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# Wavelength Conversion in Low Loss $Si_3N_4$ Waveguides

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**Abstract:** We show wavelength conversion in a compact $Si_3N_4$ waveguide. Combining low loss, long length, relatively large nonlinear coefficient, high-power handling and absence of two-photon absorption, this platform is promising for integrated nonlinear optics applications.

**OCIS codes:** 230.7390 (Optical devices; Waveguides, planar), 130.7405 (Integrated Optics; Wavelength conversion devices), 130.4130 (Integrated Optics; Nonlinear).

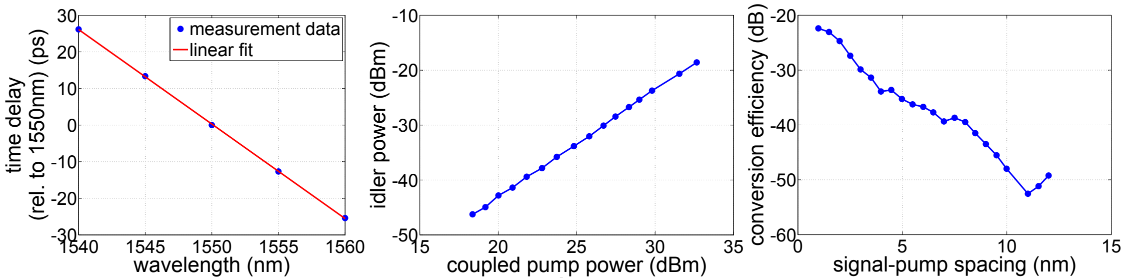
## 1. Introduction

The quest for high-performance nonlinear integrated photonics is steering research efforts towards silicon nitride [1]. Although its nonlinear coefficient is lower than what is available from silicon [2] or chalcogenides [3], the platform has very low linear losses and negligible nonlinear ones. The transparency window ranges from the short-wavelength infrared all the way up to UV, and the dispersion properties can be engineered via the geometrical design of the waveguide cross section [1].

Recently, at UCSB we developed silicon nitride waveguides with record-low propagation loss [4]. This platform was primarily conceived for linear passive integrated photonic circuits [5]. However, here we show that the combination of high-power handling, absence of two-photon absorption and low propagation loss actually make it a very attractive candidate for integrated nonlinear optics. In this paper, we report on the device characteristics and a wavelength conversion experiment.

## 2. Device characterization

The $Si_3N_4$ waveguide has dimensions of 100nm (height) by 2.8$\mu$m (width) and is surrounded by a $SiO_2$ cladding. It is single mode with 6dB/m propagation loss at 1550nm for TE-polarization with a high polarization extinction ratio of over 40dB. Lower losses were achieved with thinner core thicknesses and at longer wavelength, where the hydrogen bond absorption is lower. The waveguide is 2m long. By spiraling, a compact footprint of $1.5\times1.5\text{cm}^2$ is achieved. Side coupling with tapered lens fiber is accompanied by a loss of 2.8dB per facet. From the measurement of the time delay over wavelength using the time-of-flight technique shown in Fig. 1(a), a dispersion parameter of around -0.4ps/nm/m at 1550nm and a dispersion slope of $1.4\text{ps/nm}^2\text{/m}$ was extracted.



(a) (b) (c)

Fig. 1. (a) Measured dispersion characterisics of the waveguide. (b) Idler power dependence on coupled pump power. (c) Conversion efficiency dependence on the signal-pump detuning.

