MICROCONNECTORS FOR THE PASSIVE ALIGNMENT OF OPTICAL WAVEGUIDES AND RIBBON OPTICAL FIBERS

N. Kaou, V. Armbruster, J.C. Jeannot, P. Mollier, H. Porte, N. Devoldère*, M. de Labachelerie

Institut des Microtechniques de Franche-Comté, 32 av. de l'Observatoire
25044 Besançon, Cedex, France (labachel@lpmo.univ-fcomte.fr)
* CNET - France Telecom, 2 av. P. Marzin, 22307, Lannion, Cedex, France

ABSTRACT

This paper describes the fabrication of a new mechanical microconnector, which is used for the precise optical self-alignment of multi-waveguide Optical Integrated Circuits (OIC) to ribbon optical fibers, without injecting light in the fiber. Nickel alignment pins are electrodeposited on the OIC using a photolithographic process, and the pins are inserted into suitable openings made on a silicon micromachined platform, on which optical fibers are accurately positioned using V-grooves. Design and fabrication issues are reported, as well as preliminary experimental results which show that excess optical losses on the order of 3 dB can be obtained.

INTRODUCTION

It is well known that the connection of optical fibers to Optical Integrated Circuits can be the most important part of the overall device fabrication cost. In currently used active alignment processes, this high assembly cost is mainly due to the numerous manipulations, which are required. Light should be injected in the input fiber which is placed on a micromanipulator, then the fiber should be individually aligned and the position is then optimized while monitoring the power at the waveguide output, and finally the position should be blocked and the connection secured. Such a process becomes more and more complicated when several optical fibers should be connected to a multiwaveguide OIC. Therefore, it is useful to develop an alignment process that only relies on passive mechanical structures to obtain the alignment. Such procedures have already been reported [1, 2, 3, 4, 5]. However, the alignment structures on the waveguide side were often micromachined by etching the waveguide material itself, and the fabrication process was thus specific for the considered waveguide material. Another drawback of such methods is that they do not allow polishing easily the waveguide input or output facets. In our study, we tried to establish a fabrication process which does not depend on the waveguide material (Glass, Silicon, Lithium Niobate or semiconductor compounds) by adding some material to the waveguide instead of etching it. We have thus chosen to deposit metallic alignment pins on the waveguide surface, which can be made on most of the known waveguide materials. In addition, it is still possible to polish mechanically the waveguide exits in order to obtain facets of optical quality. Our approach is therefore quite close to the strategy which was described in ref. 3, but we tried to improve the structure design in order to obtain a true 3D positioning, with rather high aspect ratio alignment marks, which makes the alignment procedure easier.

PROPOSED DEVICE GEOMETRY

The coupling process was developed with SiO_2/Si waveguides provided by CNET/France Telecom. These waveguides have a 7 µm thick x 8 µm large germanium doped core, embedded in non-doped silica cladding layers. Several groups of 11 waveguides separated by a 250 µm pitch were made on the wafer, and alignment marks are also made on the waveguide substrate during its fabrication. These alignment marks are used for a precise positioning of Nickel pins, which were fabricated on the waveguide surface. The Nickel pins have the shape of a mushroom as can be seen on fig. 1.

On the other hand, a silicon platform was fabricated to maintain simultaneously the optical fibers and the OIC on the same mechanical reference. In this platform, V-grooves, inside which optical fibers can be precisely positioned, are machined as well as precise openings in which the Nickel alignment pins can be inserted. These openings have a large part in which the cap of the mushroom can be inserted and a narrower part. The openings are made in 25 μm thick membranes that were machined at the same time as the V-grooves. Therefore, the cap of the mushroom can slide under the membrane in order to bring the mushroom base in contact with the opening's sidewalls. This insertion procedure provides simultaneously the lateral alignment of the waveguide and its locking in the vertical direction.

negligible. Most of the losses will come from misalignments, residual Fresnel reflections (if an index matching liquid is not employed), or technological defects on the interfaces (scratches or rugosities on the waveguide or the fiber output facets). Assuming that the beams are nearly Gaussian, the optical losses versus misalignments can be estimated analytically. Longitudinal tolerances are not very severe, since a large fiber translation of 50 μm produces only a 1 dB loss. The less tolerant misalignments are transverse ones (see fig.2), and also angular misalignments which lead to a loss of 1.5 dB for only 3° of angular shift between the waveguide axis and the input beam axis. Consequently, we have decided to concentrate the efforts on transverse tolerances and to butt-couple the optical fibers by sliding them in the V-grooves.

