Optical Waveguides Processed by Internal Diffusion in Photosensitive Doped Host/Guest Polymer

Heinrich Sieber[1], Uwe Hollenbach[1], Jürgen Mohr[1], Karl Pfeiffer[2], Ute Ostrzinski[2], Gabi Grützner[2]

[1] *Institute of Microstructure Technology (IMT), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, heinrich.sieber@kit.edu, uwe.hollenbach@kit.edu, juergen.mohr@kit.edu*
[2] *micro resist technology GmbH (MRT), Berlin, Germany, k.pfeiffer@microresist.de, u.ostrzinski@microresist.de, g.gruetzner@microresist.de*

Abstract: We report on manufacturing and characterization of planar optical single mode waveguide structures in a photosensitive negative tone resist. The resist is based on a two component host/guest-polymer. Diglycidester-oligomer as host polymer is doped with a special glycidyl-monomer. The refractive index of the mixture is adjustable by an internal diffusion processes during the pre- and post- exposure bake. This allows a "one-material" processing which avoids chemical wet etching after exposure. The refractive index distribution shows nearly step index profiles. The near field intensity distributions present perfect Gaussian modes. Prototype CWDM waveguide structures have been fabricated.

Introduction: Today optical fibers are used as point to point interconnects between separated electrical boards for data transfer between electrical processors. In view of higher data rates optical parallel processing on optical printed circuit boards (OPCB's) is under development. It needs a higher integration of optical network routing using hybrid integrated optical circuits. Polymeric multimode (MM) waveguide structures for applications in OPCB's are described in [1]. We are focusing on the development of an easy handling process which is suitable for single mode (SM) waveguide fabrication using UV- lithography or direct laser writing at 365nm.

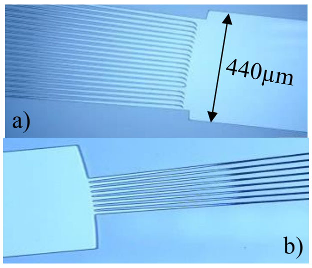

Fig. 1. Pictures of CWDM parts; a) AWG out at star coupler, b) 8x WG output

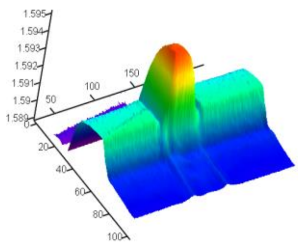

Fig. 2. RI- profile across WG core, w=h=6µm, Δn~0.0050, @ 678nm

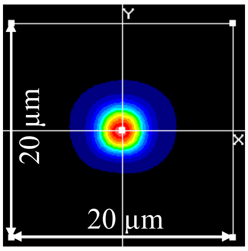

Fig. 3. NFP of a SM-WG, $\omega_{x,y}$=5.9µm ($1/e^2$), @ 808nm

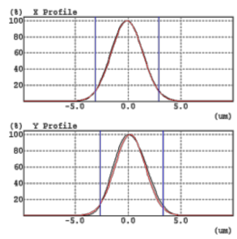

Fig. 4. x-y-intensity profiles of NFP, and Gauss fits @ 808nm

Polymer Synthesis: We developed a novel mixed polymer to improve the condition for an internal diffusion which allows refractive index (RI) adjustment between cladding and core. This resist was developed and tested in a 3-years project named POLINA [2]. A diffusible additive glycidyl-monomer is used as low RI solvent of 15-30w% in 80-65w% of oligomer (pre linked units of bisphenol-A-diglycidether) which is the curable high RI part of the mixed polymer approach. The catalytic accelerator in the photosensitive polymer is a 5w% standard photo acid generator (PAG, bis/thio- triarylsulfonium hexafluoroantimonate).

Polymer Processing: The basic process steps to fabricate waveguide cores in polymers are well known [3] and encompass a) spin coating, b) pre bake (PB), c) UV- exposure, d) post exposure bake (PEB) and hard bake (HB). Basic carrier is a 4-inch diameter Si-substrate. At first we prepare an app. 20µm thick under-cladding followed by the manufacturing of the waveguide (WG) core layer in a thickness of app. 5-6µm and 8-9µm for different operation wavelengths of 780-980nm and 1260-1600 nm respectively. Finally we cover the WG core layer by an over-cladding of app. 20µm to protect the WG cores. The structuring of the core layer is done using standard i-line lithography at 365nm and a light field COG-mask. The UV-light activates the PAG and during the PEB at temperatures up to 95°C the polymerization is only possible outside of the core structures. The crosslinking runs a) inter- and b) intra-molecular between the oligomers and c) between the oligomers and the dopant monomers. Therefor the concentration of free monomers decreases quickly and the dopant monomer diffusion starts in plane from the core area into the cladding area. Additionally in both areas an out-of-plane diffusion of free dopant monomers runs which, due to the polymerization, is much stronger in the core area than in the cladding area. This leads to the required RI difference between the waveguide core and cladding. Instead of UV- lithography we also demonstrate direct laser writing at 365nm for waveguide patterning. After PEB and crosslinking of the cladding the whole layer is flood exposed and in a second PEB also the core structures are cured. At last a hard bake up to 180°C is done to shift the glass temperature up to app. 160°C.

