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# Photonic Devices Based on Optical Forces

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**Abstract**

A self-aligned photonic coupler, consisting of a tapered fiber and a suspended rectangular waveguide, is presented as a new approach for optical interfacing from SMF fiber domain to integrated photonic domain. The alignment occurs due to optical forces and a theoretical maximum transmitance of -1.4dB as well as significant attractive optical force range of 1.25µm for 1mW of input power are demonstrated. For a non-optimized geometry of 660nm taper diameter and 240x220nm waveguide, this result already matches transmitance for typical approaches for this interfacing.

***Key words:***
*Optics, Photonics, Optical Forces, Optomechanics, Self-alignment*

## Introduction

Optical forces originate by radiation pressure and dipole induction on dielectric materials under strongly varying electromagnetic field profile. In this project we explore this fenomena to tackle a technical challenge in photonics: the optical interfacing between the optical fiber domain (mode diameter of tens of micrometers) and the integrated photonics domain (mode diameter of hundreds of nanometers). Typical approaches to launch light from one domain to another, either require submicron alignment precision (as in edge coupling with lensed fiber and inverse taper) or faces polarization and bandwidth limitations (as in grating couplers).

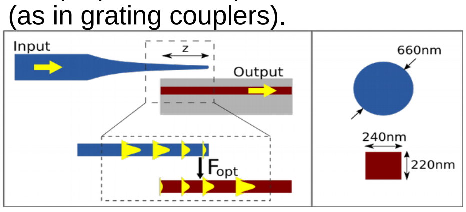


**Image 1.** Schematic of the coupler concept. Blue represents silica, red, silicon and yellow, power and modal profile. Light is lauched in a 660nm diameter tapered fiber and coupled to an integrated waveguide with 240nm width and 220nm height. The fiber is subject to an optical force that aligns the system.

To overcome those limitations, our goal is to design a photonic coupler that is self-aligned by means of optical forces. On image 1 we show a schematic of our coupler concept. The geometry was chosen to allow high coupling efficiency, by matching effective indexes, and attractive optical force for center-to-center distances of over a micron.

## Results and Discussion

We characterize the four modes of this two-waveguide system as TE or TM like - for horizontal or vertical polarization - and symmetric or antisymmetric according to the relative symmetry to the field polarization in each waveguide. Symmetric (antisymmetric) modes excerts attractive (repulsive) forces.

The input mode (carrying a power *P*) excites each mode with effective index $n_{eff,i}$ at the interaction section of length *z*. Thus, the amount of excitation is related to the coupling coefficients, $a_i$. From the Response Theory of Optical Forces[1], the optical force can be expressed as follows:

$$\mathbf{F}_{opt} = \frac{Pz}{c} \sum_{i=1}^{M} a_i \, \nabla_{\mathbf{q}} n_{eff,i}$$

where the summation is performed over the four modal families on the interaction length and the gradient is with respect to ***q***, the center-to-center taper position. On image 1, we show the acceleration map, due to the optical force, for a horizontally polarized input mode. It can be seen that for a range of one micron the attractive optical force can result in accelerations of tens of g's – gravity acceleration.

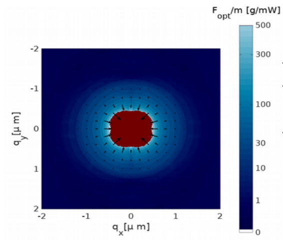


**Image 2.** Acceleration in g's (g=9.8m/s²) for a silica cylindrical rod under the optical force for 1mW of input power. In red is represented positions not allowed for the fiber taper center due to the waveguide's presence at the origin. For a distance of 1.25µm the optical force corresponds to 1g and is rapidly increasing as q decreases.

The transmitance for a horizontally polarized input and a TE output shown on image 3. For taper positions at the axis, the guided modes have orthogonal polarization due to symmetry, meaning no beating and a constant transmitance with respect to z.

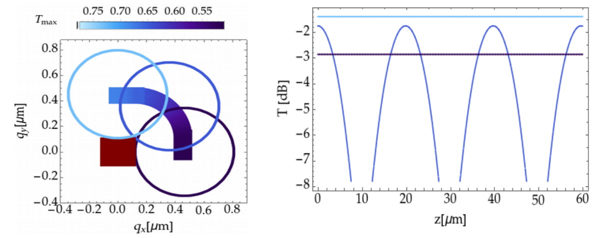


**Image 3.** Device transmitance for final positions – taper touching the waveguide. Curve for taper center final positions with the trasmitance for z=0 represented by the color scheme (left). Transmitance as a function of interaction length for the three respective situations depicted on left (right).

For non-symmetric taper positions the output power depends on beating lengths of tens of micrometers – manageable experimentally.

## Conclusions

Theoretical results show a self-aligned photonic coupler with optical force range of 1.25µm (for optical-induced acceleration of 1g/mW) and maximum coupling efficiency of -1.4 dB. Although the chosen geometry is not optimized, it shows better performance than grating couplers (-3.5 to -5 dB) [2] and comparable to edge coupling (-1dB) with the advantage of coarser alignment precision. However, other mechanisms should play important role on the device actuation, such as brownian motion and mechanical stresses, and will be explored.

## Acknowledgement

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[1] Wang Z, Rakich P., Optics express. 2011 Oct 24;19(22):22322-36.
[2] M. H. Lukas Chrostowski, Silicon Photonics Design: From Devices to Systems, 1st ed. (Cambridge University Press, 2015).

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