

# Surface mounted tapered vertical Coupler for photonic Nanowires

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**Abstract**—A vertical nanowire coupler enables incoupling of Vertical-Cavity Surface-Emitting Lasers (VCSEL) into silicon photonic nanowires and connects electronic and photonic devices on the same substrate.

## I. INTRODUCTION

Single mode, high refractive index contrast silicon photonic wires offer small bending radii high integration density on a chip. High data rates on CMOS-CPU can be achieved due to the absence of electric interference. Typical dimensions for single mode waveguides with an oxide cladding are 220nm times 600nm, the losses are in the range of 2 dB/cm, but only a few millimetres are required for on chip systems.

An efficient coupler for the interface between the electric signal and the photonic wire is the key feature for the photonic integration on CMOS-CPU's. Grating couplers e.g. show coupling losses of less than 3 dB, but they need a certain angle of incidence (often  $10^\circ$ ) to insert the light without any reflections [1]. Since the wavelength range of gratings is limited as well, they have to be designed carefully to fit the bandwidth windows of other wavelength selective components. Filters showing production tolerances may run out of the coupler's bandwidth window. Coupling into cleaved wave guides ("endfire") overcomes those limitations, but a cleaved sidewall of the chip is required. The distance from the fiber to the system may be long, leading to increased costs (due to a higher demand of area) and higher signal losses. The number of "endfire"-couplers per chip depends on the edge length, which grows linearly, while the area grows quadratically.

In general, the output mode of an optical fiber or a semiconductor laser does not match the nanowire mode. In inverse tapers [2] the mode is enlarged, when the waveguide dimensions becomes smaller than the wavelength inside the material. These inverse tapers are short (a few  $10 \mu\text{m}$ ) in comparison to conventional adiabatic tapers, but an additional polymer wave guide is needed to guide the light exactly to the inverse tapers[3].

The critical alignment is done in the photolithography.

In this paper a  $45^\circ$ -mirror turns perpendicular irradiated light, which can be placed everywhere on the chip surface, into a polymer wave guide. An inverse taper couples the light from the polymer waveguide into a silicon nanowire.

## II. DESIGN AND FABRICATION

DUV (248 nm wavelength) contact lithography is used to fabricate the photonic wires. The wave guides are additionally smoothed and shrunk by thermal oxidation. This shrinkage enables the fabrication of very small tip widths ( $<50 \text{ nm}$ ) for the inverse tapers, having larger sizes ( $> 300 \text{ nm}$ ) on the mask. The fabrication steps are shown in fig. 1. A more detailed description is given in [4]. The topside of the waveguide is protected by a LPCVD-TEOS (Tetraethyl orthosilicate) silica to reduce unwanted height loss during oxidation. After DUV-lithography an anisotropic ICP-oxide and ICP-silicon etch is used for structuring. After photoresist removal, a low loss silicon dioxide cladding is built up by thermal oxidation. The oxidation temperature is  $1100^\circ \text{ C}$  in a dry process using 3 l/min pure  $\text{O}_2$ .

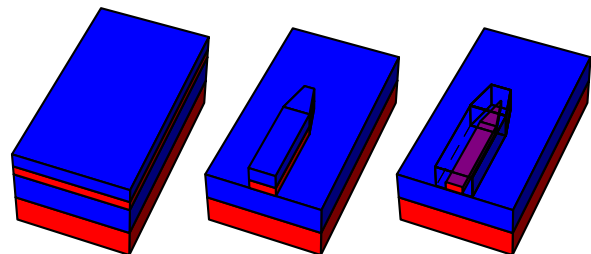


Fig. 1. Wave guide and inverse taper fabrication steps: TEOS deposition, lithography and TEOS/Silicon etch, thermal oxidation

The further fabrication steps are shown in fig. 2. The lithography for the mirror fabrication is done by a collimated laser beam with a wavelength of 405 nm and a power of 50 mW, which can irradiate the substrate under

angles from  $10^\circ$  to  $90^\circ$ . For this design, an angle of  $45^\circ$  is chosen. A 200 nm thick aluminium layer was sputtered as a mirror, using a low power process to avoid thermal damage to the photoresist. I-line contact lithography and wet chemical etch were used to remove the aluminium from the substrate except the mirror and the contact plane for the VCSEL. The photoresist on top of the aluminium is removed by an oxygen-plasma, while the photoresist beneath is protected by the aluminium. The polymer for the connection wave guide is spun on with a thickness of  $2\ \mu\text{m}$ . A negative photoresist (SU-8-2) is used, because it has low absorption at 1550 nm [5] and can be structured by I-line contact lithography. The system is completed and a VCSEL or a fiber can be applied.

