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# Research Report

## SiON-Based Integrated Optics Devices for WDM Networks

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*Abstract* - We have used silicon-oxy-nitride (SiON) waveguide technology to fabricate low-loss, compact and tunable integrated optical devices. Examples of devices realized in this technology include thermo-optically tunable gain equalizers and flat-passband add-drop filters.

# 1. Introduction

## Introduction

We give an overview of devices made using SiON waveguide technology. These waveguides consist of a waveguide core made of silicon-oxynitride between cladding layers made of silicon-oxide [1]. Variation of the nitrogen-to-oxygen ratio in the core layer allows the refractive index contrast of the waveguide to be adjusted, from the low index contrast of fiber-matched technologies to the high contrast of semiconductor waveguides. For the devices presented here, the refractive index contrast was chosen about four times higher than in standard fiber-matched technologies. This allows us to use small bending radii and make complex devices on a small area, while retaining low coupling and propagation losses.

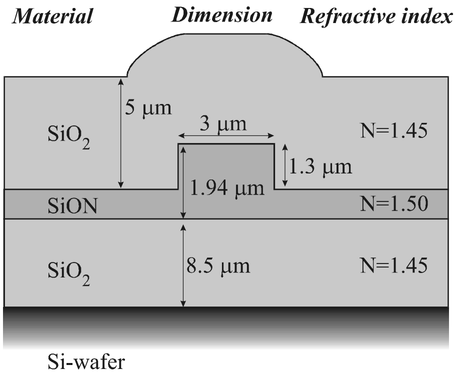


*Fig. 1: Cross section showing the geometry of the SiON waveguide structure.*

*Technology*

A cross section of the waveguide geometry is shown in Figure 1. The lower cladding layer is formed by thermal oxidation of the silicon substrate. The SiON core layer and $SiO_2$ upper cladding layer are deposited by plasma-enhanced chemical vapor deposition (PECVD). The waveguide pattern is defined by optical contact lithography and transferred to the SiON layer by reactive ion etching (RIE) [1]. To enable device tuning, adjustable thermo-optic phase shifters are implemented by chromium heaters deposited over the waveguides.

The refractive indices of core and cladding layers are approximately 1.50 and 1.45, respectively. This strong guiding of the mode allows a bending radius of less than 0.8 mm without introducing noticeable radiation losses. The propagation losses of the waveguides are below 0.1 dB/cm in the 1550 nm band.

The waveguides have a relatively small geometrical cross section compared to standard single-mode fibers. Nevertheless, a coupling loss of less than 0.6 dB per facet can be obtained by using a short section of small-core fiber, fusion-spliced to the standard fiber and butt-coupled to the optical chip.

## Devices

The small bending radius of SiON waveguide technology allows the fabrication of complex optical components by combining a number of simple building blocks:

- asymmetric Mach Zehnder (MZ) stages or delay lines for wavelength filtering,
- symmetric MZ stages, which can be used as tunable couplers as well as switches,
- ring Resonators with free spectral ranges of up to 50 GHz, which can be used in narrow-band phase and amplitude filters.

One example of a device where we have used this approach is a fully tunable $7^{th}$-order Finite Impulse Response (FIR) filter [2], used to dynamically flatten the gain curve of an erbium-doped fiber amplifier (EDFA) [3]. This device consists of a chain of 15 tunable MZ elements: eight tunable couplers, and seven delay lines.

The device layout is shown in Figure 2, together with the measured gain-flattening results. The fiber-to-fiber losses for this device are 3.5 dB.

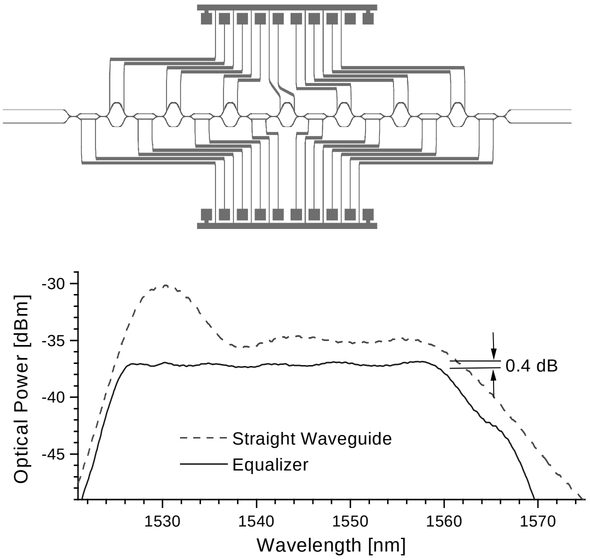


*Fig. 2: Gain equalizer, realized as a seven-stage FIR filter. Top: device layout. Bottom: Spontaneous emission spectrum of an EDFA (dashed line) flattened using the gain equalizer (solid line).*

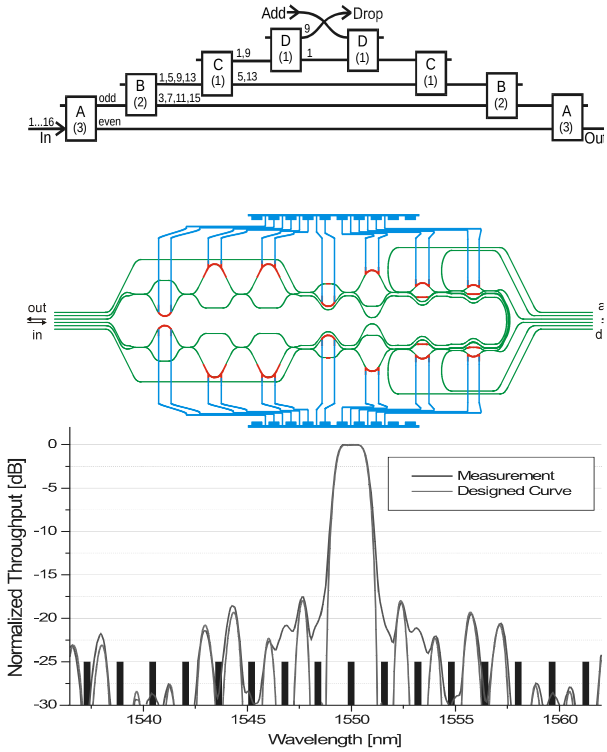


*Fig. 3: Logical (top) and physical (middle) layout of the binary tree 1-from-16 add-drop filter, and in-to-drop transfer function (bottom).*

In the second example, we have used up to three tunable asymmetric MZ stages and fixed directional couplers to build tunable flat-pass-band wavelength slicer units. By combining eight slicer units on one optical chip in a binary-tree-like structure we have realized a tunable 1-from-16 add-after-drop filter [4]. The logical and physical device layouts and measured transmission curve for this filter are shown in Figure 3. The fiber-to-fiber losses are 4 dB. The channel isolation is 20 dB.

*Conclusion*

These two wavelength-filtering examples show that, due to the small bend radius, complex devices consisting of many optical building blocks can be made using SiON waveguide technology. Using ring resonators, phase-filtering devices such as dispersion compensators [5] can also be made. Owing to the low-transmission-loss waveguides and low-loss coupling to standard single-mode fiber, the high device complexity does not come at the expense of high losses.

**References:**


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