# Grating assisted mode selective optical waveguide coupler

Sebastian Schlangen*, Kort Bremer*, Steffen Lochmann**, Ludger Overmeyer*, Bernhard Roth*

*Hannover Center for Optical Technologies, Leibniz University Hannover
**Communications Signal Processing Group, Hochschule Wismar

sebastian.schlangen@hot.uni-hannover.de

In fiber optical communication technology, the transmission capacity of single-mode fibers will soon be achieved. To keep pace with the increasing demand for transmission bandwidth, multimode division multiplexing (MDM) techniques are widely investigated. In this work, the proof-of-principle of a MDM based coupler structure is discussed using 2D-simulations.

## 1 Introduction

Today, several approaches to enhance the transmission capacity of single-mode (SM) waveguides appear feasible, based, e.g., on exploiting polarization, phase or wavelength of the light. Nevertheless the transmission capacity of SM-waveguides will soon be achieved [1]. One technique to keep pace with the increasing demand of transmission bandwidth is spatial division multiplexing (SDM) using multi-mode (MM) waveguides. In particular, mode division multiplexing (MDM) is a promising approach. There, different modes [2] or mode groups [3] of a MM-waveguide are used as transmission channels. One key challenge for MDM is the realization of transverse mode selective coupling elements. In our work we aim at the development of such waveguide couplers consisting of a SM- and a MM-waveguide with low crosstalk between neighboring mode-channels and low loss. The coupler will be manufactured by a fiber tapering-process which is simple and cost efficient. The coupling between individual modes is based on an optical grating structure in the SM-waveguide.

## 2 Grating assisted mode selective coupler

The coupler-structure consists of a SM- and a MM-waveguide, as shown in Fig. 1, to be realized by the above fiber tapering-process. The power exchange between the SM- and MM- waveguide cores can be realized by adaption of the propagation constants and evanescent fields. Usually, the former is achieved by tapering the waveguides beforehand. One disadvantage of this approach is that the waveguides have to be custom tapered for every mode, leading to more complicated manufacturing processes. To avoid this problem, the propagation constants can also be adapted by an optical grating structure inscribed in the SM-waveguide core. Thus, only the grating periods need to be adjusted for efficient coupling between different modes. The grating structure can be fabricated by illuminating a germanium doped UV-sensitive SM-waveguide using an excimer laser. The period length of the grating structure for coupling to individual modes is defined by

$$\Lambda = -\frac{2\pi}{\beta_{SM} - \beta_{MM}} \qquad (1)$$

where $\beta_{SM}$ and $\beta_{MM}$ are the propagating constants of the SM-waveguide mode and an arbitrary mode of the MM-waveguide.

*Fig. 1 CAD-Design of the SM-MM waveguide coupler with optical grating structure in the SM-waveguide (indicated by black structure).*

## 3 Proof-of-principle

2D-Model:

At the beginning the feasibility of the coupler principle was evaluated using 2D-simulations based on the Iterative Beam Propagation Method (IBPM) implemented with the BeamProp module in RSoft [5]. The coupler structure was defined by the core diameters of the SM- and MM-waveguides $d_{SM}$ and $d_{MM}$ as well as the distance $x_{MM}$ between them. The optical characteristics of the coupler are defined by the refractive indices of the SM- and MM-waveguide cores $n_{SM}$ and $n_{MM}$ and the cladding $n_{CL}$ which were adopted from [4], the maximum possible refractive index difference in the grating structure $\Delta n$, and the wavelength $\lambda$ of the optical field (see Fig.2). Typically, the grating structure is modulated with a sinusoidal index change. The parameters determined from the CAD-model are the effective refractive indices of the SM-waveguide mode and the fundamental, first and second mode

DGaO Proceedings 2016 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2016-P055-8
submitted: 4.Jul.2016 - published: 12.Aug.2016

of the MM-waveguide as well as the grating period Λ for co-directional coupling.

