Novel multilayer waveguide technology for optical fan-out structures

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The increase of packaging densities as well as the ongoing integration of microoptic and electronic components leads to the opening of the third dimension for integrated optic devices, see e.g. /1/ and references therein. The rapid progress in this area drives the development of new materials and technologies. Those have to meet the requirements of the applications with regard to the fabrication tolerances but also to the opportunities for cost-effective mass-production /2,3/.
Within the framework of the project "DONDODEM" (Development of new dielectric and optical materials and process-technologies for low cost electrical and/or optical packaging and testing of pre-competitive demonstrators), sponsored by the Brite Euram contract, the IOF developed a novel three-dimensional optical multilayer fan-out structure.
It was the first time in the focused field of application that such a highly integrated device was conceived and realized. The scale of this work included all steps from design up to carrying out a suitable manufaction technology.
The aim of the fan-out structure is to bring together signals coming from different sources so that they can be detected at the output with one sensor. Essential for the design is to achieve equal path lengths for all waveguides which leads to the layout, composed of four uncoupled layers of waveguides. All of them are shown in Fig. 1.
The incoming signals will be fed into the device by standard fiber 1 x 8 arrays butt-coupled to the input facet. BPM and FEM calculations predict a total loss of 1.6 dB @ l = 1.3 mm for a 5 mm x 5 mm quadratic waveguide cross-section and a device length of 41 mm. Pitch, layer distance and cross-sections have to be designed in such a way that the fields at the output do not overlap.

Experimental investigations show that the inorganic-organic ORMOCERä copolymers, developed by the Fraunhofer Institute of Silicate Research, Würzburg, offer the potential for a multilayer technology. Especially properties like temperature stability of up to 250°C, low absorption in the telecommunication wavelengths regions and the possibility to structure the material by common photopatterning processes qualify polymers of the ORMOCERä family for the manufacturing of highly integrated waveguide devices.
The stacking process for realizing the different layers of the fan-out structure follows a successive scheme of spinning, photopatterning and heating steps. A key point for the device operation is an excellent waveguide homogeneity regarding the index distribution and the cross-sections. To this end, several processing steps had to be optimized:

- The structures are sensitive to exposure parameters like exposure gap and time. The actual height of the stack has to be carefully considered.
- Back reflection of light from the substrate during exposure has to be avoided. Otherwise scattering effects will occur and lead to waveguide broadening. The real exposure conditions would change from core layer to core layer in dependence on the changing structure in deeper layers.
- Layers manufactured so far had to be passivated prior to the preparation of the following layer. If material diffuses into deeper regions, index gradients will appear, losses and cross-talk will increase.

The final technology scheme which meets the requirements mentioned above is shown in Fig. 3.
Before the preparation of ORMOCERä layers an UV-absorbing undercladding

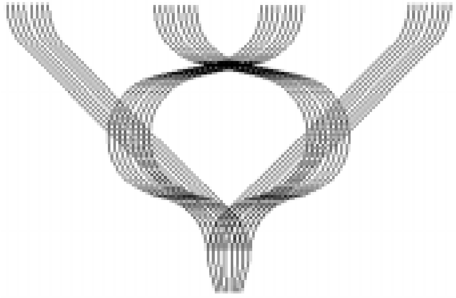

Fig. 1:
Design of fan-out structure, four stacked layers of single mode waveguides

