Laboratory manuskript:

**integrated grating couplers**

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1 Introduction

1.1 Nanowaveguides

Silicon photonics based on silicon-on-insulator (SOI) nanophotonic waveguides is a promising technology for integrated photonics due to unique properties of the ultra-high index contrast silicon waveguide systems, and due to the use of advanced microelectronics manufacturing technologies. In addition, the use of common process tools and advanced SOI substrates make silicon nanowires a natural choice for integration with advanced microelectronics.

1.2 Index contrast

Nanowaveguides are dielectric waveguides based on the refractive index contrast between a Silicon core and a Silicon oxide cladding. Due to the high index of Silicon (≈ 3.5), nanowaveguides differ considerably from more classic waveguide systems such as optical fibers. Optical fibers exhibit a small index contrast between core and cladding, nanowaveguides have a high index contrast. High index contrast results in particular properties of nanowaveguides. Without considering the physics behind these properties, we list in the following the most important features related to the high index contrast.

- increased polarization dependence (birefringence and polarization dependent loss)
- high confinement and small bending loss, leading to the possibility waveguide bends of just a few micron radius
- high intensities in the core of the waveguides, allowing for exploitation of nonlinear properties.
1.3 Mode mismatch

Despite such positive prospects a major stumbling block on the way to nanophotonics applications remains the issue of coupling light in and out of nanophotonic circuits by means of optical fibers. The major problem stems from the large mismatch in modesize of nanowires ($\propto$ a few hundred nanometers) and standard single mode fibers (e.g. SMF28, $\propto 10\mu m$), which is illustrated in 1.1.

![Figure 1.1: Comparison of mode field diameters of standard optical fiber (SMF28) and silicon nanowire waveguide. Nano-waveguide dimensions are typically $\propto 200nm \times 500 \text{ nm}$](image-url)
2 Gratings for coupling in/out light

One solution to this problem is lateral spotsise conversion in an adiabatic taper plus out-of-plane coupling by diffraction via a waveguide grating. The principle is sketched in Figure 2.1: Operation principle of a nanowire waveguide grating coupler (Source: D. Tail-laert et al., JJAP, 2006)

The physics underlying the operation principle of the grating couplers is straight forward. The equation governing this process can be deduced from fig. (2.2). In this simplified arrangement, two rays of light diffract upon a grating surface. If the optical path difference of ray 1 and ray 2 is a multiple of the wavelength \( \lambda \), constructive interference occurs. Figure (2.2) shows ray 2 undergoing an additional path of \( AB \) before diffracting, whereas ray 1 undergoes an additional path of \( CD \) after diffracting. The optical path difference is therefore given by:

\[
AB - CD = d(\sin(\Theta_i) + \sin(\Theta_m))
\]

(2.1)

If the optical path difference is a multiple of \( \lambda \), such as:
Figure 2.2: Sketch of diffraction principles on a grating

\[ d(\sin(\Theta_i) + \sin(\Theta_m)) = m\lambda \]  \hspace{1cm} (2.2)

we have constructive interference. Here \( m \) is an integer and is referred as the diffraction order, \( d \) refers to the grating period. Grating couplers are usually based on the 2nd order diffraction peak, which couples into the horizontally propagating fundamental mode of the nano-waveguide. The details concerning grating performance such as efficiency and filter characteristics are tightly connected to the high index contrast and the grating profile. The quantitative characteristics can therefore only be determined by numerical techniques such as FDTD (Finite Difference Time Domain). In the following, we shall just present the basic SOI waveguide grating characteristics without any further reference to grating physics.

### 2.1 1D grating couplers

The simplest grating coupler is based on a 1D grating structure 2.3. A grating period consists of a rectangular bar and a rectangular groove. The underlying waveguides are fabricated on 220nm thick SOI. The following features are characteristic for such grating structures:

- high index contrast due to relatively deep etch (≈70nm)
- relatively few grating periods (≈ 20)
Figure 2.3: 1D grating structure on an SOI nanowire waveguide

- tilted coupling out/in (i.e. not under normal incidence)
- only one polarization couples (e.g. TE)

A simulated spectral efficiency distribution is shown in Fig. (2.4). Typical coupling losses between a simple 1D structure and standard fibers are ~4 dB. A very important feature of grating couplers is their alignment tolerances with respect to the lateral alignment of the fiber above the grating structure (Fig. (2.5))

Figure 2.4: Efficiency of a 1D grating structure as a function of wavelength. The grating was optimized for coupling out at 1550nm
Figure 2.5: Alignment penalty of a standard single-mode fiber when misaligned to a 1D grating coupler. Depicted is the coupling efficiency as a function of displacement.

### 2.2 2D grating structures

To overcome the polarization dependence of 1D coupling structures the move to 2D grating structures is required. 2D grating structures offer the basic functionality of polarization splitting and rotation. They are therefore useful for polarization diversity schemes. The basic operation principle is depicted in Figure (2.6)
Figure 2.6: A 2D grating coupler decomposes the two orthogonal linear polarizations of the incoming light and couples them to the fundamental TE-modes of the waveguides. This way, polarization diversity can be achieved (Source W. Bogaerts et al, Opt. Express).
3 Experiment

Fig. (3.1) shows the experimental setup. The tunable laser (Agilent) is centered around the wavelength of $\lambda = 1.55\mu m$. The wavelength sweep averages about 100 nm and is used to characterize the transfer functions of the grating couplers. The optical output power of the tunable laser propagates through a single mode fiber (SSMF) into a polarization controller. The polarization controller is used to maximize the output power of the grating coupler which are very strong polarization dependent. The grating couplers are used to couple light into the nano-wire and to couple light out of the nano-wire into the SSMF as shown in Fig.(3.1). The optical power is then detected with a photo diode and the electrical output signal is processed in the PC.

3.1 Measurements

Your task is to measure:

- Coupling efficiency
- Polarization dependency
- 3-dB bandwidth
Bibliography


