

Silicon-on-Insulator Grating Duplexer for Fiber-To-The-Home Transceivers

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Abstract— We present the design of an ultra-compact duplexing structure in the silicon-on-insulator material system based on a diffractive grating structure. This device has a $10\mu\text{m}\times 10\mu\text{m}$ footprint and combines fiber-to-chip interfacing and duplexing operation.

I. INTRODUCTION

The high refractive index contrast that can be achieved in the silicon-on-insulator (SOI) material system, makes it a promising platform for high-density integrated optics. Moreover, standard complementary metal oxide semiconductor (CMOS) technology can be used for fabrication, improving the performance, yield and reproducibility, while reducing the cost of the integrated circuits due to economies of scale. However, the high refractive index contrast induces a large mismatch between the size of the SOI waveguide mode and that of a single mode optical fiber, making efficient coupling of light between the optical fiber and the SOI waveguide circuit a nontrivial task. Diffractive grating couplers have been proposed to achieve efficient coupling [1], which are very compact and do not require a polished facet to couple light into the photonic integrated circuit. This allows wafer-scale testing and easy packaging of the photonic integrated circuits. Although the use of high index contrast gratings allows a 3dB optical coupling bandwidth on the order of 50-100nm, in transceivers for fiber-to-the-home optical networks (FTTH) a larger optical coupling bandwidth is required, because of the fact that light in two distinct (and widely separated) wavelength bands needs to be processed by the photonic integrated circuit [2]. In these optical networks, a 1310nm wavelength is used at the subscriber side to transmit upstream data over the network, while a 1490nm downstream optical signal needs to be processed by the transceiver circuit (and vice versa at the central office side). As the wavelength span required in this application exceeds the optical bandwidth of the fiber-to-waveguide grating coupler, an alternative approach is needed, which increases the effective wavelength span. However, the advantage of

being compact and allowing wafer-scale testing and ease of packaging should be maintained. Therefore, in this paper the use of a grating coupler is extended to allow operation in two distinct wavelength bands. Moreover, while both wavelength bands will be efficiently coupled into or out of the photonic integrated circuit, they will be duplexed at the same time, as they are spatially separated on the photonic integrated circuit, thereby combining fiber-to-chip interfacing and duplexing operation.

II. GRATING DUPLEXER DESIGN

The proposed grating coupler structure to achieve duplexing operation and fiber-to-chip interfacing is presented in figure 1. It consists of a one-dimensional grating structure defined on an SOI waveguide platform. The single mode optical fiber is tilted by an angle θ with respect to the vertical axis. While in standard fiber-to-waveguide grating couplers only one access waveguide is used, in this grating structure both access waveguides are used to expand the wavelength range over which light can be efficiently coupled between the photonic integrated circuit and a single mode optical fiber, while at the same time perform the duplexing operation for wavelength band λ_1 and λ_2 , as shown in figure 1. While depicted in a standard transceiver configuration, both wavelength bands can be used for upstream and downstream communication, due

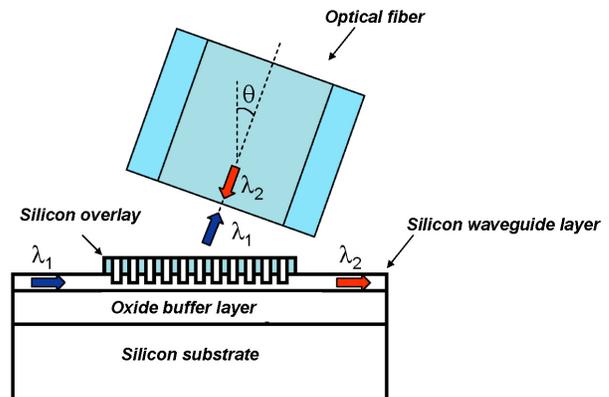


Fig. 1. Layout of the proposed diffractive grating duplexer structure

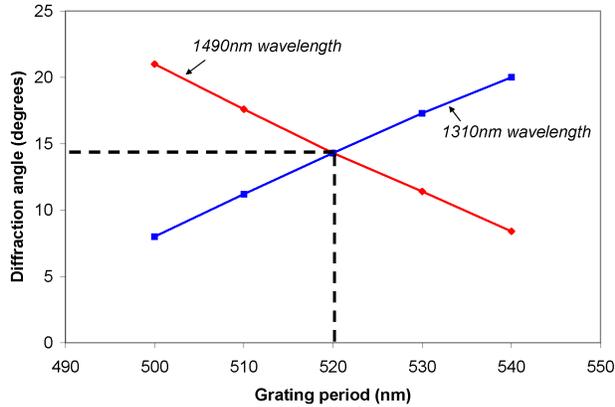


Fig. 2. Diffraction angle of light with a wavelength of 1310nm (1490nm) exciting the grating from the left hand side (right hand side)