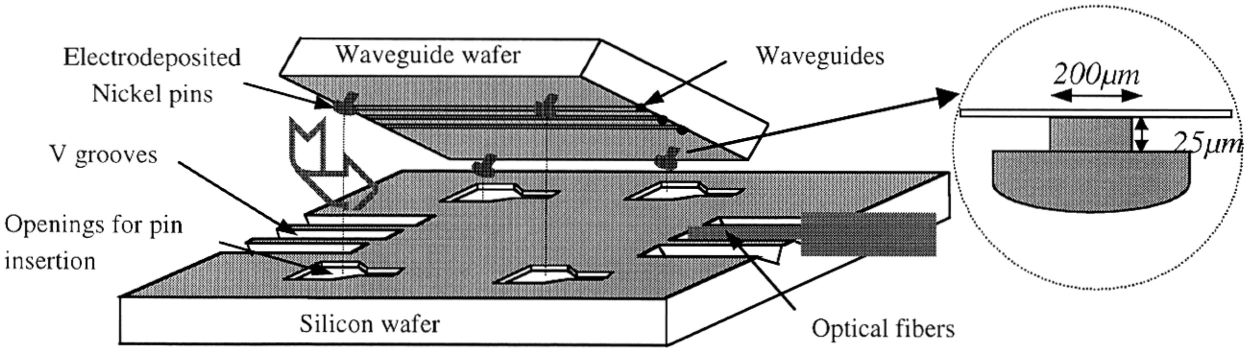

Figure 1: Principle of the optical microconnector.

ALIGNMENT REQUIREMENTS

The chosen waveguides are nearly mode-matched to standard telecommunication optical fibers. Therefore, the optical coupling losses coming from mode

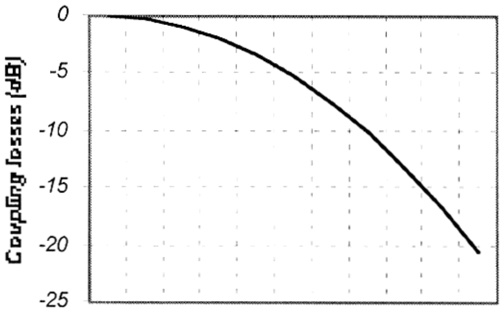

Figure 2: Optical coupling losses versus transverse misalignments of the optical fiber.

mismatch are on the order of 0.04 dB, which is

Therefore, the alignment procedure consists first in locking the waveguide to the silicon platform, and then sliding the optical fibers up to their contact with the waveguide. The main problem is to ensure that the optical fiber core will be centered on the waveguide input.

FABRICATION PROCESS

For the fabrication of the Nickel alignment pins (see fig. 3), a thin Cr/Ni layer was first sputtered on the waveguide substrate. Then, a thick polymer layer is deposited over this metallic layer and patterned, in order to make cylindrical holes in the polymer layer. For the polymer layer, we have used either PMMA, or a thick photosensitive resist (SJR 5740). In the former case, the holes were machined by excimer laser ablation, whereas a standard UV lithography was used in the latter case. Then, Nickel was electrodeposited inside the cylindrical holes, using a Nickel sulfamate solution. When the nickel reaches the upper surface of the polymer layer, its growth is no more spatially constrained, and it continues to grow isotropically over the polymer layer, which produces the mushroom shape. All these operations are performed collectively on the waveguide wafer without separating individual waveguide groups. Then, the waveguides are sawed, their end facets are polished, and individual multiwaveguide chips are separated, without removing the polymer layer that serves as a protection. The polymer layer is removed only at the final stage, just before assembly.