A four-wave-mixing experiment was done as follows. A strong continous-wave (CW) pump at 1563nm was mixed together with a signal 1nm apart. The influence of phase mismatch is negligible at this small detuning. The power of the signal is held constant at 16.1dBm and we track the power of the generated idler as we increase the pump power. The results are shown in Fig. 1(b). As expected the plot shows the constant (quadratic) dependence of the FWM process on the pump power without any saturation of energy conversion. At a coupled pump power of 32.7dBm an idler power of -18.6dBm is observed at the end of the waveguide. The achieved output conversion efficiency ($P^{out}_{idler}/P^{out}_{signal}$) of -22.4dB is 18dB lower than with state-of-the-art SOI waveguides [6], but the absolute generated idler power is about an order of magnitude higher. The estimated nonlinear coefficient of this system is 285/W/km in agreement with [5]. The influence of an increased signal and pump spacing on the converted idler is shown in Fig. 1(c). The detuning results in a higher phase mismatch in the FWM process and thus worse conversion efficiency. At 2.1nm signal-pump spacing the conversion efficiency dropped by 3dB. Broader conversion bandwidths should be possible by optimizing the waveguide cross-section geometry for lower dispersion while maintaining low losses.

## 3. Bit-Error-Rate (BER) measurements

In order to study the feasibility of the wavelength conversion process, we analyze its suitability for typical optical communication signals. We consider 10Gb/s Non-Return-to-Zero (NRZ) on-off keying (OOK) data. The setup can be seen in Fig. 2(a). After the chip, the converted idler wave is filtered out, its power controlled via a variable optical attenuator (VOA), and launched into the receiver stage. The receiver consists of a pre-amplifier and filter in the optical domain as well as RF-amplifier and decision circuit after the photodiode. The converted data is benchmarked with respect to the modulated signal before being sent into the chip. Our BER analysis shows 1dB penalty (at BER of $10^{-9}$) for signal-pump spacings up to 3nm as shown in Fig. 2(b).

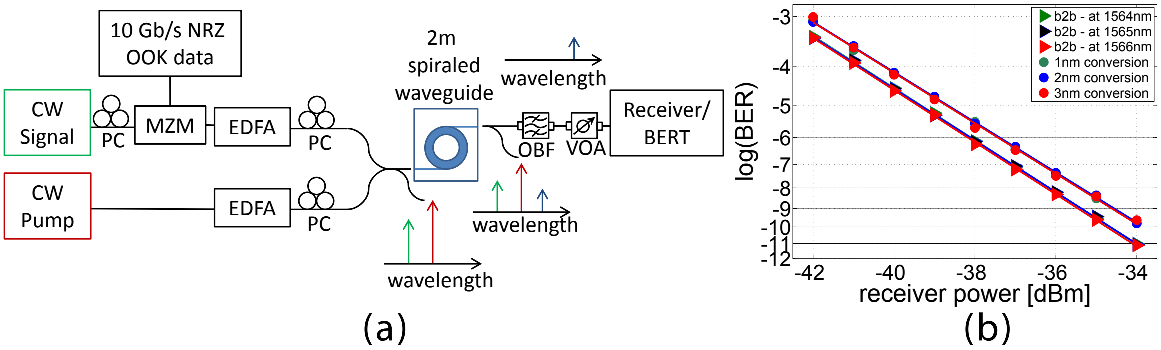


Fig. 2. (a) Setup for BER meaurements. Polarization Controller (PC). Mach-Zehnder Modulator (MZM). Erbium-Doped Fiber Amplifier (EDFA). Optical Bandpass Filter (OBF). Variable Optical Attenuator (VOA). Receiver/Bit-Error-Rate-Tester (BERT). (b) BER curves.

## 4. Conclusion

We have demonstrated that low loss (6dB/m) $Si_3N_4$ waveguides [5] have strong potential in the integration of nonlinear optics. The waveguide design allows the usage of high coupled power (32.7dBm) while it shows no significant two-photon absorption. A 2m long waveguide was used to generate an absolute idler power of -18.6dBm. A dispersion value around -0.4ps/nm/m limits the bandwith of the system. Work is ongoing towards dispersion optimization while maintaining low loss. The feasibility of the wavelength conversion process was shown in a BER measurement experiment with 10Gb/s NRZ on-off keying data.

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