Compact and Efficient Silicon Nanowire to Slot Waveguide Coupler

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***Abstract*—We propose a Y-branch coupler to efficiently transfer light from a silicon nanowire waveguide to a slot waveguide. The coupler is 500 nm long and functions with greater than 90 % efficiency over a 200 nm bandwidth when operated either in air or solvent. Its versatility makes it a good candidate for photonic circuits with applications including sensing, nonlinear optics and information processing.**

I. Introduction

Planar lightwave circuits (PLC) offer an attractive platform for dense integration of photonic devices. In applications such as sensing, nonlinear optics and optical trapping, it is desirable to have a confined high electric field outside of the host slab material, in the surrounding medium. Slot waveguides are candidates for such applications as they confine light to a small gap ($\sim$ 100 nm) between two dielectric slabs [1]. Resonator structures, such as ring resonators and photonic crystal cavities can be integrated with slot waveguides in order to further enhance the field intensity within the slot.

Since ridge or nanowire waveguides are most often used for routing signals in PLC, it is important and nontrivial to efficiently couple light from them into slot-style waveguides. The challenge is rooted in the effective index and mode profile mismatch between typical nanowire and slot waveguide modes.

Several proposed designs for efficient coupling between nanowire and slot waveguide modes include structures in which tapers delocalize the mode from the nanowire and the evanescent fields are coupled into the slot [2], [3], [4], [5]. High transmission efficiencies ($\sim$ 97%) have been achieved with tapered structures [2], [3] which are approximately 10 μm in length.

In this work, we propose a Y-branch nanowire to slot waveguide coupler which is $\sim$ 500 nm in length and has $>$ 90% efficiency for both forward and reciprocal coupling, both in air and solvent, over a bandwidth of 200 nm.

II. Design and Simulation

A compact coupler, shown in Fig. 1, is designed to efficiently couple light between the fundamental transverse electric (TE) mode of a 500 nm wide nanowire waveguide in a 220 nm silicon slab and the lowest order TE slot waveguide

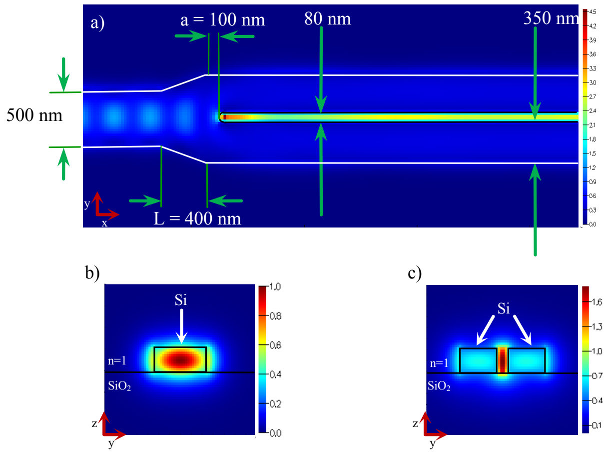

Fig. 1. a) The proposed nanowire to slot waveguide structure is outlined in black along the outer extremities and in white along the slot. The intensity profile at $\lambda = 1550$ nm is plotted along the $z = 0$ plane for a coupler with L = 400 nm, and a = 100 nm and coupling efficiency 92%. For positive (negative) a, the slot end is outside (inside) of the tapered region. Mode intensity profile is plotted for a) the fundamental silicon nanowire mode, and b) the lowest order slot waveguide mode at $\lambda = 1550$ nm.

mode of two 350 nm wide dielectric slabs, separated by a 80 nm wide slot. The silicon nanowire is linearly expanded over length L out to the two dielectric slabs. The slot is truncated with a circular end cap, positioned a distance a away from the slot waveguide end. The silicon slabs sit above silicon dioxide, and is immersed in either air or solvent with refractive index 1.365 at 1.55 μm.

The structure is studied using finite-difference time-domain simulator from Lumerical Solutions [6]. The nanowire mode is launched and the transmission through the cross-section of the slot waveguide is monitored. In order to determine the coupling efficiency of light into the lowest order slot waveguide mode, the overlap integral between the transmitted field and the slot mode profile is calculated. The nanowire and slot waveguide mode intensity profiles in the cross-section plane are plotted in Fig. 1(b) and (c), respectively.

The width of the two dielectric slabs of the slot waveguide are chosen such that light is primarily coupled into the mode shown in Fig. 1(b), and there is minimal coupling to other slot

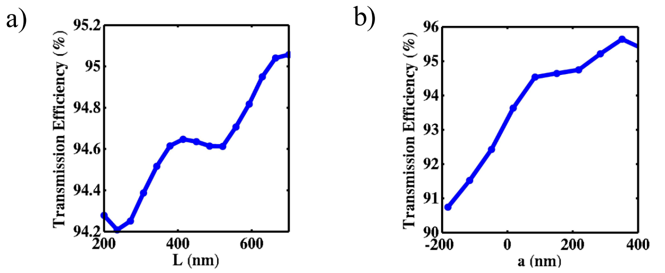

Fig. 2. The transmission is plotted as a function of a) the coupler length L (with a =100 nm), and b) the position of the slot end a (with L = 400 nm), for λ = 1550 nm.

waveguide modes which have lower concentration of light in the slot region.

The structure is optimized based on the transmission from the nanowire to the slot waveguide, as measured by the monitor. Fig. 2(a) shows that the transmission varies slowly as a function of the taper length, for L = 200 to 700 nm and $a = 100$ nm. A coupler length of 400 nm yields a transmission efficiency of $> 94\%$, and offers a desirable balance between efficiency and footprint. The transmission is further investigated by adjusting the position of the slot end, a, as plotted in Fig. 2(b). The transmission for a coupler that is 500 nm long (L = 400 nm and a =100 nm) is 94%, and the coupling efficiency of light into the lowest order slot waveguide mode is 92% at λ = 1550 nm. The reciprocal coupling efficiency, for light propagation from the slot waveguide mode to the nanowire waveguide mode is also found to be 92% for the same coupler design. To simulate a solvent environment, as might be used in sensing or trapping applications, the background index of refraction, n, was changed from air to hexane (n = 1.365) and the new coupling efficiency at 1550 nm is found to be 94%. The coupling efficiency is found to be $> 90\%$, over a 200 nm bandwidth centered at λ = 1550 nm, for both forward and reciprocal couplings in air and hexane.

III. Conclusion

We present the design of an efficient and compact structure for coupling between silicon nanowire waveguides and slot waveguides. The coupler length is ~ 500 nm long, and 90% coupling efficiency is achieved over a bandwidth of 200 nm both in air and solvent environment. This efficiency is higher than that found for the other reported submicron designs and is on par with those found for tapered converter designs which are several microns long. This shows potential for compact and efficient integration of slot waveguides based devices in photonic circuits for applications in sensing, nonlinear optics and optical trapping.

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