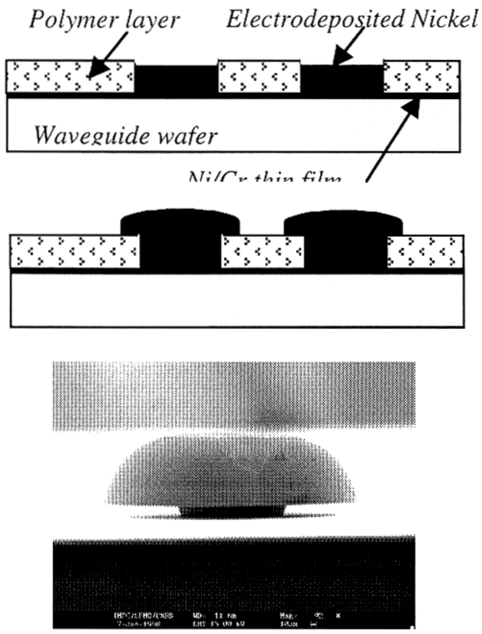

Figure 3: Fabrication process of the Nickel alignment pins and SEM picture of a fabricated pin with a mushroom shape

The most important elements contained on the silicon platform are i) the precision V-grooves, and ii) the insertion openings. The silicon V-grooves are machined using wet anisotropic etching in KOH using 1.3 µm thick thermal SiO_2 as a masking layer. In order to obtain a geometrical precision on the order of one micron, we had to pay attention to the alignment of V-grooves with Silicon crystalline directions, and also to calibrate our mask etching process. The mask alignment along crystalline directions was performed using a preliminary wet etching to reveal the crystalline directions, similar to the method described in ref. 6. Then the underetching of the resist mask and the $Si0_2$ mask were systematically measured on several samples. It was observed that the process is reproducible enough to use a mask correction which takes in account a total systematic variation of +3 µm between the design value of the mask width, and the width of the opening in the SiO_2 layer obtained on the wafer. The V-grooves were measured by comparing the vertical position of an optical fiber that was first laid on the wafer surface, and then inserted in a V-groove. It was found that the mean difference between the measured value and the target value of the fiber vertical position was 0.6 µm, with a RMS variation of ± 0,32 µm. This machining precision is quite enough for our application.

The fabrication of the insertion openings starts from the fabrication of thin membranes by silicon anisotropic etching on the backside of the wafer. This step is performed at the same time as the V-grooves fabrication. After that, a Reactive Ion Etching with SF_6 on the front side of the wafer allows to etch through the membranes with the desired shape. By varying the oxygen flow, some efforts have been made to obtain vertical sidewalls for these insertion openings. However, the lowest slope which was obtained for the sidewall was about 20% with respect to the vertical direction, therefore, the lateral position of the sidewall will vary by about 5 µm from the top to the bottom of the membrane.

DESIGN ISSUES

Positioning accuracy:

Technological studies have shown us that the geometry of silicon V-grooves can be almost perfectly controlled, therefore, the fiber position can be very well controlled. However, the sidewalls of the Nickel pins, as well as the insertion openings, are not vertical and we doubt that it can be made very reproducible. Therefore, the contact of the Nickel pin to the sidewall does not allow controlling perfectly the lateral position of the waveguide. In order to obtain a precise lateral positioning of the waveguide chip, we have thus designed openings, which are V-shaped at their narrow end (fig. 4). During the insertion process, the pins are pushed up to the contact of their sidewalls to both sides of the silicon V-shape. With such a design, the center of the alignment pins will always be aligned with the V symmetry axis, irrespective of the sidewall slope. The only condition to obtain this property is that the

