3-D MICROSYSTEM PACKAGING FOR INTERCONNECTING ELECTRICAL, OPTICAL AND MECHANICAL MICRODEVICES TO THE EXTERNAL WORLD.

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ABSTRACT

This paper reports the realization of a pigtailed silicon platform with 8 WDM filters based on a new 3D packaging technology. Four silicon pieces are released out of a silicon wafer by using ICP-RIE as a very accurate dicing tool. One edge of the piece containing the filters is patterned into pin-shapes to be vertically inserted into a mother board with electrical connections. A V-groove board for the optical fibers is mechanically aligned in the mother board. This technology enables precise assembly of active optical devices with ribbon fibers, electrical connections to 3-dimensional micromechanical subsystems and reconfiguring the system in the module level.

I INTRODUCTION

It is always a problem to interconnect MEMS/MOEMS to the external world. Firts of all, from the technological point of view, the most sophisticated way of a microsystem packaging could be a monolithic integration of all the circuits on a single chip. However, hybrid assembling is the only solution to the practical production, with MEMS devices made of a various kind of materials, technological process... To interconnect MEMS/MOEMS means to connect many inputs and outputs, located in different parts of a microsystem. From the communication point of view, the most sophisticated solution to interconnect could be the use of an autonomous microsystem connected to the external world through wireless communications. However, most of the microsystems use electrical connections or optical connections to communicate with our world and need always interconnections at the elementary device level. Solutions for such interconnections have been proposed : the planar ligthwave circuit platform [1] for only optical connections and microelectrical connectors [2] for only electrical connections. This paper reports a 3 Dimensional Microsystem (3DM), as a new packaging with both optical and electrical interconnections. We have extended silicon micromachining technology to solve the electrical and optical packaging issue with subsequent mechanical assembly in the module level which allows for each submodule the use of different technological process which may not be compatible together, such as CMOS process, III-V devices ... To demonstrate the ability of this packaging, a first realization using only silicon micromachinning is reported: the WDM filters are based on Fabry Perot cavity with a moveable silicon mirror.

The concept of this 3 Dimensional Microsystem is first reported, showing that four silicon pieces are needed to realize such a microsystem and how they are inserted one in the other. Then the technological fabrication process of each piece is described, presenting that the pieces have been precisely cut thanks to the use of the ICP-RIE deep etching. The mechanical characterization, exposing then the accuracy of the insertion, verifies the proposed 3DM packaging. Finally, the optical characterization of the filters shows that the electrical circuits and connections is able to actuate efficiently the filters.

II CONCEPT

The 3DM integrates:

- electrical connection to be able to actuate the mirror from outside;
- the alignment between the filters and the optical fibers.

That is the reasons why the following key technologies are essential bases for the 3DM :

- V-grooves, well known to permit an easy and precise alignment of optical fibers
- micro-connectors, previously developed in our laboratory [2] to perform electrical connections of multichip microsystems
- Delay Masking Process [3, 5] for multiple height structures using Deep RIE, which can be also used as a very accurate dicing tool.

To guarantee a very precise assembly, the 3DM is composed of three silicon boards, precisely cut and inserted in on another:

- an optical filter board which contains the optical devices (series of eight filters) and one edge patterned in pin shape, which constitutes the microconnectors.
- a V-groove board with a well defined chip size, which allows the alignment of the optical fibers from both side of the filter board.
- a mother board which has a recess and receptacle holes to accommodate the two precedent boards. Its role is in two folds : to establish the alignment between the V-groove board and the filter board ; to allow the electrical

