NEW DESIGN FOR A WAVELENGTH DEMULTIPLEXING DEVICE

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ABSTRACT

Arrayed waveguide gratings (AWG) originally designed as demultiplexing device and manufactured with well established silicon wafer technology are already used successfully as compact spectrometers with high resolution[1].

In this paper, the concept of a new design for a wavelength demultiplexing device based on tailor-made polymers is presented. The motivation for a new design is a smaller footprint of the device and the avoidance of bended waveguides and the associated losses. Extensive simulations were performed to optimize the design. Using microscope projection lithography and hot embossing a first polymer based device was realized. Its characterization and the achieved performance in terms of resolution and covered wavelength range will be discussed.

1. INTRODUCTION

Optical methods have become a versatile tool for many applications, e.g. gas monitoring can be accomplished via spectroscopic methods down to trace levels, but also temperature and humidity measurement is possible optically. Most methods are dispersive, i.e. it is necessary to discriminate different wavelength which is commonly done by use of a spectrometer. However, most spectrometers have a large footprint and are not suitable for realizing planar integrated optical circuits. Wavelength demultiplexing devices like AWGs are small and capable of being integrated into an optical ciruit.

The aim of the Collaborative Research Centre “PlanOS” funded by the German Research foundation (DFG) is to realize a planar polymer foil with integrated devices for optical sensing of different environmental conditions like strain, temperature and surrounding gases and liquids.

2. METHODOLOGY

The operation scheme of an arrayed waveguide grating is sketched in figure 1 and can be summarized as follows: the incoming light is guided within the input waveguide and enters a first large free propagation zone, where it diverges. This diverged beam is then coupled into an array of waveguides; the light within each of the waveguides propagates independently of the other arms of the array. The waveguides possess different optical pathlengths. The lengths of adjacent waveguides differ by an integer multiple of the center wavelength of the device as given in equation (1):

$$\Delta L = \frac{m\lambda_0}{n_a} \quad (1)$$

Here, m is the order of the array, λ_0 is the center wavelength of the device, and n_a is the effective refractive index of the arrayed waveguide. At the center wavelength of the AWG, the wave in each arm of the array enters the second free propagation zone with the same relative phase, thus producing a mirror image at the second free propagation zone. For all other wavelengths, the differences in path length will cause the phase front to tilt as the field propagates along the

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waveguides. Therefore constructive interference of these wavelength components will occur at an angle relative to the path of the center wavelength. The output waveguides are positioned in such a way as to properly guide and confine the output light.

The free propagation zones in a commercially available AWG are based on a Rowland circle geometry (refer to Fig. 1) By proper design the device can be adapted to the need of the application in terms of covered wavelength range, number of output channels and their spectral difference. Fig. 1 shows an example with 4 output waveguides on the right hand side.

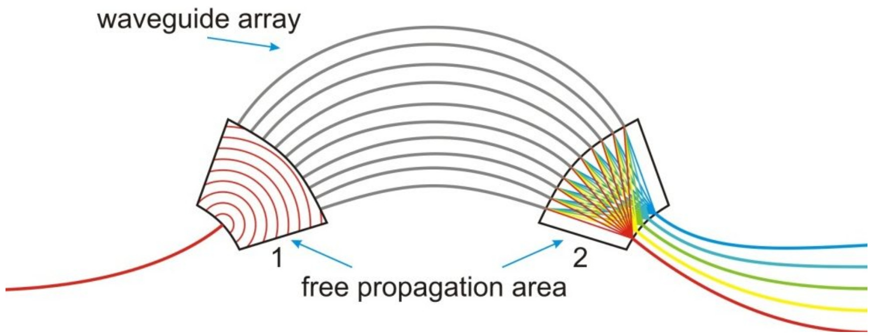

Figure 1. Schematic of an AWG.

There are different possibilities to create a waveguide array with path length differences. Two examples are shown in Fig. 2.Geometry (a) can be designed with larger radii as in geometry (b) which is favorable in terms of minimizing bend losses, however, on the expense of a larger footprint.