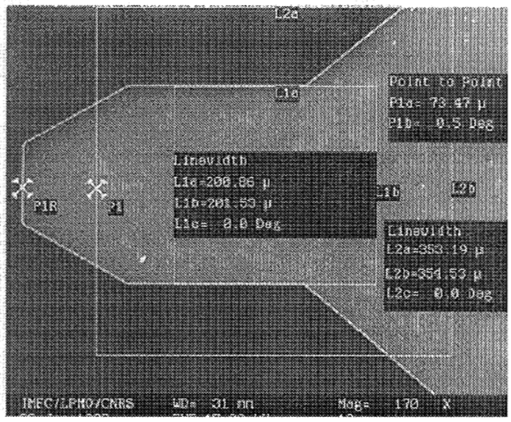

Figure 4: SEM view of an insertion opening ended by a V-shape, and dry etched in a 25 µm thick silicon membrane.

sidewalls of the V, as well as those of the pins, are symmetric. We believe that this property is true for all the fabrication techniques that we use, therefore, this design can considerably relax technological constraints. The alignment of the RIE mask with the wet etching mask is defined by a set of 4 wet etched inverted pyramids obtained at the same time as the fiber V-grooves. When properly lighted on the mask aligner, these inverted pyramids will appear black with a high contrast because they do not reflect light in the direction of the observer.

Mechanical resistance of the assembly:

Due to their bimorph nature, the waveguides that we have used are not flat : the compressive stress present inside the lower silica waveguide layer leads to an upward deformation. Therefore, when the rectangular chip is laid on the silicon platform, it will be in contact at its center but its sides will be about 40 µm above the surface. Consequently, in order to insert the pins under the membrane, it is first necessary to exert a force F which flattens the waveguide chip (fig. 5). A numerical model of this chip has shown that the required force is on the order of F = 0.13 N for each alignment pin. Once inserted, the waveguide chip will exert the same force on the membranes and alignment pins (see fig. 6), which deforms the thin membrane and could lead to its breakage, or to the breakage of the pins. The bonding strength of the pins to a standard SiO_2/Si optical

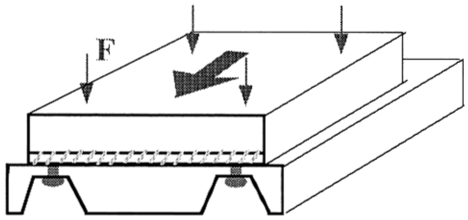

Figure 5: Illustration of the forces, which should be applied to the waveguide for its insertion on the silicon platform.

waveguide has been experimentally studied. When submitted to a normal stress, this bonding always breaks at the Ni/Cr layer interface with the silica layer. The maximum stress, which can be applied to the Nickel pins, is about 5.5 MPa, in accordance with ref. 7. Therefore, in order to keep the applied stress lower than the breakage limit, the alignment pin diameter should be greater than 200 µm. Experimentally, we indeed observed that the 100 µm diameter pins that we first manufactured were not strongly bonded. They often broke when inserted in the Si platform openings, whereas the 200 µm diameter pins seldom broke. Then, mechanical resistance of the silicon membranes was also studied with the help of an ANSYS FEM model.

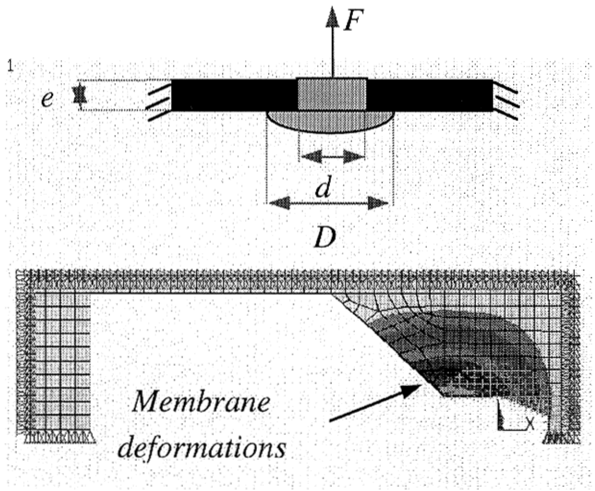

Figure 6: Force applied on the alignment pins, and FEM model of the corresponding deformation of the silicon membrane (only one half of the insertion opening is shown).