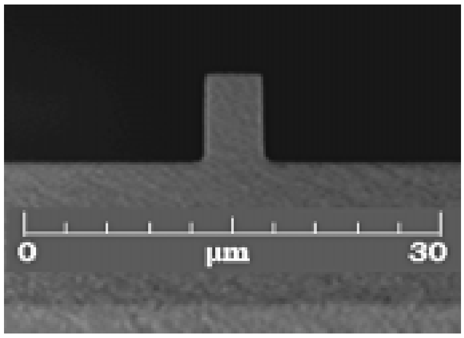

Fig. 2:
Waveguide after exposure and dissolving the unexposed material

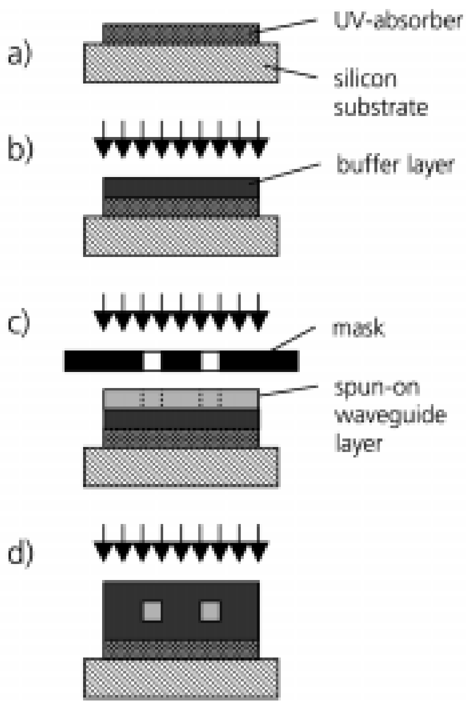

Fig. 3:
Technology scheme for the stacking process

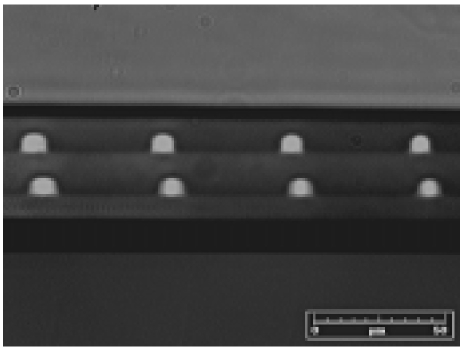

Fig. 4:
Stack of single mode waveguides according to the technology scheme of Fig. 3

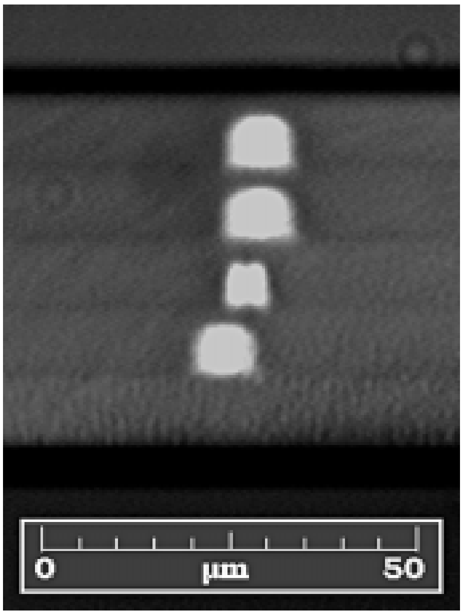

Fig. 5:
Stack of 4 waveguides

is manufactured (a). This measure leads to precise waveguide cross-sections (Fig. 2) and a homogeneous index distribution in the stack without any gradients in the cladding layers (Fig. 4).

The further technological steps (compare Fig. 3b-d) are:

– Spinning and curing of cladding material (b)
– Spinning of waveguide layer (core material), photo-structuring in a mask aligner by a proximity exposure (c) and washing out the unexposed uncured polymer
– Spinning of cladding layer and flood exposure (d)
– Continuation at step (b) after activation of the last surface by an oxygen plasma treatment and repetition until four layers (compare Fig. 5) are prepared

In conclusion, the developed new stacking technology enables for the fabrication of vertically stacked integrated optics devices with high precision. The demonstrated fan-out structure represents passive circuits without any evanescent coupling of waveguides, neither horizontally nor vertically. Decreasing of the height of the cladding layers and of the waveguide spacings leads to coupling via the evanescent fields in both transversal directions. Consequentially, this is the formation of an array of directional couplers. The fact that the described fabrication process is also applicable to these structures /2/ proves its potential for future vertically integrated optoelectronic applications.

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References

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