Integrated microresonator frequency comb source for massive-parallel optical communication

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Abstract

We demonstrated ultra-dense wavelength-division multiplexing (WDM) data transmission using an intensity modulation and direct detection (IM-DD) scheme. We discuss the feasibility of SiN and MgF_2 microresonators for WDM applications regarding output power, bandwidth, and required pumping power. In addition, we discuss that IM-DD communication is relevant to the next-generation optical communication that requires ultra-low latency.

1. Introduction

We believe that massively parallel wavelength division multiplexed (WDM) optical communications are required to support high transmission rates and low latency. Optical frequency comb using optical microresonators, now known as a microcomb, is being actively studied as a possible candidate that replaces existing single wavelength lasers.

Microcomb is based on the four-wave mixing (FWM) that occurs in a tiny microresonator. When a continuous wave (CW) laser with a single wavelength is injected into an optical microresonator, degenerate and non-degenerate FWMs occur, resulting in the generation of different wavelength components. In order to obtain FWM efficiently, a high-Q cavity is needed. Various platforms exist, including magnesium fluoride (MgF_2) whispering gallery mode (WGM) resonators [1] and silicon nitride (SiN) microring resonators.

In this paper, we first explain our experiments on the generation of the soliton combs and then discuss the feasibility of the modulation instability comb for optical data transmission.

2. Comparison between MgF_2 and SiN microresonators

Before we show the transmittance experiment, we would like to discuss which microresonators are advantageous for WDM applications.

Figure 1 shows the output power per longitudinal line (i.e., channel) for SiN (Fig. 1(a)) and MgF_2 (Fig. 1(b)) microresonators, in function to the *Q*, free-spectral range (FSR), and input power, when soliton comb is generated [2]. Typical *Q* and FSR for the SiN microring are a few million and a few hundred GHz. It means that we can obtain –10 dBm/channel output at a pumping power of ~100 mW. On the other hand, Fig. 1(b) is a map for the MgF_2 WGM microresonator, of which Q is usually much higher. The Q is typically 10^9, and FSR is > 10 GHz. It suggests that a soliton is obtained at much lower power of ~10 mW, but the output is as low as –25 dBm. It shows that these platforms have pros and cons.

The following is a very simplified discussion: If we need a dense WDM with channel spacing of 10 to 40 GHz, a MgF_2 resonator is advantageous. It also allows us to generate a comb with much lower pump power. On the other hand, if we need a WDM light source with much higher power per channel, SiN microring is advantageous. It also allows us to build an on-chip integrated system, but the FSR is as sparse as > 100 GHz.

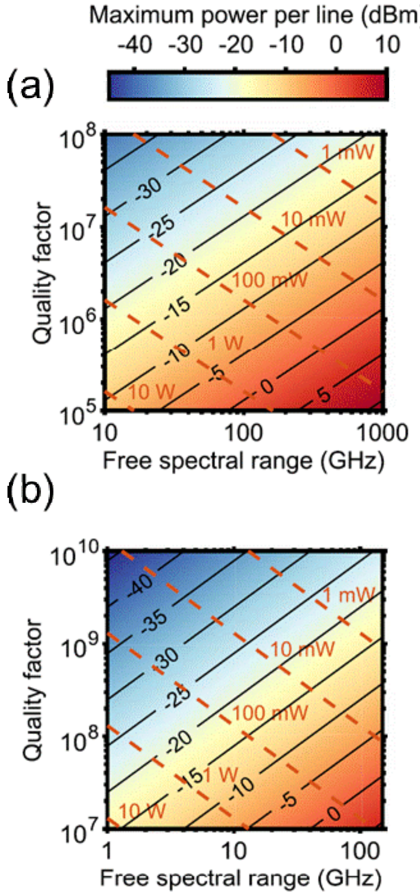

Figure 1: This color map shows the maximum power output per comb line when a soliton comb is generated. The red dotted lines are the required pump power to obtain a soliton comb. (a) SiN microring. (b) MgF_2 WGM microresonator. [2]

3. Optical transmittance experiment

Here we will show our experimental results of ultra-low latency optical transmission using the IM-DD scheme. We want to note that coherent digital communication requires powerful electrical signal processing, and the delay caused by the signal processing is not negligible. Forward error correction (FEC) is also often used, which further increases the delay in the electrical stage.

Therefore, to construct an ultra-low latency transmission system, it is necessary to reduce the electrical signal processing load by utilizing FEC-free transmission. It is expected to achieve massively parallel transmission and high transmission capacity as the overall system performance.

