Modulation depth enhancement in radio-over-fiber systems using a Si$_3$N$_4$ ring resonator notch filter for optical carrier reduction

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Abstract—Optical carrier reduction via the use of a Si$_3$N$_4$ ring resonator notch filter (RRNF) is proposed and experimentally demonstrated for improving the modulation efficiency in a 10 GHz radio-over-fiber (RoF) system.

I. INTRODUCTION

Radio-over-fiber (RoF) is a very attractive technology for meeting future bandwidth demands in cellular communications and radar. An important characteristic of RoF systems is the modulation depth since it determines the dynamic range directly. One technique for enhancing modulation depth is through removal of a portion of the optical carrier immediately after modulation. This technique is applicable in systems where the modulation efficiency is limited and the overall optical power cannot be increased due to the danger of damaging the photodetector. Previously reported methods for reducing the carrier include the use of Brillouin scattering [1,2] and external optical filters such as silica delay lines [3], Fabry-Perot [4], fiber Bragg gratings [5,6] and arrayed waveguide gratings (AWG) [7].

Some of these methods are complex while others are not applicable to a wide range of frequencies and modulation depths. With the exception of the AWG (which in itself is a complex device to realize) none of them can be integrated monolithically with other devices. Silicon photonics has now emerged as a very promising platform for the production of low cost transceivers such as those required in future RoF applications. Hence a silicon-based filtering device for optical carrier reduction would be of great interest. Here, we propose and experimentally demonstrate the use of a Si$_3$N$_4$ ring resonator notch filter (RRNF) to reduce the optical carrier and enhance the modulation efficiency in a 10 GHz RoF system (as a proof-of-concept for application to X-band radar).

II. FILTER FABRICATION AND MEASUREMENT

SEM micrographs of the fabricated RRNF are shown in Fig.1. The Si$_3$N$_4$ layer was deposited using low pressure chemical vapor deposition (LPCVD) and was patterned using i-line photolithography and dry etching. The RRNF has a ring radius of 100 μm, a length of 676 μm and a coupling length of 24 μm. The waveguide is 0.3 μm thick and 1.1 μm wide. The coupling coefficient between the ring and the bus waveguide was designed to provide both a narrow bandwidth and a high extinction ratio (ER), as required for carrier reduction. The transmission spectrum of the device was measured for TM polarization using butt-coupling and is shown in Fig.2 (a). An insertion loss of 18 dB, due to a non optimized fiber-to-waveguide coupling, and a free spectral range (FSR) of 2 nm were achieved. Fig.2 (b) shows the notch at the 1550.351 nm resonance clearly achieving an ER of 16.5 dB and a 3-dB bandwidth of 6 GHz. These parameters are suitable for 10 GHz RoF carrier reduction.

![SEM micrographs of the fabricated RRNF.](image)

![Optical transmission spectrum of the RRNF.](image)
III. EXPERIMENTAL DEMONSTRATION OF MODULATION DEPTH ENHANCEMENT FOR 10 GHz ROF APPLICATIONS

The test-bed shown in Fig. 3 was used to evaluate the potential for optical carrier reduction with the fabricated RRNF. The TLS, set at 0 dBm, drove a MZM biased at quadrature and the optical carrier was modulated by a 10 GHz sinusoidal signal of 10 dBm power. This produced a double-sideband signal. An EDFA was used immediately after the MZM to boost the signal power before entering the RRNF. The RRNF was then inserted in the system along with a polarization controller (PC) in order to select the polarization state of light coupled to the filter. The RRNF was used to reduce the carrier. The optical carrier wavelength was moved into the filter notch until optimum carrier reduction was achieved. Optimum carrier reduction is achieved when the power level of the carrier approaches or aligns with the level of the sidebands. With the optical carrier moving towards the minimum point in the filter notch, we see a steady improvement in the carrier-to-sideband-ratio (CSR), thus increasing the modulation depth.

![Test bed schematic](Image)

In order to keep the optical power at the input of the photodiode constant, with changing optical wavelength, another EDFA was used at the RRNF output. The TLS was initially set to $\lambda=1550.2$ nm, lying just before the beginning of the notch shown in Fig. 2 (b), and the optical spectrum was measured with an OSA. This measurement was repeated for several slightly shifted wavelengths in order to realize a varying amount of carrier reduction and hence an improved (lower) CSR. For all wavelengths, the incident power to the OSA was kept constant at 5.3 dBm. The results are shown in Fig.4. At $\lambda=1550.2$ nm, the notch of the filter does not interact with the optical carrier or upper-sideband (Fig. 4a) yielding a CSR of 17 dB. When the source wavelength shifts to 1550.325 nm (Fig. 4b), the optical carrier starts to enter the slope of the filter notch, thus reducing the CSR to 15 dB. The optimum CSR of 8.5 dB is obtained at $\lambda=1550.37$ nm and the respective spectrum is shown in Fig. 4 (d). As the wavelength moves away from that value the CSR increases again. It can be concluded from the spectra of Fig. 4 that the realized filter suits perfectly the purpose of carrier reduction, achieving a CSR of 8.5 dB.

![Optical spectra](Image)

IV. CONCLUSIONS

We have demonstrated for the first time the use of a Si$_3$N$_4$ RRNF to reduce the optical carrier for a 10 GHz RoF system application. The proposed technique allows the control of the modulation depth with a minimum CSR of 8.5 dB. The advantage of this method, apart from its simplicity, is that it offers the option for monolithic integration on silicon with other devices such as modulators and multiplexers as part of a photonic integrated circuit for RoF and other microwave photonic applications (such as antenna remoting).

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REFERENCES