Novel Concept for a Tunable Optical Microwave Source

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Abstract: A novel concept for a tunable optical microwave source is presented and experimentally verified. The performance of the new device is demonstrated with locking experiments at 40GHz.

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1 Introduction

Recent developments in high speed all optical networks have increased the demand for all optical devices mainly due to the speed limitations of electronics. A key functionality for all optical networks will be optical microwave sources which are required for several applications in optical signal processing such as clock recovery and add-drop multiplexing in OTDM-systems. The generation of microwaves using optics offers many advantages compared to electronic solutions. Besides the speed limitations of electronical counterparts these advantages are low power consumption, low cost and high reliability.

There are several solutions for the design of monolithically integrated devices for optical microwave generation. Mode-locked lasers [1] as well as dual-mode lasers of the DFB/DFB-type can be applied to achieve this goal [2, 3]. Monolithically integrated mode-locked lasers suffer from the fact that the tunability of the microwave frequency is limited by the current controlled wavelength shift of the Bragg-reflector. For the DFB/DFB-type dual mode lasers the microwave frequency has to be precisely adjusted by different gratings of the DFB sections. This results in a complicated technology and finally in a reduction of yield.

In this paper we present a novel approach for an optical microwave source which combines the stability of monolithical integration and the possibility to tune the microwave frequency over a wide range. We first present the concept and the principle of operation. In the following section we demonstrate basic characteristics of the device: the operation conditions and the tunability of the microwave via the DC driving currents. We finally demonstrate the locking of the microwave to an external optical signal.

2 Scheme of the Devices and Principle of Operation

Theoretical studies [4] on DFB lasers with short external cavities [EC] have shown high frequency pulsations up to 30GHz due to compound-cavity mode degeneracy. A compound cavity is required which allows the adjustment of two longitudinal modes having the same threshold gain. The frequency separation of the modes determines the microwave frequency. The origin of the stable phase condition between the modes (which is required for microwave generation) is mainly due to nonlinearities in the semiconductor.

However, an important result from theory is that the microwave frequency f scales as $f \propto \eta \,/\, \tau$ with η being the feedback coefficient and τ being the roundtrip time in the EC. Supplying enough feedback from the EC the upper frequency limit is therefore determined by the mode spacing of the external cavity.

For a practical realization of such a device, the EC has to be integrated as a passive section with a high reflectivity at its end. Applying a current to the passive section, the phase of the light re-injected to laser can be varied due to the free carrier induced index shift. The drawback of the design for real devices are the high losses in the EC. This limits the amplitude of the light fed back into the DFB laser and therefore also limits the frequency for a fixed external cavity length.

To avoid the limitations imposed by the losses in the EC we propose the setup for a new device with a phase tuning section and an additional amplifier section with a high reflectivity at its end [Fig. 1]. This approach enables us to control the optical feedback in amplitude and phase via the current injection into the active and passive section of the device. The *amplifying mirror* guarantees to compensate for the losses in the phase tuning section.

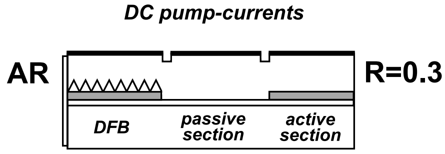

Fig. 1. Scheme of the DFB with an amplifying mirror.

Compared to the device proposed in [4] new operation regimes can be found with feedback levels exceeding the original output power of the DFB, giving the flexibility for large operation regimes as well as large frequency tuning ranges.

3 Experimental Verification of the Device Concept

To prove the proposed device concept, we have fabricated an index coupled (κ=130cm^{-1}) bulk heterostructure ridge waveguide laser consisting of a 200μm DFB section, a 550μm passive phase tuning section and a 250μm active section, corresponding to a EC length of 800μm. The DFB facet is anti-reflection coated, while the end facet is as cleaved with a power reflectivity of 0.3.

The DFB current as well as the temperature of the device were kept constant throughout the experiments at 100 mA and 20°C, respectively. The optical spectra of the fabricated device are summarized in Fig. 2 left (I_{active}=30mA...70mA). The current in the phase section was adjusted to give the same phase relation for the light re-injected to the DFB laser. Two main modes appear in the optical spectra as consequence of the compound cavity. The spacing between the modes increases as the current in the active mirror section and therefore the feedback coefficient η increases. The side mode suppression of modes which are not involved in the microwave generation is more than 40dB.

