Efficient, Fiber-to-Chip Coupling and Optical Through-Silicon Vias for Monolithically Integrated Electronic-Photonic Circuits

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We show the design of efficient, vertical (out-of-plane) fiber-to-chip couplers for silicon photonics, monolithically integrated into state-of-the-art electronics CMOS. The designs improve upon standard grating couplers in photonics by breaking the symmetry of the structure (see Figure 1) to radiate all power up and nearly none downward. They are inspired by array antenna design, and make effective use of the available CMOS layers, particularly the polycrystalline silicon gate and crystalline body silicon layers for MOSFET transistors. In these layers, radiator elements are patterned to produce a unidirectional radiation pattern. The design is a compound grating structure, comprising repeated scattering "antenna elements" each of which comprises two blocks, and produces destructive interference downward and constructive interference upward.

Unidirectional grating designs proposed here show very high directivity of 50:1, and a bandwidth of ~100nm. Because they are uniformly periodic in this work, they have an insertion loss theoretically limited by the mode mismatch of the grating radiation pattern and the optical fiber mode which brings the efficiency to 75% typically giving an estimated insertion loss of 1.2dB, a 3dB improvement over standard uniform gratings whose directionality limits their coupling loss to ~4.2dB.

We also propose an efficient approach to "optical through-silicon vias" to enable low-loss optical coupling between dies in a multi-die stack. We show the optimum design of finite reach vias, and discuss the design of unidirectional grating structures to realize them.

Efficient fiber-to-chip and chip-to-chip coupling is critical to future integrated photonic interconnect applications including energy efficient CPU-to-memory interconnects. The designs presented, in future work combined with mode matching, demonstrated separately in previous work, will enable approaching nearly lossless couplers in design, and low-loss optical vias for multiple die stacking, an emerging technology for dense integration.

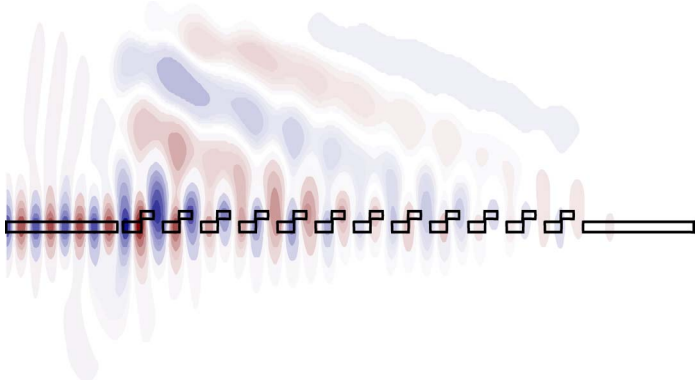

Figure 1: Radiation pattern and silicon distribution of unidirectional grating coupler.