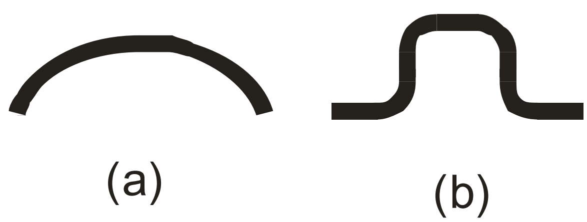

Figure 2. Examples of possible geometries for realization of waveguide arrays.

3. SIMULATION AND DESIGN OF AN AWG

Simulations have been performed to determine the geometrical dimensions of the different parts of the AWG like input/output waveguides, free propagation zone and the waveguide array itself. For the geometrical dimensions of the waveguides the fully vectorial mode solver tool FIMMWAVE Photon Desing has been used. The simulations of the AWG have been performed with the simulation tool BeamPROP of the RSOFT CAD Enviroment.

Simulations on single mode behavior

Single mode waveguides are essential for the arrayed waveguides of an AWG since the wavelength multiplexing relies of interference effects within the second free propagation zone. Therefore it is important to find waveguides dimensions that allow for single mode waveguiding in the polymer material. In a single mode waveguide only two fundamental modes are guided. The refractive indices of the used materials that were used in the simulations are given in Table 1.

Error! Reference source not found. Table 1: Refractive indices of the used materials.

Substrate	PMMA	n_s	1.49 @ 850nm
Waveguide	ormosil	n_w	1.55 @ 850nm
Upper cladding	PMMA	n_c	1.49 @ 850nm

Figure 3 summarizes the results of the simulations. From this, pairs of waveguide height and width can be identified that guarantee single mode guidance.

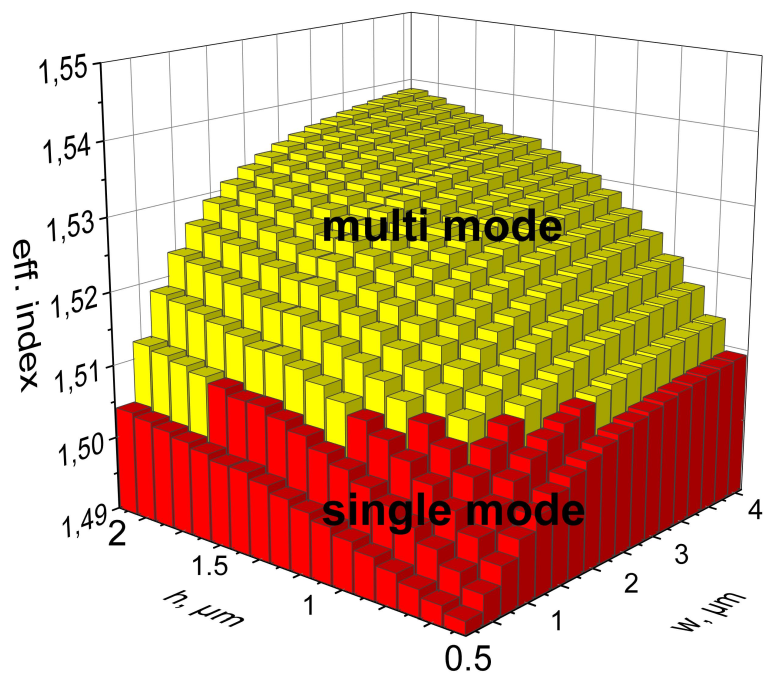

Figure 3. Results of the simulation for the waveguide calculated with FIMMWAVE Photon Design®.

For further simulations waveguide dimensions with a height h = 1µm and a width w = 1µm are used.

Losses in bent waveguides

For small AWG devices small bend radii are needed; e.g. Fukazawa et al.[2] use r = 5 µm. However, the smaller the radius of curvature is, the higher are the induced losses for the waveguide, which means that a tradeoff between miniaturization and tolerable losses has to be found. In Figure 4 the simulation of the mode losses as a function of the radius are shown. For radii r < 10µm the simulation tool finds no guided modes for the waveguide because of the small refraction index difference between substrate and waveguide.