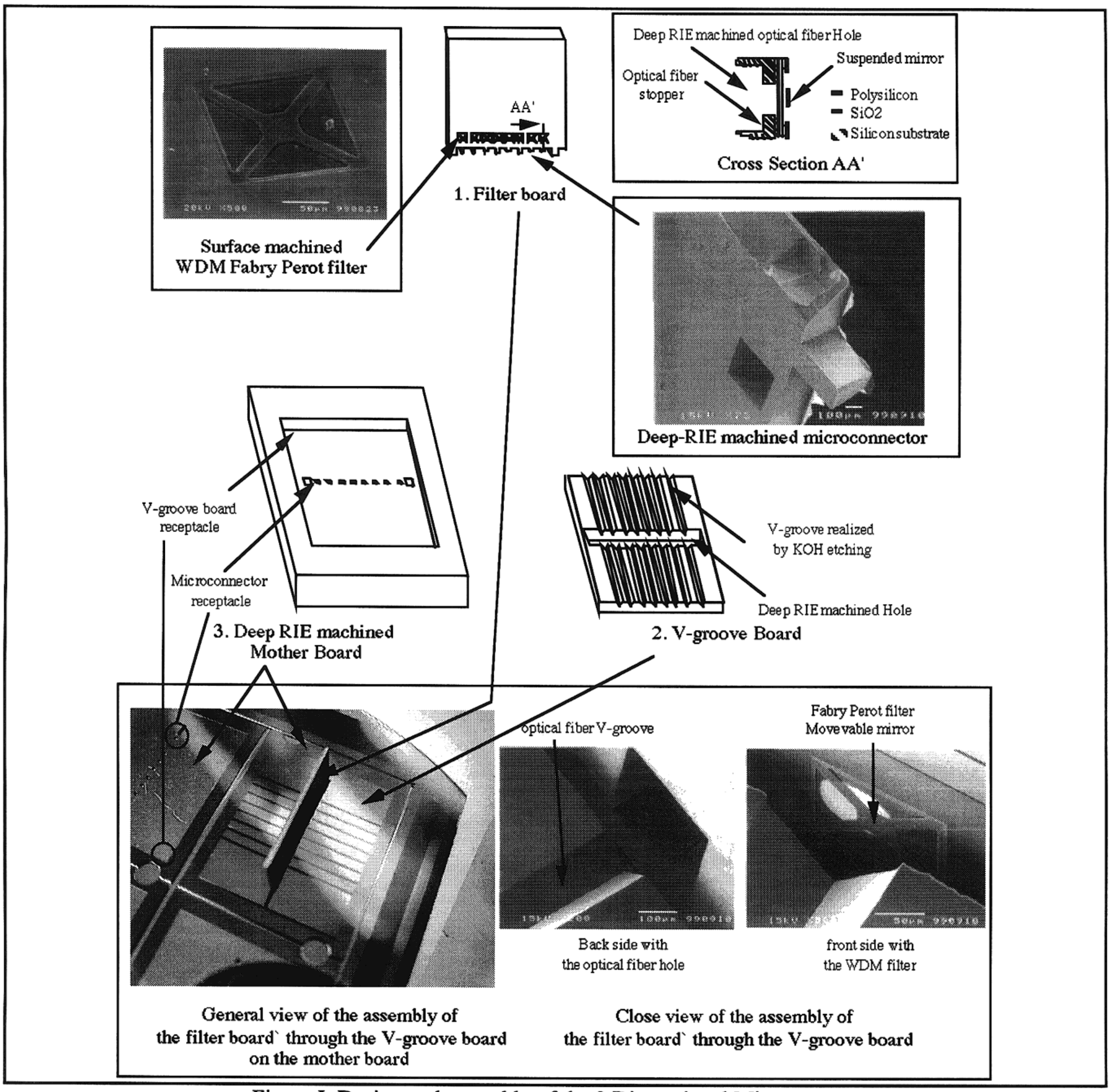


Figure I: Design and assembly of the 3 Dimensional Microsystem.

Using a tweezer, the 3 silicon submodules are assembled. The V-groove board (2) is inserted in the receptacle of the mother board (3), and then, through the large hole in the V-groove board, the filter-board (1) is vertically assembled to the mother board, with electrical contacts realized with the microconnectors.

connection between the external world and the microconnectors.Therefore the accuracy of the optical alignment and the electrical connections are insured

All of these boards have either receptacle hole or patterned edges fabricated with Deep-RIE.