The membrane deformation and internal stress were computed (see fig. 6), and it was shown that a membrane thickness of at least 25 µm is required in order to keep a high enough resistance with a small enough membrane deformation. The residual membrane deformation is 2 µm for a membrane thickness of 25 µm. These values should be taken in account for the platform design. For instance, the optical fiber position has to be raised in order to take in account the waveguide vertical displacement associated to the thin membrane deformation.

INSERTION EXPERIMENTS

The assembly of waveguide chips with silicon platforms has been performed manually under microscope. First, the silicon side of the optical waveguide was set on a flat mechanical part in which small holes connected to a vacuum pump allowed to flatten the waveguide chip. The alignment pins were then visible from the top. After that, the silicon platform was laid on the waveguide chip (this chip is thus supported by the alignment pins) and was moved until the cap of alignment pins was visible through the large part of the insertion holes. Then, the platform was pushed in order to insert the pins into the narrow part of the insertion openings and to bring them in contact with their V-shaped ends. It was observed that the contact force, which applies a shear stress to the pins, does not cause their breakage, even though it sometimes breaks the thin silicon membrane when the

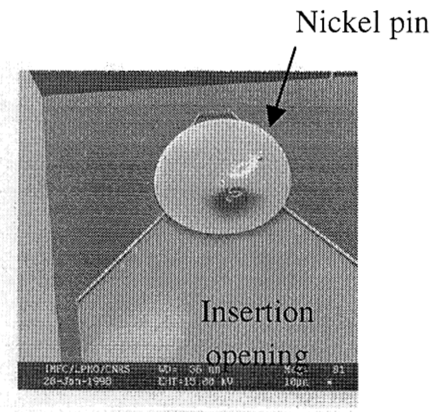

Figure 7: SEM picture of a Nickel alignment pin inserted inside a corresponding 25 µm thick insertion opening on the Silicon platform (viewed from the backside of the Silicon platform).

applied force is too strong. However, the normal restoring force, which is applied when the vacuum is stopped, was a major cause of breakage in our first experiments with 100 µm diameter pins. This problem was solved with a better mechanical design detailed in the previous discussion. With these design parameters, it was possible to insert repeatedly the pins in the membranes without breakage. Figure 7 shows the

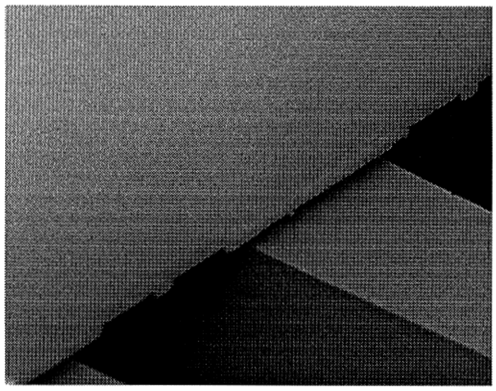

Figure 8: SEM picture of the output of a waveguide chip (top wafer) connected to the Silicon platform (bottom wafer). The Silicon V-grooves are clearly aligned in front of the waveguide output.

detail of an alignment pin inserted in the opening of a Silicon platform. Some samples were observed with a SEM after pin insertion in order to measure the alignment of the waveguide outputs with the silicon V-grooves. The measurement performed with the SEM showed a misalignment on the order of 2 µm in both lateral directions.

OPTICAL COUPLING EXPERIMENTS

Preliminary optical coupling experiments have been performed on half silicon platforms in order to facilitate the observations. The silicon V-grooves were mechanically connected to the waveguides using 4 alignment pins. Since one half of the silicon platform was used, the output of the waveguide chip is free, which allows observing the exit facet with an optical microscope. The waveguide transmission has first been measured with an active coupling method (the fiber was mounted on a micropositioning equipment and the output power optimized). This measurement showed that a mean loss of 1.7 dB can be attributed to the whole measurement setup, even for a precise alignment of the fiber to the waveguides. The optical coupling procedure with the silicon connector is illustrated on fig 9. For this preliminary experiment, a single fiber is placed inside each V-groove and brought closer to the input waveguide facet while the exit facet is observed. When the fiber is far from the waveguide, a rather large fraction of the input light escapes from the slab waveguides, which are adjacent to the main single mode waveguide. When it is brought closer, it can be observed that almost all the optical power emerges from the single mode waveguide. For all waveguides, the coupling light was observed when the fiber is brought closer to the waveguide input facet. A subsequent measurement of the optical losses has shown that these losses are on the order of 3 dB for about one half of the waveguides. For the remaining waveguides, coupling losses were higher and randomly distributed. Since the waveguide was not locked to the silicon platform, we suspect that some micro-movements are produced when the fiber is brought in contact with the waveguide, and cause some random additional misalignments. Therefore, we believe that it should be possible to improve the coupling reproducibility by improving the alignment procedure.