Results: After the WG structure processing (see Fig. 1) we analyze the RI using a scanning RNF-method at 678nm (Fig. 2). The RI profile gradients show nearly step index distribution and the RI contrast Δn is about 0.005 (0.006) for a core size of 6µm x 6µm (8µm x 8µm). The near field intensity pattern (NFP) is given in Fig. 3. The fundamental modes have perfect Gaussian shapes and the x-y mode field intensity diameters are 5.9µm (8.0µm) at the $1/e^2$ intensity levels at 808nm (1310nm). The far field intensity patterns (FFP) have divergence angles of app. 15° at the 1% intensity levels at 808nm which is consistent to an aperture value of NA=0.13. The typical (best) insertion loss values are 0.25dB/cm (0.14dB/cm) at 808nm and 0.42dB/cm (0.33dB/cm) at 1310nm. Polarization analysis shows PDL values of <0.3dB which is the limit of our Jones-matrix method accuracy.

Based on the encouraging results with different test structures (straight WG with different mask widths, curved WG with diff. radius and arc-lengths) we produce functional structures like splitters, symmetrical and asymmetrical interferometers, couplers for 780/905nm, 850/960nm and 1310/1550nm and CWDM wavelength filters for 1300nm. Exemplarily the characterization of a 1x8 channel CWDM structure is shown in Fig. 5. The design for a first prototype has a structure size of L x W=36mm x 3mm (Fig. 5a). The arrayed WG (AWG) contains only N=20 WG to minimize the chip size.

The intensity distribution in the front and middle of the AWG is shown in Fig. 5b-c. The output spectral transmission has a smallest insertion loss (IL) of 5dB at 1285nm using a Super-Continuum-Laser (Fig. 5d) and 4 dB at 1305nm using a tunable laser source. The cross talk depression is >20dB at channel center and >10dB in spans of ±6.5nm side wall distance around 1305nm. The aimed channel space of 20nm is realized to 19.6nm with ±0.9nm standard deviation. The thermal sensitivity of the CWDM chip was tested between RT and 70°C and the drift coefficient is about -0.11nm/K.

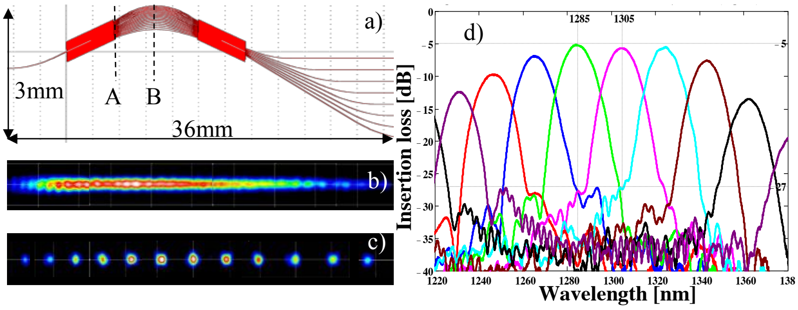

Fig. 5. a) 1x8 CWDM design; b-c) Int. distribution in front (cut A in 5.a) and middle (cut B in 5.a) of the AWG; d) Spectral transmission at the output ports 1-8 using Super-Continuum-Laser @ 1200 – 1400 nm

Resume: Our newly developed and applied mixed polymer was demonstrated in a "one-material"-technique of WG core formation based on internal diffusion of dopant monomers. It simplifies the manufacturing and avoids wet etching steps. Rapid prototyping and cost efficient manufacturing for examples guides to complex functional structures such as splitters, interferometers for app. 780-980 nm and couplers for 1310/1550nm wavelength range. Furthermore we realized CWDM's for 1250-1350nm wavelength ranges where SM and high degree MM structures are operated in combination.

Acknowledgement: The POLINA- project "Polymere Lichtwellenleiter für die Nanophotonik" was sponsored by the German Federal Ministry of Economics and Technology under grant BMWi-AIF (ZIM) KF 2308201MF9.

1. Fuad E. Doany, et al, *IEEE Transactions on Advanced Packaging*, **Vol. 32**, No. 2, May 2009, P. 345 – 359
2. Heinrich Sieber, et al, *Proc. of Photonics Europe, Bruxelles*, 2012, **Series 8431**
3. A. del Campo, et al, *J. Micromech. Microeng.*, **17** (2007), R81-R95