80 GHz compact photonic microwave generation from a solitary distributed feedback laser on silicon

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Abstract – *Microwave generation at 80 GHz is achieved from a distributed feedback laser on silicon made with a harmonic photonic potential from which a coherent beating between confined modes occurs. These results pave the way for all-optical microwave generation using compact and energy efficient semiconductor devices.*

Microwave photonics continue to gain a significant amount of attention in particular for applications in broadband wireless networks, sensor networks, radars, communications, among others [1]. The main advantages of microwave photonics systems include photonic generation, processing, control and distribution of microwave signals. Many optical techniques for generating microwave signals have been reported, including but not limited to, direct and external modulation of semiconductor lasers, optical heterodyne with an optical phase-locked loop, mode-locked lasers, optoelectronic oscillators, and periodic oscillations of semiconductor lasers [2]. Although these different techniques have strong interests regarding the different applications, all of them remain however bulky and costly. In this work, we concentrate on all-optical microwave generation from a compact semiconductor laser chip made with a harmonic photonic potential. The device consists of a distributed feedback (DFB) cavity on silicon that is monolithically hybridized to a III-V active section. Prior work already showed that this such a configuration leads to a high Q-factor hence transforming into a large cavity photon lifetime [3]. Here, taking advantage of a coherent beating through four wave mixing (FWM) between a highly and weakly confined modes in the active region, we report the generation of a 80 GHz signal along with a radiofrequency (RF) linewidth as narrow as 500 kHz. Overall, this work offers exiting perspectives to achieve a compact and cost-efficient integrated DFB laser source capable of delivering microwave signals without the need of electrical modulation.

I. Device description

As shown in fig. 1a, the device study consists in a silicon cavity made of a tapered DFB shallow grating, which is monolithically hybridized to III-V active section. In a quantum mechanical oscillator, it is known that in case of a harmonic potential, the fundamental mode wave-function spatial distribution is a Gaussian. Therefore, by analogy with quantum mechanics, the width of the grating is tapered longitudinally to create an effective confining photonic potential which allows a single, bell-shaped longitudinal mode within the stop band of the DFB. This fundamental mode which is a tightly confined mode has a large internal Q factor leading to a cavity photon lifetime of ~ 100 ps [3].

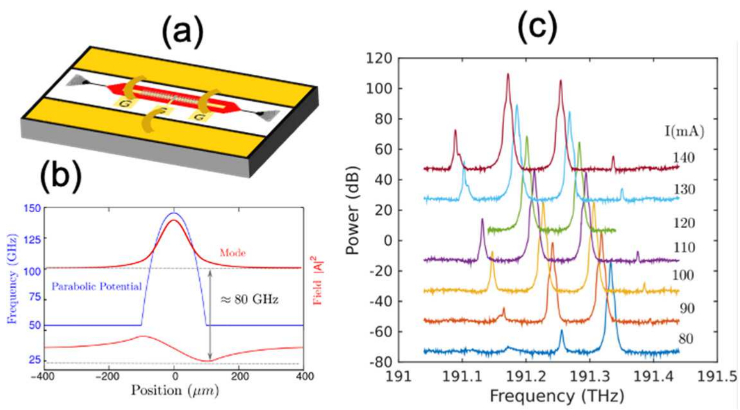

Fig. 1 (a) Schematic of the tapered DFB cavity; (b) band structure showing the offset frequency of 80 GHz (c) Measured optical spectra at different bias current conditions.