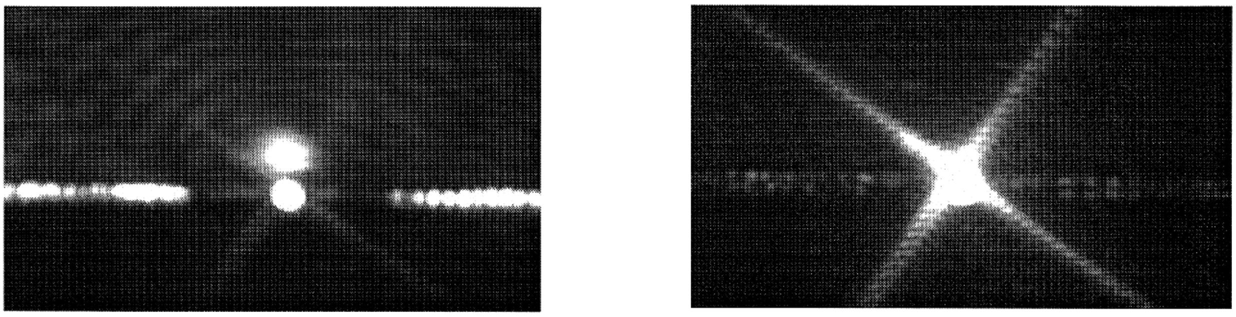

Figure 9: Optical coupling experiment: the pictures show the waveguide output after being connected to the silicon platform. In the left side picture, a fiber is set in the V-groove, far from the waveguide input. When being approached close to the waveguide entrance (right side figure), the light is concentrated in the waveguide output.

CONCLUSION

The feasibility of a new optical microconnector using MEMS technology has been established. The fabrication process has been described as well as the main design issues for the connector reliability. The connection procedure has been demonstrated and preliminary experiments show that optical losses on the order of 3 dB can be expected with this connection procedure.

ACKNOWLEDGMENTS

This work has been done with the financial support of the CNET / France Telecom contract number 95 8B.

REFERENCES

[1] Y.Yamada, M.Kobayashi 'Single Mode Optical Fiber connection to high silica waveguide with guiding groove', Journ. of Lightwave Tech., Vol. LT-5 (12), (1987), pp. 1716-1720

[2] H. Kaufmann, P. Buchmann, R. Hirter, H. Melchior, G. Guekos, Electron. Lett., Vol. 22 (12), (1986), pp. 642-644

[3] E. J. Murphy, T. C. Rice, IEEE Journ. of Quantum Electron.. Vol. QE-22 (6), (1986), pp. 928–932

[4] G. Grand, H. Denis, S.Valette, 'New method for low cost and efficient optical connections between singlemode fibres silica guides', Electron. Lett., Vol. 27 (1), pp. 16-18.

[5] A.Bruno, B. Mersali and L. Menigaux, 'Multi-pigtailing using V-grooves and mechanical cleaving on the same InP substrate', Electron. Lett., Vol. 33(12), 1997, pp. 1075-1076.

[6] G. Ensell, 'Alignment of mask patterns to crystal orientation', Sensors and Actuators, A, 53 (1996), pp. 345-348.

[7] Bharat Shivkumar and Chang-Jin Kim, MEMS 1997, Jan. 1997, Nagoya -Japan, pp. 197-202