Optical frequency doubling for multichannel radio-over-fibre system based on integrated phase modulator and silicon coupled microring notch filter

L. Xu, C. Li, H.K. Tsang and C.W. Chow

An integrated optical millimetre-wave signal generator based on a coupled microring resonator, which doubles the frequency of the electrical signal driving a phase modulator, is proposed and experimentally demonstrated for future radio-over-fibre systems. The coupled microring notch filter was fabricated on a silicon-on-insulator wafer. A high extinction ratio optical millimetre-wave signal was obtained.

Introduction: The radio-over-fibre (ROF) technique is attracting much attention for the distribution of broadband wireless access networks. Optical millimetre (mm)-wave generation is a key technique for ROF networks [1]. Optical generation of microwave and mm-wave signals based on phase modulation has been investigated extensively [2, 3] and has the advantage that the optical phase modulators do not require any precise DC bias. Microwave frequency doubling was achieved using an optical phase modulator followed by a fibre Bragg grating (FBG) serving as an optical notch filter to suppress the optical carrier [2], the technique was extended to dense wavelength division multiplexed (DWDM) systems using optical interleavers [3].

In this Letter we use a silicon coupled microring resonator to achieve optical frequency doubling in two DWDM signals. The coupled microring filter functioned as a high performance optical filter which removed the optical carrier, so that the two first-order sidebands can then beat with each other in a photodetector at the antenna site in the ROF system. The beating of the two optical sidebands generates a mm-wave at twice the frequency of the phase modulation.

Microring resonator: The coupled microring resonator was fabricated using deep-UV (193 nm) photolithography and dry etching on a silicon-on-insulator (SOI) wafer with a 220 nm-thick device layer and 2 µm-thick buried oxide [4, 5]. Light was coupled in and out of the microring filter via waveguide grating couplers [6]. The racetrack microring arc radius is 8 µm, and the straight coupling length is 6 µm, as shown in Fig. 1*a*. The waveguide width is about 500 nm. The fabricated air-gap spacing between the ring and the waveguide is about 200 nm. The loaded quality factor (Q) of the resonance is ~4 000, as shown in Fig. 1*b*.

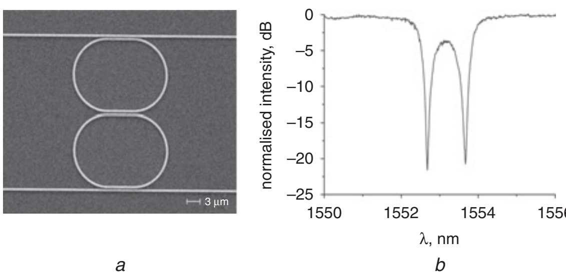

Fig. 1 *Scanning electron microscope (SEM) image and measured spectrum*
a SEM image of fabricated silicon coupled-microring notch filter
b Measured spectrum of device

Experiment and results: The proposed subsystem to generate the mm-wave signal by frequency doubling is shown in Fig. 2. Two continuous-wave (CW) optical signals at wavelengths of 1552.68 and 1553.66 nm produced by a tunable laser (Agilent 8164A) were tuned exactly to the resonance wavelengths of the coupled microring resonator. Discrete optical phase modulators may be used in this proof-of-principle demonstration, but these can eventually be integrated on the chip [7] in the ultimate design. By driving the phase modulators with 10 and 12 GHz sinusoidal signals, respectively, from a synthesiser, sidebands were produced at the respective detuning from the centre frequencies of the tunable lasers. Thus, each DWDM wavelength channel may be used to generate a different RF frequency for use in different RF cells. The coupled microring filter serves as fixed notch filters to generate the mm-wave signal generator by frequency doubling. The frequency separation between the two first-order sidebands is equal to twice the modulating signal frequency. Hence frequency doubling of the electrical drive signal can be simply achieved without needing any DC bias adjustment. Frequency quadrupling could also be achieved by filtering out the optical carrier and first-order sidebands using an appropriately designed coupled microring filter.

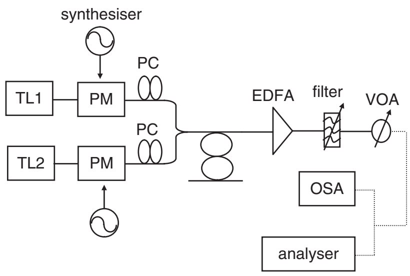

Fig. 2 *Experimental setup*

TL: tunable laser, PC: polarisation controller, PM: phase modulator, VOA: variable optical attenuator, OSA: optical spectrum analyser

The output spectra after the coupled microring filter are shown in Figs. 3*a*–*d*(*a* and *b* for channel one and *c* and *d* for channel two). The wavelength spacing between the two first-order modes were 0.16 nm (equal to 20 GHz) and 0.19 nm (equal to 24 GHz), respectively. The RF spectra of the optical signals were measured by a 32 GHz *pin* photodetector and HP8564E spectrum analyser. We believe the phase noise performance of the generated RF signal in the proposed scheme is similar to the RF signal produced by the RF synthesiser [5].

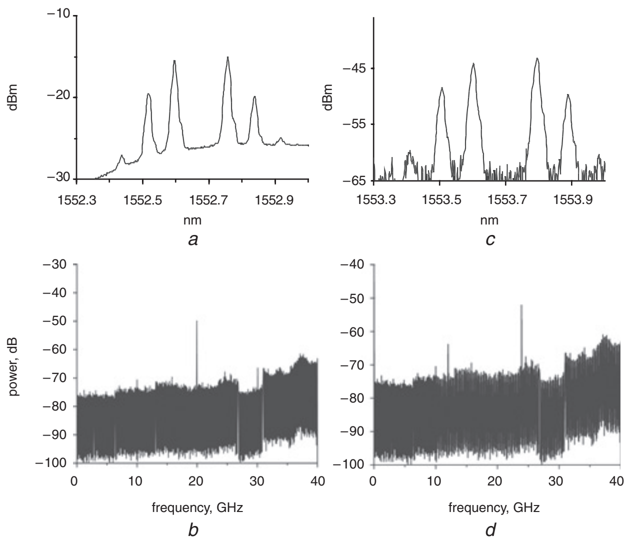

Fig. 3 *Optical and RF spectra at output of microring for two channels*

Conclusion: We have demonstrated a simple technique for DWDM frequency doubling using a phase modulator and a coupled microring. The optical carriers were removed from the output of the optical phase modulator by the cascaded microring notch filter, while the remaining sidebands produced frequency doubling at the photodetector. The generated signals had high-frequency stability and narrow linewidth. The scheme has good potential for monolithic integration and the capability of multichannel mm-wave signals generation can help to significantly reduce the cost of the DWDM ROF system.

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