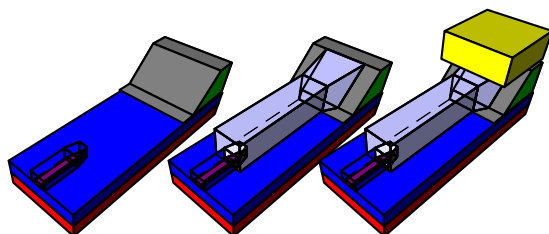


Fig. 2. Mirror and polymer wave guide fabrication steps:  $45^\circ$ -lithography and aluminium (sputtered and structured), SU-8 lithography, VCSEL application

### III. SIMULATION

Fig.3 shows a cross section SEM-picture of the  $45^\circ$  mirror with a polymer spun on. Using this cross section a FEM-simulation is done, which is shown in fig.3. The simulation results in fig. 4 show only a few percent change in coupling efficiency over a 100 nm wavelength band, which is more than a grating coupler can achieve. The VCSEL or fiber has to be positioned in a  $1.5\ \mu\text{m}$  range in propagation direction.

### IV. CONCLUSION

In this paper a short, broadband and polarization independent vertical coupler is described. A misalignment up to  $1.5\ \mu\text{m}$  does not change the coupling efficiency. The coupling efficiency can even be improved with an optimization of the mirror angle and thicknesses. The measurements are currently under investigation and will be presented at the conference.

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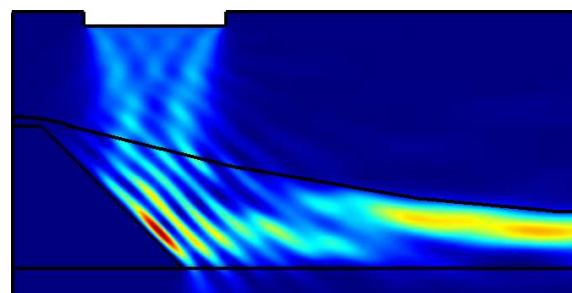
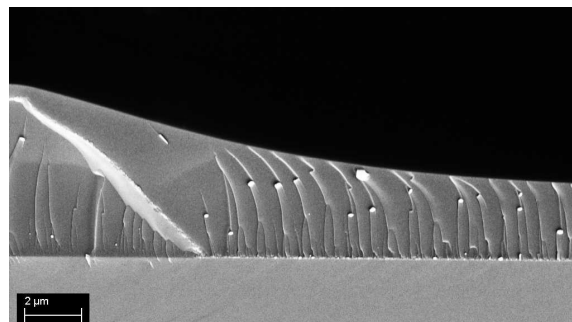


Fig. 3. a) SEM-Picture of a cross section through the mirror, b) a FEM-simulation (time-average powerflow is shown)

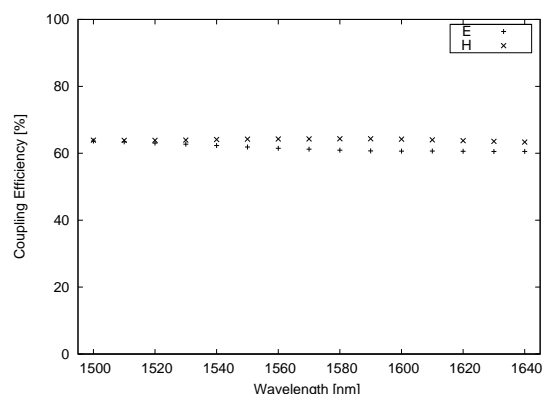


Fig. 4. Simulation results: Wavelength dependency of coupling efficiency

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