For this realization, the designed filter is a Fabry Perot cavity with two doped polysilicon mirrors. By applying a voltage, the distance between the mirrors can be reduced electrotrostatically and therefore the transmitted wavelength is tuned.

The assembly of these pieces is represented on Figure I, as well as close views of the different parts of the 3DM: a filter, a microconnector with a filter, the frontside and the backside of a filter with the aligned V-groove.

The 3 silicon boards are mechanically assembled using a tweezer. At first, the V-groove board is inserted in the mother board, and then, through a large hole designed in the V-groove board, the filter-board is vertically assembled to the mother board. It can be noticed that the mechanical loads between the filter and the mother boards are supported by larger microconnectors which also guide the filter-board during its insertion and permit to remove and insert it again easily.

From the technological point of view (which is reported more in details in section III), Deep-RIE is a common

technological step for all the 3 silicon boards, to achieve very well defined assembling structures and to realize the dicing operation. However the interest and the advantage of this packaging platform is to allow, for each submodule, the use of different technological process which may be not compatible together, such as CMOS process, III-V devices...
We started to study the ability of this packaging to insert III-V devices, as InP based tunable optical filters [4] instead of silicon devices, a new filter board is now reported. This design based on the use of two boards answers at least to two main points which occur with III-V based micromachined devices:
- up to now the difficulty to perform the precise dicing of the microconnectors shape with ICP-RIE;
- the cost of the device which increases with the surface used for the fabrication.
This is for this reason and also to enlarge the use of the 3DM that a new filter board has been designed and realized in two pieces:
- the filters bar, with a well defined chip size and the 8 filters.
- the receptacle board in which the filters bar is inserted. It has one edge patterned in pin shape, which constitutes the microconnectors.
To demonstrate the ability of this packaging, a new realization is now reported using only silicon for the filters bar. The principle of precise dicing with ICP-RIE permitting the alignment of one piece to the other is maintained. It can be noticed that the rectangular shape of the filters bar should allow the use of classical III-V dicing tools. The connection between the filters bar and the receptacle board is insured by wire bonding. As before, the receptacle board with the inserted filters bar is inserted through the large hole of the V-groove board in the mother board. As well, the microconnectors allow the alignment of the filter board to the mother board and the electrical connection towards the external world.
Figure II represents the new filter board with the filters bar inserted in the receptacle board. It can be noticed the different shapes of the microconnectors:
- the V shape allows the lateral alignment in the mother board, as its dimension at the top is the same as its corresponding hole in the mother board.
- the U shapes are microconnectors to which are connected the movable mirror of the filters.
- the |_| shape is the large microconnector permitting to guide the filter board during its insertion. It also plays the role of ground.
Figure III represents the photo of the receptacle board with the filters bar inserted in it.
The fabrication and the technological point of view of this 3DM will be now presented.

III. TECHNOLOGICAL POINT OF VIEW

To achieve very well defined assembling structures the final step of all the technological processes is an operation of dicing by ICP-RIE. The machine used is a Plasma Therm one, using the BOSCH Process optimized in Japan.

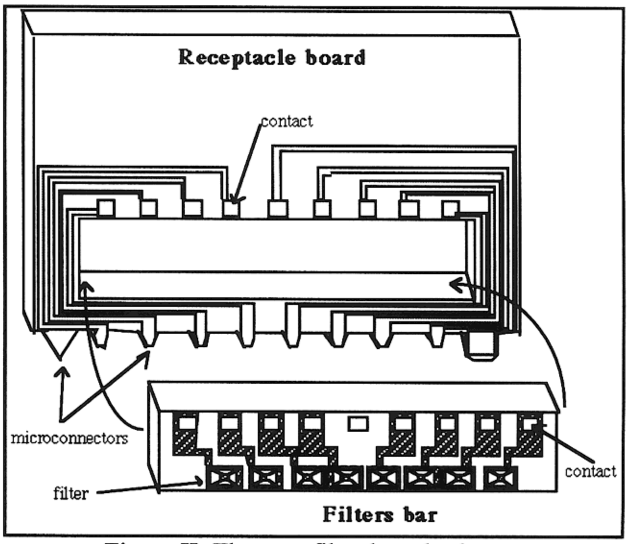


Figure II: The new filter board scheme.

