with λ_{ML1}= 1538.21 nm and λ_{ML2}= 1538.37 nm. ML1 is a VCSEL similar to the SL.

4.- Conclusion

In conclusion, we have achieved microwave signal generation using a 1550 nm single-mode VCSEL subject to dual-beam optical injection. 'Double injection locking' is observed and the VCSEL emit in the two ML frequencies. The frequency of the generated microwave signal corresponds to the frequency difference between the two ML. The wavelength range in which the slave VCSEL emits at both injected wavelengths increases as the injected powers increase. It is found that this microwave generation system is independent of the master lasers polarization.

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