to reciprocity. The grating is constructed by locally defining an additional silicon overlay after which the grating is defined by etching a one-dimensional array of slits in the layer stack. As was shown in [3], this device geometry allows an important increase in fiber coupling efficiency compared to the case of directly etching a grating structure in the silicon waveguide core layer. Although these devices can be designed to allow duplexing operation for a wide variety of wavelength band combinations, the particularly important application of duplexing a 1310nm wavelength channel and a 1490nm wavelength channel, for use in FTTH transceivers, will be discussed. Several parameters of the proposed grating structure need to be optimized to achieve optimal duplexing operation for these envisioned wavelength bands, including the silicon overlay thickness, the grating etch depth, the grating period and grating duty cycle, the number of grating periods, the tilt angle of the optical fiber and its optimal position with respect to the grating. A 220nm thick silicon waveguide core on top of a 2 μ m buried oxide layer is assumed. In this analysis, only TE-polarized light will be considered. Although the proposed one-dimensional grating duplexer is very polarization dependent, a two-dimensional grating duplexer structure could be used [1], allowing to achieve polarization independent operation by using a polarization diversity configuration. The grating etch depth is fixed to 220nm in order for the grating definition to be compatible with the etching of the SOI waveguide structures (etched completely through the 220nm silicon waveguide core), thereby reducing the amount of processing steps required for the definition of the ultra-compact duplexer structure. For the simulations, a two-dimensional vectorial eigenmode expansion tool with perfectly matched layer absorbing boundary conditions was used (CAMFR)[4]. The silicon overlay thickness and the grating duty cycle were optimized in order to maximize the average

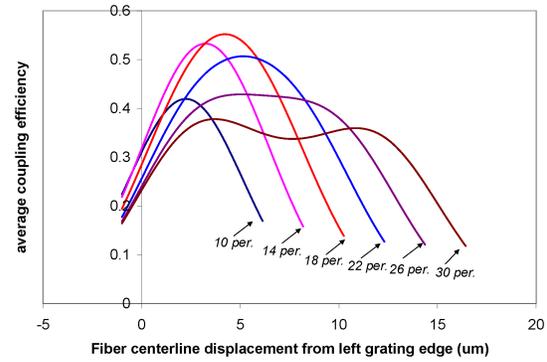


Fig. 3. Average fiber coupling efficiency of both wavelength channels as a function of the number of grating periods and position of the optical fiber

grating directionality (being the fraction of optical power diffracted upwards by the grating to the total diffracted power when excited from the SOI waveguide) for the 1310nm wavelength channel and the 1490nm wavelength channel. This led to an optimal grating overlay thickness of 140nm and a grating duty cycle (defined as the ratio of the slit width to the grating period) of 60 percent. The average grating directionality is higher than 80 percent, similar to the results obtained in previous work [3]. The grating period and tilt of the single mode optical fiber was determined by plotting the diffraction angle of light with a wavelength of 1310nm (1490nm) in the air superstrate, by exciting the grating from the left hand side (right hand side). The results are plotted in figure 2, showing that for a grating period of 520nm, both wavelengths have an identical diffraction angle of 14.3 degrees. By placing the fiber under this angle with respect to the vertical axis, duplexing operation can be achieved. A final set of parameters to optimize is the extent of the grating (the number of grating periods) and the position of the optical fiber with respect to this grating. A single mode fiber with a mode field diameter ($1/e^2$ intensity width) of 10.4 μ m was used. In figure 3, the average fiber coupling efficiency of the 1310nm wavelength channel and the 1490nm wavelength channel is plotted for different grating lengths (expressed by the number of grating periods), as a function of the position of the symmetry axis of the optical fiber (the centerline indicated by the dashed line in figure 1) with respect to the left hand side edge of the silicon overlay. The coupling efficiency to optical fiber was assessed by exciting the grating structure from the respective access waveguides with the power normalized fundamental SOI waveguide mode (for the respective wavelengths of 1310nm and 1490nm) and by calculating the diffracted field at a distance above the diffraction grating for both wavelengths. The fiber coupling efficiency for the respective wavelength channels is then obtained by