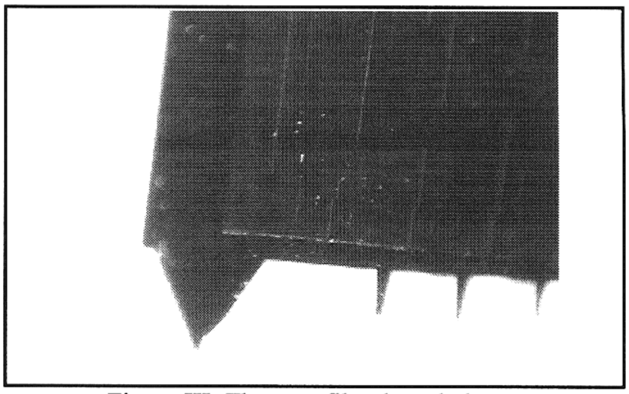
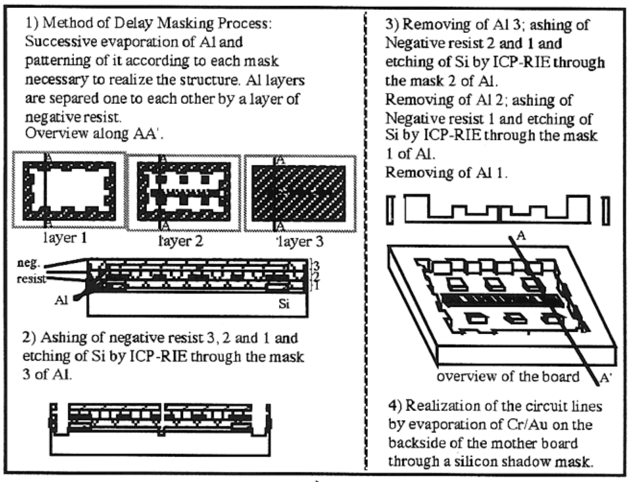


Figure III: The new filter board photo.

Each board is realized independently from each other. The mother board is realized using the Delay Masking Process [3,5]. Because its role is partly to insure the good alignment between the V-groove board and the filter board, its receptacle has to be very flat. In other words, it is essential to prevent the presence of particles which could provoke an effect of micromasking and prevent a uniform etching of Si during the step of etching of the receptacle by ICP-RIE. That is why the process has been lightly modified, in confrontation to the one for the mother board of Figure I, and it has been realized a three level mother board: the presence of pads in the receptacle area and of the loop-holes on the edges reduce the risk of having to many particle and not enough flat areas.
The process of this board is summarized on Figure IV a). More precise details of the Delay Masking Process are givrn in references [3,5]. In Figure IV b), the photo of the realized mother board is shown.
The fabrication of the mother board is followed by the realization of the circuit lines, by evaporation of Cr/Au on the back side through a shadow mask [6]. These circuit lines allow the connection between the microconnectors of the filter board and the external world.