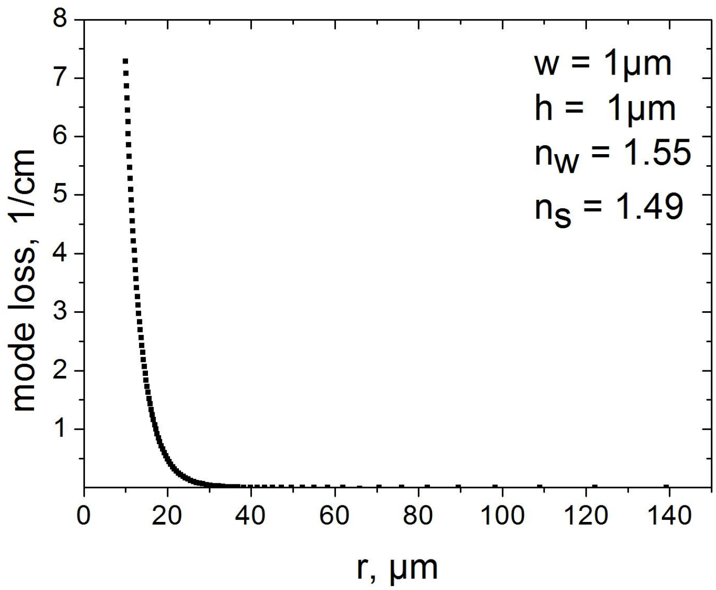

Figure 4: Simulation results: Bend losses of a circularly curved ridge waveguide with height $h = 1$ µm and width $w = 1$ µm.

Since the chosen material system PMMA/ormosil with its small difference in refractive index shows high mode losses for bended waveguides a new AWG layout has been designed avoiding curved waveguides.

New AWG layout without bent waveguides

In Fig. 5 the s schematic layout of an AWG is shown. No bent waveguides are necessary to create equal path lengths differences between adjacent waveguides.

Figure 5. Schematic layout of a new AWG design.

The first free propagation zone is a 200µm wide rectangle and the second free propagation zone is designed as a trapezium. To achieve a path length difference of an integer multiple of the center wavelength of the device an angle of 2.7° for the input aperture of the trapezium has been realized. Fig.6 shows the wavelength dependent power transmitted through the output ports as simulated for this geometry. For demonstration of the feasibility, this structure was used for realization of actual devices. However, for applications, more sophisticated designs with a larger number or output channels will be prepared.