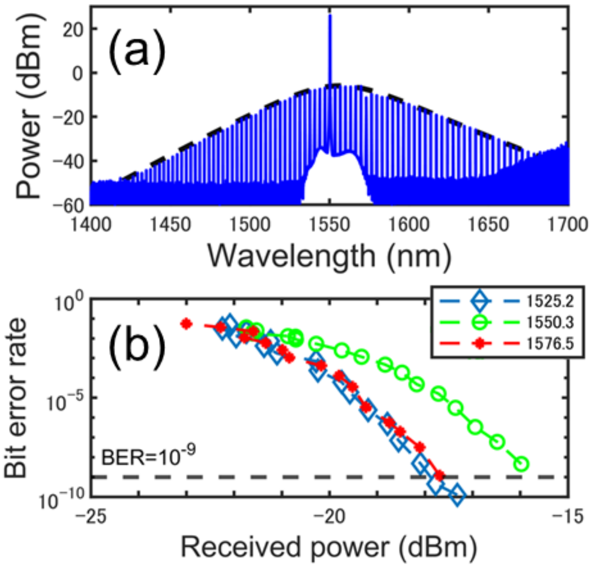

Figure 2: Optical spectrum of a soliton comb from SiN resonator with FSR of 400 GHz. (b) Bit error rate curves for three different comb lines at the wavelength of 1525.2, 1550.3, and 1576. nm.

Figure 2(a) shows the spectrum of the soliton comb generated with a SiN microring. The FSR is 400 GHz. We use a fast-scan method to generate the soliton comb. Comb lines at wavelengths of 1525.2, 1550.3, and 1576.5 nm were filtered out by a BPF, and the signal light is modulated at 10 Gbps with an intensity-modulator. Note that 1550.3 nm is the CW pump light. The modulated light propagated through a 40-km single-mode optical fiber. Figure 2(b) shows the BER at different received power. All three comb lines achieved a BER < 10^{-9} (error-free), which is necessary for FEC-free transmission.

Next, we show the results of transmission experiments using an MgF_2 resonator with an FSR of 10 GHz (Fig. 3(a)). The spectrum's full width at half maximum is 1.22 THz, with 386 comb lines in the C-band. Figure 3(b) shows the lowest BER values for the transmission for each comb line. The 145 comb lines achieved error-free transmission with a total transmission capacity of 1.45 Tbit/s. The BERs are degraded near the pump wavelength due to the spontaneous emission of amplified light at the optical fiber amplifier. The BER is also degraded at both wings of the spectrum due to the small output power of the comb line. The spectral efficiency was 1 bit/s/Hz, the highest spectral efficiency achieved to our knowledge for microcomb-based transmission without FEC.

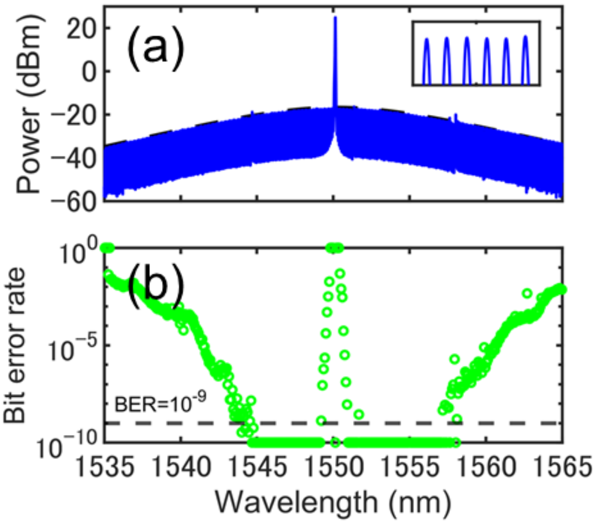

Figure 3: Optical spectrum of a soliton comb from MgF_2 resonator with an FSR of 10 GHz. Inset: Enlarged spectrum between 1549.0 and 1549.5 nm. (b) Bit error rate spectrum of 386 comb lines across the C-band. 145 comb lines exhibit error-free operation (BER < 10^{-9}).

4. Conclusions

We discussed the feasibility of the microresonator frequency combs generated with MgF_2 WGM microresonator and SiN microring for WDM application. We demonstrated massive-parallel FEC free transmittance which is needed for high-capacity low-latency optical transmittance.

Acknowledgments

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References

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