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Particle Swarm Optimization for Polarization-Independent and Low Loss Grating Couplers

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Silicon-on-insulator waveguide grating couplers suffers from some key problems like high polarization dependency due to its high index contrast. In order to overcome this problem refractive index engineering has been demonstrated as a suitable solution [1, 2]. However, the design complexity is highly increased interfering with the search of the optimal design. This work presents a particle swarm optimization (PSO) strategy applied to a polarization-independent grating coupler based on subwavelength structures for the near-infrared band. Furthermore, the achieved design is suitable to be fabricated with a single-fully-etch step and was constrained to have a minimum feature size ≥ 100 nm.

The first step is to define the silicon layer thickness. Although, experimental sub-decibel efficiencies with standard 220nm-thick-Si has been demonstrated [3], this layer thickness cannot fully exploit the basis of metamaterial polarization-independent grating couplers due to the small difference between the effective indices of TE and TM modes within the artificial material. We choose 320nm as the Si-thickness since it provides single-mode condition in a square Si/SiO_2 strip waveguide for polarization-independent performance in silicon photonic circuits (see Fig. 1b insets). Then, the non-optimized grating parameters are selected and fixed. In our case we fixed a total number of 20 grating periods, the depth of the buried-oxide-layer (2 μm) and top-oxide-layer (750 nm), fibre angle θ (10°), fibre-to-first-period grating (3.85 μm) and the pitch of the subwavelength structure (400 nm).

Due to time computational simulation constraints, it was necessary to make a trade-off between population size and the total optimized variable. We found that a good strategy was to treat each grating period separately and only put in the swarm as independent variables the filling-factor of the subwavelength trenches and the operating wavelengths. Hence, the longitudinal filling-factor and pitch are calculated to satisfy the phase matching condition. By this manner, a small population of 20 particles can work out the problem. Additionally, position boundary limits were taken into account to fulfil the fabrication constraints.

Coupling efficiency was calculated with 2D-FDTD simulations and the effective refractive index of the metamaterial trenches were obtained from a look-up table approximated by finite element method. To implement the algorithm, we developed an in-house script made in C along with RSoft software. Nonetheless, this algorithm can be implemented in any photonic software that supports scripting.

The algorithm took 150 iterations to converge towards the minimum fitness (see Fig. 1a). It has to be noted that there is a chance that the algorithm converged to a local minimum. However, the results show that coupling efficiency peak rises previous top-oxide-cladding PDL free gratings designs [1]. Fig. 1b shows the spectra coupling efficiency obtained by 2D-FDTD with the reported algorithm design. The peak coupling efficiency rises -3.5 dB for both polarizations and a PDL bandwidth of ~80 nm below 0.5 dB is also achieved. 3D-FDTD simulations were carried out for a waveguide width of 12 µm. It is interesting to notice that the 3D spectra are shifted with respect to the 2D results. Furthermore, the wavelength shift is larger for TE polarization. Similar differences for the 3D-FDTD simulated TE and TM spectra have also been shown in previous works [2].

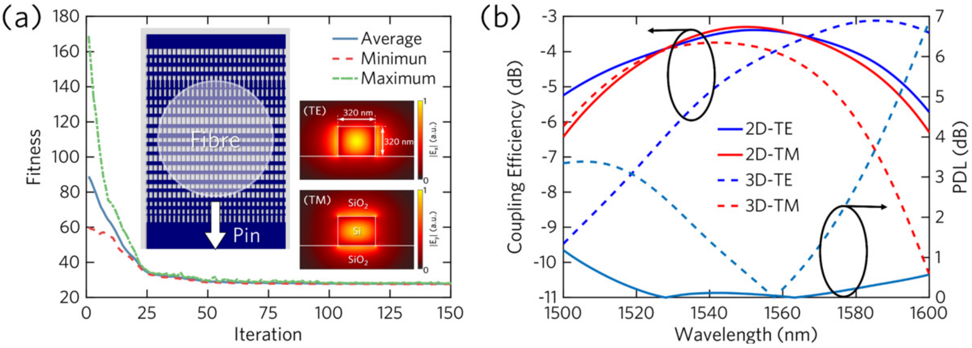

Fig. 1. (a) Fitness as function of iterations (insets show optimal grating top view and strip waveguide cross section). (b) Coupling efficiency calculated with 2D and 3D-FDTD.

In conclusion, particle swarm optimization has been used to obtain low loss grating couplers for enabling a polarization-independent performance in silicon photonics. Discrepancies between 2D and 3D-FDTD results have been obtained and are currently under investigation.

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