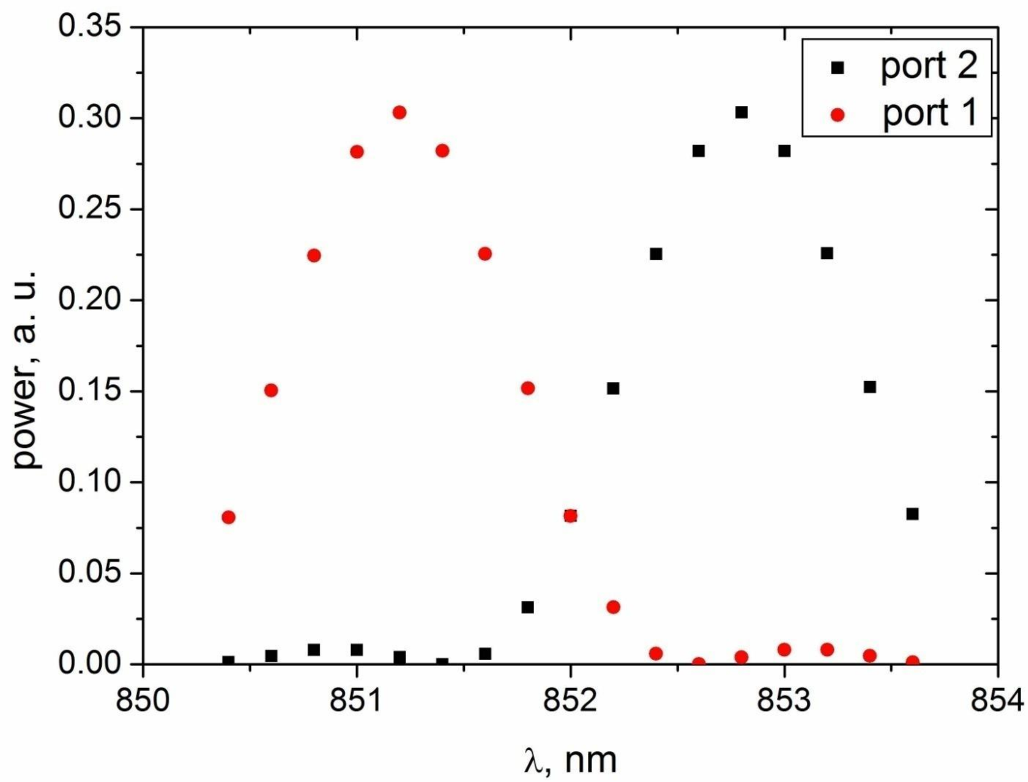

Figure 6. Simulated transmitted power as a function of wavelength for the two output ports.

4. EXPERIMENTAL RESULTS

Based on the simulation results first AWGs were produced by microscope projection photolithography (MPP). MPP is very useful for rapid prototyping of small polymer devices. More information about the production method can be found in [3]. Figure 7 shows a first AWG device.

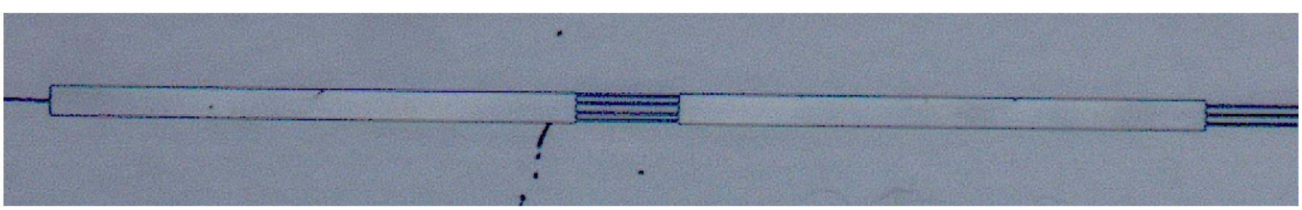

Figure 7. AWG fabricated with MPP.

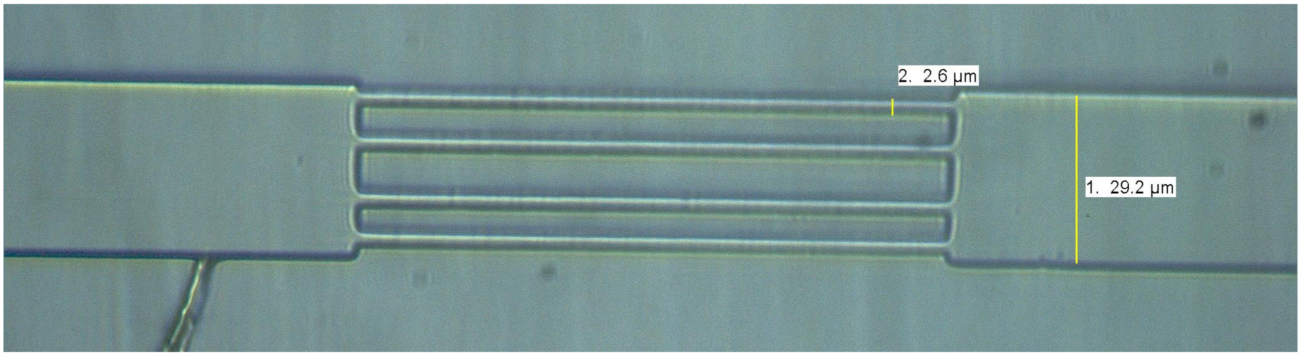

Figure 8. AWG fabricated with MPP.