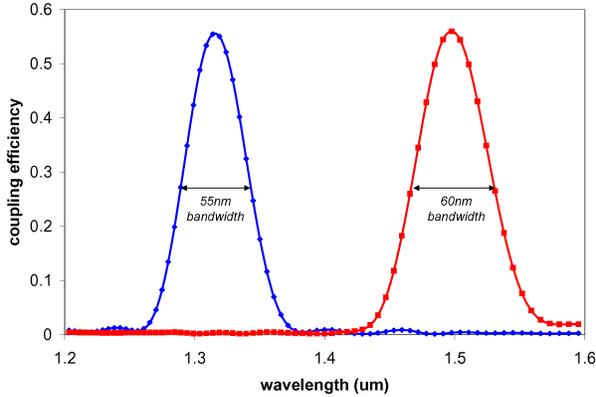


Fig. 4. Coupling efficiency spectrum for both wavelength channels for the optimized duplexer grating

evaluating the overlap integral with the Gaussian fiber mode. This overlap integral is evaluated for both wavelength channels, while varying the fiber centerline position, leading to the average fiber coupling efficiency as a function of fiber position and grating length, as plotted in figure 3. From this simulation we can conclude that there exists an optimum grating length (corresponding to 18 grating periods) and fiber position, for which the average fiber coupling efficiency is maximal. The fiber-to-grating alignment tolerance is about $\pm 1\mu\text{m}$, which is sufficient for practical applications. The optical bandwidth of the ultra-compact duplexer was assessed by two-dimensional FDTD simulation, in which the fiber-to-waveguide coupling efficiency of the optimized device was calculated by illuminating the duplexer structure with the optical fiber mode. The resulting coupling efficiency spectrum into the respective wavelength channels is depicted in figure 4. This coupling spectrum shows a 3dB optical bandwidth of 55nm (60nm) for the 1310nm (1490nm) wavelength channel.

When using the diffractive grating structure in a transceiver application, in which one wavelength channel is used for upstream optical data transport (λ_1 in figure 1) while the other wavelength channel is used for downstream optical data transport (λ_2 in figure 1), the crosstalk between both wavelength channels has to be evaluated. This is illustrated in figure 5 for an upstream wavelength λ_1 and downstream wavelength λ_2 , while the simulated crosstalk as a function of grating length (number of grating periods) is plotted in figure 6 both for the 1310nm wavelength channel and the 1490nm wavelength channel as an upstream channel (1310nm at the subscriber side, 1490nm at the central office side). From this simulation, it is clear that sufficiently low crosstalk levels can only be obtained for long gratings, at the expense of a reduction in average fiber coupling efficiency. An alternative solution implies working in the optimum average coupling efficiency point (18 grating periods), while implementing an SOI waveguide

bandstop filter in the downstream path to improve the crosstalk performance of the device.

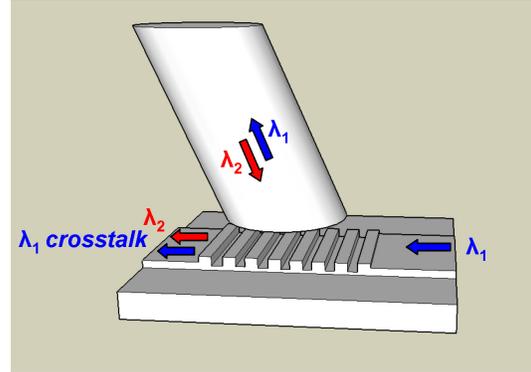


Fig. 5. Origin of crosstalk when the grating duplexer is used in a transceiver application

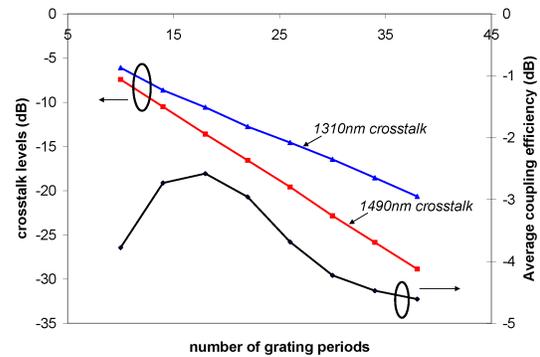


Fig. 6. Crosstalk and average fiber coupling efficiency as a function of the number of grating periods

III. REFERENCES

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