The Q factor term is an alternative description of the laser's losses meaning that high-Q lasers are low-loss devices. In order to harness the low internal loss of the silicon resonator, the contribution to loss from the active material is reduced, by decreasing the overlap between the optical field and the gain material [4-5]. Therefore, the increase of the width of the patterns forming the distributed Bragg grating induces a frequency shift of the edge of the transmission stop band, leading to a confining potential where a single mode is allowed to have a large Q factor. However, an additional weakly confined mode with a lower Q also exists at a lower optical frequency. The band structure illustrating this purpose is displayed in fig. 1b and shows that the offset frequency between the two modes is about 80 GHz. In the experiments, the DFB laser is biased with electric probes while a fiber is used to extract the output from one of the two grating couplers at the two edges of the silicon waveguide. A Peltier module is used to stabilize the temperature at 20°C. Fig 1c represents the evolution of the optical spectrum at different bias currents. As the bias is increased, the aforementioned additional mode with a low- Q initiates lasing simultaneously with the fundamental. This competition between the two modes shows a clear signature of four-wave-mixing (FWM), hence indicating coherent interaction between modes. In semiconductor lasers, FWM is known to be an important nonlinear phenomenon responsible of frequency comb formation and self-mode locking in quantum dot lasers [6].

II. Experimental results

Fig. 2a displays the relative intensity noise (RIN) of the DFB laser with respect to the bias current. A flat RIN is obtained namely independent of frequency hence demonstrating that this laser behaves as a quasi-class A oscillator for which the damping factor is larger than the oscillation frequency. However, as the laser shows some mode competition, the RIN remains at a quite high value. At 110 mA, when the laser displays strong FWM, the radio-frequency (RF) beatnote is extracted with a fast photodetector straight after the laser output, and analyzed with an ESA equipped with a mixer module for down conversion. A beatnote at about 80 GHz is detected as the current, consistently with the optical spectra. Fig. 2c shows that the beatnote frequency increases nonlinearly with the bias current. Fig. 1d indicates the corresponding standard deviation which does not exceed a few MHz. For I > 90 mA, the RF linewidth fitted with a Voigt profile narrows down to about 500 kHz, but remains however quite unstable due to residual technical noise. It is important to stress that that this DFB laser operates under free running and that no stabilization technique is required to achieve this high-frequency microwave generation.

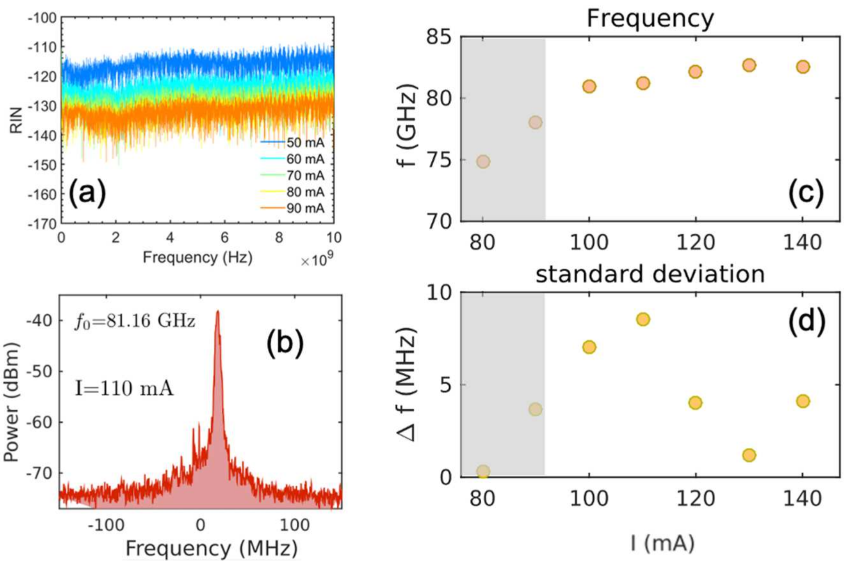

Fig. 1 (a) The relative intensity noise (RIN) captured at different bias currents; (b) The radiofrequency (RF) beatnote at 80 GHz measured at 110 mA. The linewidth is measured at 500 kHz; (c) Measured tunability of the RF beatnote with respect to the bias current; (d) Corresponding standard deviation with respect to the bias current.

To sum, using a DFB laser made with a harmonic photonic potential, a microwave signal generation at 80 GHz is reported owing to FWM coherent beating between confined modes. We also observed very flat relative intensity noise as a result of the very long cavity photon lifetime. These results are meaningful for all-optical microwave generation from compact and energy efficient semiconductor devices

III. References

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