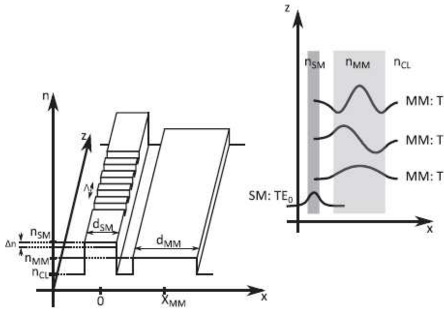

***Fig. 2*** *Refractive index structure of the waveguide coupler and the electric fields of the coupler modes [5].*

The optical grating periods Λ and grating lengths l for coupling in the fundamental and first mode of the MM-waveguide were determined with $\Lambda_0$ = 500 µm, $l_0$ = 4 mm as well as $\Lambda_1$ = 260 µm and $l_1$ = 3,5 mm, respectively. In Fig. 3 spectral characteristics of grating assisted mode coupling between SM- and MM-waveguide modes are shown [5]. As one can deduce, the coupling process is extremely wavelength sensitive. Fig. 3(a) also shows that there is no coupling without a grating structure. This is because $x_{MM}$ is deliberately chosen sufficiently large to prevent evanescent field coupling without grating structure. Furth more as maximum crosstalk of higher order mode to the fundamental mode of the MM-waveguide we obtain about -20 dB. The minimum side lobe suppression yielded -9 dB. Self-Bragg coupling occurs only to a very small extent and is insignificant. The bandwidth of the spectral peak where mode-selective coupling occurs varies depending on the MM-waveguide mode excited.

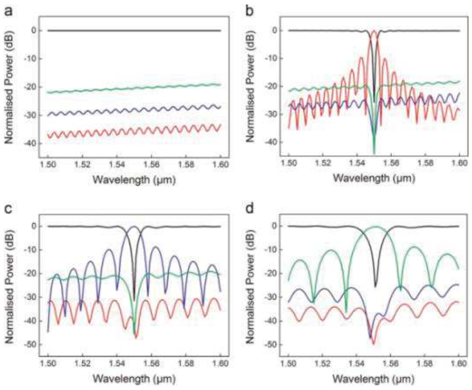

***Fig. 3*** *Spectral characteristics of the SM-waveguide and MM-waveguide modes (SM: black $TE_0$; MM: red $TE_1$ and green $TE_2$) of the proposed coupler without (a) and with grating structure and the periods 598 µm (b), 476 µm (c), and 361 µm (d), respectively [5].*

3D Modell:

After the 2D-model has been successfully evaluated, the proposed coupler has been implemented in 3D, as already illustrated in Fig. 1. The first results for this case are shown in Fig. 4.

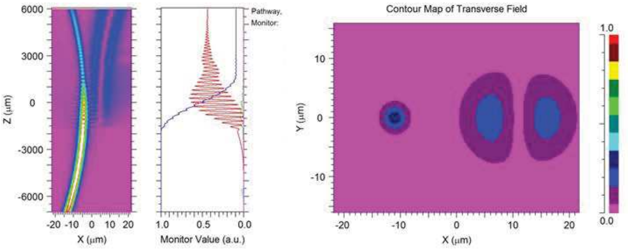

***Fig. 4*** *Coupling between the SM-waveguide mode $TE_{00}$ (left in each contour panel) and the first mode $TE_{01}$ of the MM-waveguide (right in each contour panel) with optical grating and a grating period of 260 µm as function of the coupler length (left) and the transverse field (right) simulated with the grid approach. The power in each case is normalized to the mode power of the SM-waveguide and shown in false colors. The graph in the middle shows the coupling efficiency (blue line $TE_{00}$ – mode, red line $TE_{01}$-mode).*

## 4 Conclusions

The simulations performed showed that the investigated coupler-structure is capable of efficient mode selective coupling with low crosstalk. The grating assisted coupling leads to a cost efficient manufacturing process of the coupler structures by matching the propagation constants using the grating-structure. Also we found that the coupling process is extremely wavelength sensitive. Consequently, the combination of mode division multiplexing and wavelength division multiplexing can bring a further increase in the transmission bandwidth. Furthermore, the selective coupling between individual transverse modes can lead to progress in the development of new high performance fiber lasers.

## 6 References

[1] R.G.H. van Uden, R. Amezuca Correa, E. Antonio Lopez, F.M. Huijskens, C. Xia, G. Li, A. Schlüzgen, H.de Waardt, A.M.J. Koonen, C.M. Okonkwo, Ultra-high-density spatial division multiplexing with a few-mode multicore fiber, Nat. Photonics 8 (2014) 865-870.

[2] D.J. Richardson, J.M.Fini, L.E.Nelson, Space-division multiplexing in optical fibres, Nat. Photonics 7 (2013) 354–362.

[3] B. Franz, H. Büllow, Experimental evaluation of principle mode groups as high-speed transmission channels in spatial multiplex systems, IEEE-Photonics Technol. Lett. 24 (2012) 1363–1365.

[4] A. Kumar, S. Ghadirli, K. Thyagarajan, Performance of a dual-mode-single-mode waveguide coupler as a modal filter, Appl. Opt. 31 (1992) 5092–5095.

[5] K. Bremer, S. Lochmann, B. Roth, Grating assisted waveguide coupler to excite individual modes of a multi-mode waveguide, Optics Communications 356 (2015) 560-564.