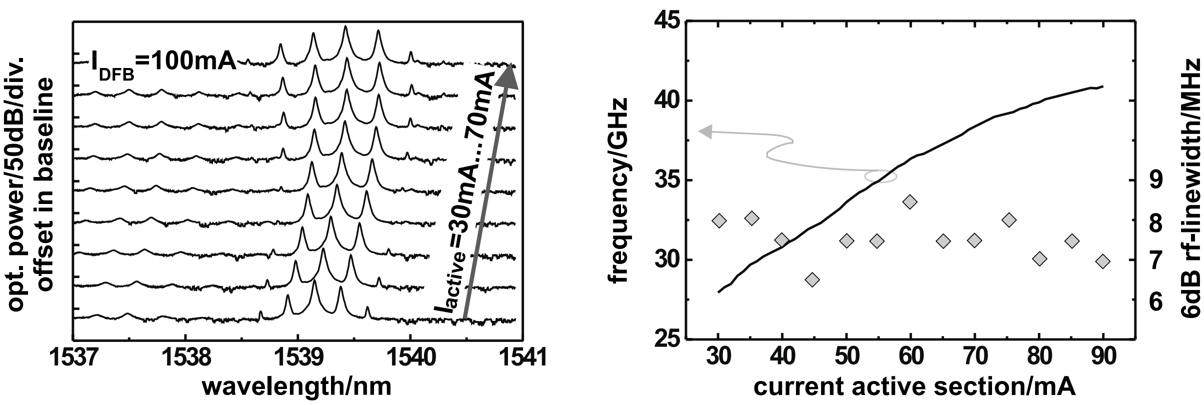

Fig. 2. Optical spectra for different microwave frequencies (left). Right side: Continuous frequency tuning range by increasing the current in the active section. Diamonds show the linewidth of rf-spectra.

The generated microwave was detected using a fast photodiode which was allocated in front of a rf-analyzer. The results of the measurements are depicted in Fig. 2 right. A continuous frequency tuning from 28GHz to 41GHz was achieved by changing the current in the active section without degradation of the microwave. The detected linewidth of the free running microwave was about 8MHz for the whole tuning range [Fig. 2 right].

An important characteristic for every microwave source is its locking capability to an injected signal. To demonstrate this feature we have performed locking experiments with our device.
The pulse source consisted of a 10Gbit/s gain switched laser supplying pulses with FWHM of 13ps and a wavelength of 1550nm. It was modulated by an external modulator with a PRBS 2^7-1 sequence. Injecting this subharmonic data via a circulator into the DFB-section of our device, the free running oscillator locked to a frequency of 40GHz, showing no patterning effects due to the locking signal (mean injected power 0dBm). The device has an output power of 0dBm with an extinction ratio of the pulses of 6dB. A variation of the locking signal power by 6dB showed no major increase of the jitter which has been extracted from phase noise measurements to be as low as 300fs.

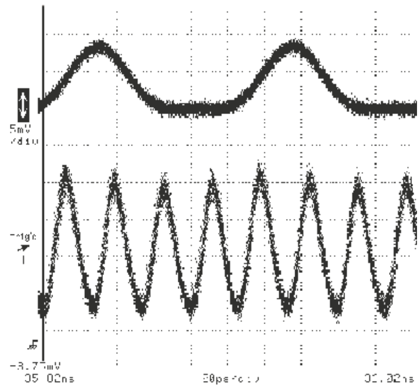

Fig. 3. Microwave source locked to a 10Gbit/s subharmonic PRBS 2^7-1 pulse train.

4 Conclusion

We have developed an amplifying mirror DFB for high speed tunable microwave generation. We experimentally demonstrated a continuous tuning range of 13GHz without degradation of the microwave. A single device can therefore be applied to cover the frequency range from the base frequency of a TDM-channel to the frequency resulting from a overhead due to forward error correction. Moreover, this tuning range eases the demands on precise cavity lengths and other critical design parameters. By shortening the external cavity length the device has at least a speed potential of 160GHz.
In conclusion, due to the high performance, the speed potential and the straightforward fabrication we expect the amplifying mirror DFB to be a promising device for application in future optical networks.

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