

# CMOS-compatible low-loss silicon nitride waveguide integration platform for interferometric sensing

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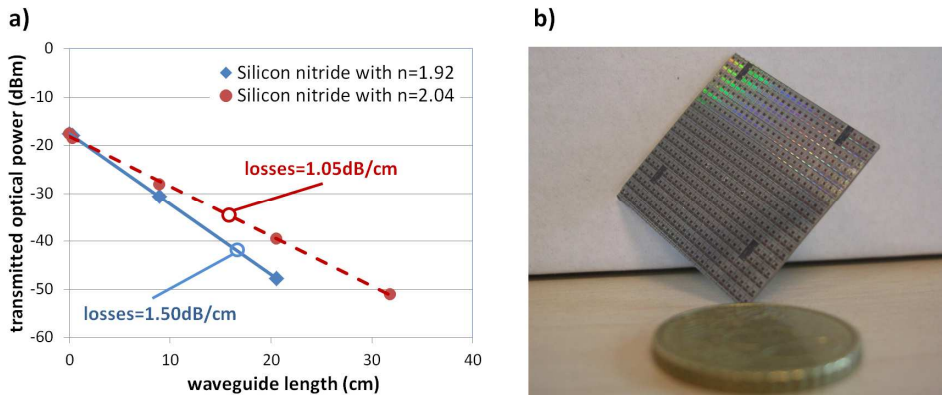
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During the past fifteen years, the major driving force for extensive research in the field of silicon photonic integrated circuits has been the continuously increasing data traffic to be transmitted over optical fiber links. The focus has therefore been on silicon-on-insulator (SOI) based optical waveguide technology, which cannot be applied for shorter wavelengths in the visible and near infrared region at wavelength smaller than 1.1 $\mu$ m. However, the <1.1 $\mu$ m wavelength region is most relevant for life sciences and health related applications such as evanescent biosensing and novel medical imaging diagnostic applications, which gained significant importance in recent years. Many of these applications are based on interferometric sensing principles.

In order to overcome the drawbacks of SOI, we present a silicon nitride waveguide based photonic integration platform realized by means of a low temperature plasma enhanced chemical vapour deposition (PECVD) process for the silicon nitride waveguide layer and the top & bottom silicon dioxide (SiO<sub>2</sub>) cladding layers. Such an approach has already been pursued successfully in the past [1, 2]. However, in contrast to preceding works, we aim at the monolithic integration of the waveguides on top of a CMOS optoelectronic chip comprising photodiodes with which the light propagating in the waveguides can be directly detected. A main challenge in this context is the planarity of the lower buffer oxide covering the uneven surface of the optoelectronic chip. To this end, a process is required that provides a sufficiently planar surface for the waveguides.

A first task was the development of a low-loss silicon nitride waveguide fabrication process on bare silicon wafers without integrated photodiodes. For this purpose, we compared the losses of waveguides with different thicknesses measured for TE and TM polarization at a wavelength of 850 nm. From these results we were able to determine the main sources of the losses. About 90% of the losses can be attributed to absorption and scattering in the silicon nitride waveguide core. Only ~10% of the 1.5 dB/cm (see blue line in Fig. 1a) losses for a waveguide cross-section of 600x250 nm<sup>2</sup> are caused by other loss mechanisms such as roughness at the dry etched sidewalls or scattering in the SiO<sub>2</sub> cladding. This proves the high quality of the etching process. The observed propagation loss of 1.5dB/cm is slightly higher than in our previous demonstration [3]. This can be attributed to the fact that SiO<sub>2</sub> was used as top cladding instead of photoresist SU-8 in our former experiments. Since the refractive index of SiO<sub>2</sub> (n=1.46) is lower than that of SU-8 the light is more strongly confined in the waveguide core, which gives rise to loss.



**Fig. 22. a) Transmitted optical power for different waveguide lengths and two different types of silicon nitride. From the slope a loss value of 1.5 dB/cm can be calculated for the silicon nitride with a refractive index  $n=1.92$  (blue line) and 1.05 dB/cm for the silicon nitride with  $n=2.04$ . b) Optoelectronic chip with several hundreds of integrated photodiodes. In the foreground a 50 € cent coin is shown for the sake of size comparison.**

With an optimization of the deposition process of the silicon nitride waveguide layer we were able to significantly reduce these losses. The red dashed line in Fig. 1a) is the result of loss measurements for a silicon nitride waveguide layer with a refractive index of 2.04. The measured loss value of 1.05 dB/cm corresponds to a decrease of the losses by 30%. Eigenmode simulations suggest that for a waveguide cross-section of  $160 \times 800 \text{ nm}^2$ , which represents an optimized geometry for interferometric sensing applications, losses as low as 0.4 dB/cm can be achieved.

In a second step, the waveguide layer stack was fabricated on top of a wafer tightly packed with integrated photodiodes (see Fig. 1b). After adapting a chemical mechanical planarization process, the same low propagation loss was measured as on the samples without integrated photodiodes.

It has to be pointed out that all fabrication steps were performed in a commercial CMOS foundry environment. The results of this study open up the path for interferometric measurements employing optical waveguides monolithically co-integrated with silicon photodiodes.

## References

- [1] A. Gorin et al., *Fabrication of silicon nitride waveguides for visible-light using PECVD: a study of the effect of plasma frequency on optical properties*, Optics Express, Vol. 16, No. 18, pp. 13509–13516, 2008.
- [2] A. Z. Subramanian et al., *Low-Loss single mode PECVD silicon nitride photonic wire waveguides for 532–900 nm wavelength window fabricated within a CMOS pilot line*, IEEE Photonics Journal, Vol. 5, No. 6, pp. 2202809, 2013.
- [3] P. Muellner et al., *CMOS-compatible  $\text{Si}_3\text{N}_4$  waveguides for optical biosensing*, Procedia Engineering, Vol. 120, pp. 578–581, 2015.