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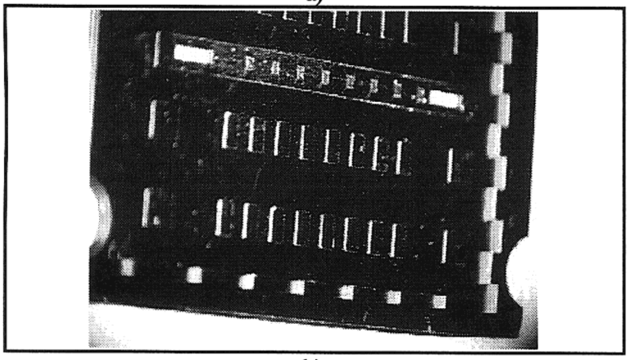
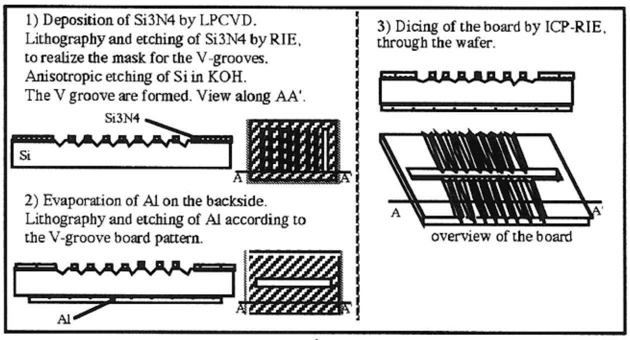


b)

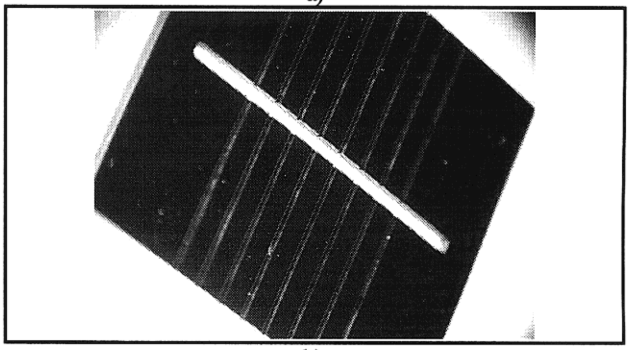
Figure IV: a) Technological Process steps of the fabrication of the mother board. b) Photo of the mother board.

Figure V : Detail of the V-groove board inserted in the mother board

On Figure V, the photo shows the good insertion of the V-groove board in the mother board: only the corner of the V-groove board in the mother board is shown.
The V-groove board is realized according to the process presented on Figure VI a). On Figure VI b), the photo of the V-groove board is shown.
The filter board is inserted through the large hole of the V-groove board, inside the receptacle holes of the mother board. On Figures VII and VIII, the technological steps of the fabrication process of the receptacle board and the filters bar are summarized.



a)



b)

Figure VI: a) Technological Process steps of the fabrication of the V-groove board. b) Photo of the V-groove board.

The photography of these two inserted pieces is shown on Figure III. The electrical contacts and the lines of connection are realized as a final step of the process by evaporation of Cr/Au through a shadow mask [6].

The fabrication of the receptacle board is very simple as it consists only of a dicing with the ICP-RIE.
To realize the filters bar (Figure VIII), the frontside is first micromachined to realize the filters patterns. Just after patterning the ploy-2 layer, a layer of SiO_2 is deposited by LPCVD as a passivation layer: during the dicing by ICP-RIE (step 3) from frontside, this layer prevents the poly-2 layer from the damage due to this etching step.

On backside, just behind the filters, holes for insertion of the optical fibers are realized using the Delay Masking Process method. Its realization needs two levels of mask: the layer with the small hole, whose diameter (80 µm) is smaller than the optical fiber diameter (125 µm), is in fact a stopper for the optical fiber arriving in the large hole (diameter of 300 µm).

On step 5, on the overview of the bar, it can be seen that each movable mirror (made in poly-2) is isolated onefrom the other one. And each movable mirror is connected to one independent Cr/Au bonding pad. Each board has been designed with precise dimensions and has been precisely diced by ICP-RIE, in order each can insert the other one with not a too large play. The next section will present the measurements of this play.