The geometrical parameters of the processed devices differ from the simulated parameters because of the fabrication method. Adaption of the layout to the constraints of the production technique will lead to realization of single mode waveguides.

Preparation of the end facets

For efficient coupling of light into a photonic device by use of the end facet of the input waveguide, the surface quality must be good. To achieve a high quality facet surface the waveguides must be cleaved and/or polished. It was not possible to polish the polymer waveguides of the AWG device, because the polymer waveguides were too soft for polishing. A self-made POV-cleaver (refer to Fig. 9) designed according to results of Stefani et al.[4] and Abdi et al.[5] was used for cleaving. The main elements of the cleaver are a heated base plate and a heated razorblade on linear guides, shown in Fig. 9. With a two-level controller the temperature of the base plate and the blade can be controlled independently. The cleaving process at elevated temperature allows a ductile cutting of the devices, avoiding a brittle fracturing that would lead to undesirable surface quality.

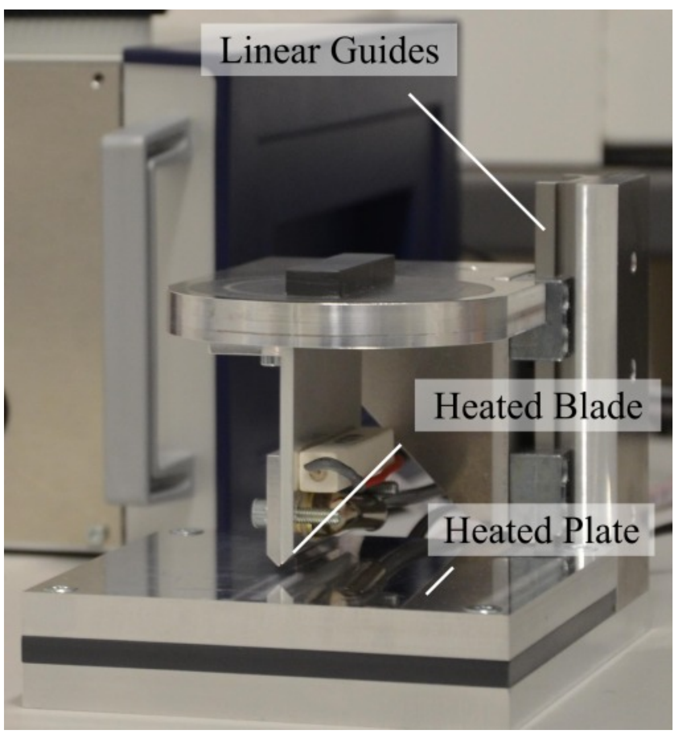

Figure 9. Photograph of the self made POF cleaver.

The first step of the cleaving process is to place the device at the heated base plate. Depending on the sample thickness after some minutes the thermal equilibrium is reached. In the second step of the cleaving process, the blade is manually pressed with low force onto the sample to cut it. For our devices the base plate temperature was T_p= 67°C and the razorblade was T_b= 60°C. With these adjustments satisfactory surface quality was reached, as shown in Fig. 10.

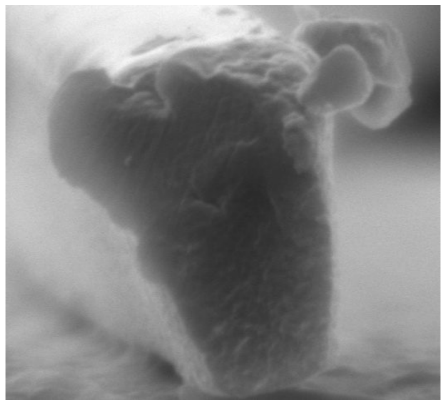

Figure 10. Cleaved end facet.

5. CONCLUSIONS

For the realization of a new AWG layout extensive investigations have been carried out to determine optimal design parameters using simulation tools. Different loss mechanisms have been studied and bend losses have been identified to be the dominant ones. Based on the simulations first AWG devices have been produced using microscope projection lithography. With a self-made POV cleaver the end facets of the input and output waveguides were prepared for further studies.

ACKNOWLEDGEMENT

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