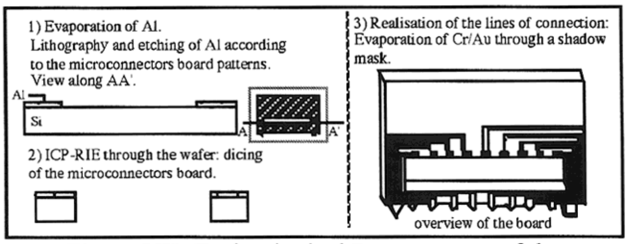


Figure VII: Technological Process steps of the fabrication of the receptacle board.

Difference	Designed values (µm)	Measured values (µm)
m.a - v.a	3	5.5
m.b - r.c	0	5
	1.5	7
r.b - f.b	0	3.5
	3	4.5
	7	6.5

Table I: Theoretical and measured plays along the lateral direction.

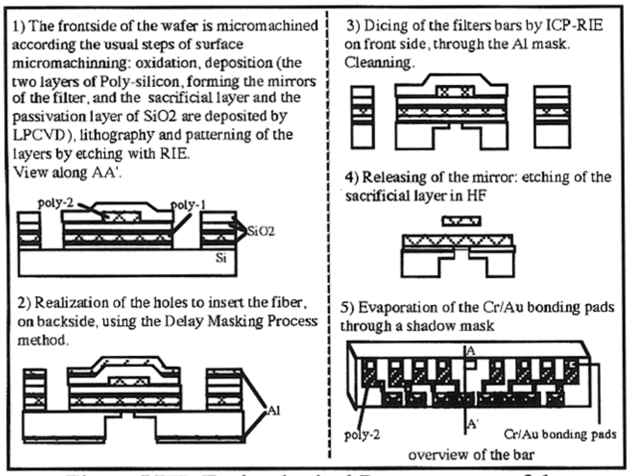


Figure VIII: Technological Process steps of the fabrication of the filters bar.

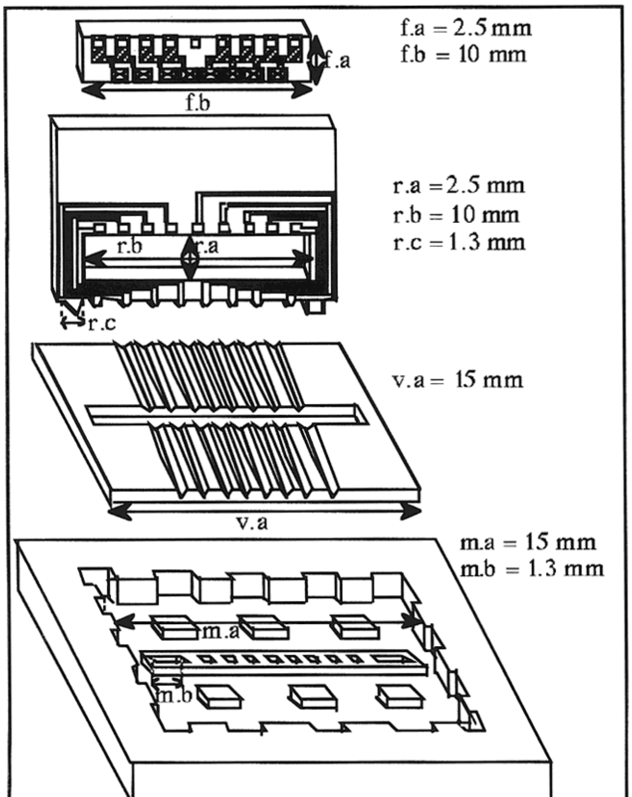


Figure IX: Boards with their rough dimensions.

IV. MECHANICAL CHARACTERIZATION

On Figure IX is represented each board with its rough dimensions. On table I, the difference between the dimension of the hole and of its corresponding inserting pin is reported.

In the worst case, the total play is given by the sum of all the plays reported in the table I. Depending on the considered design, the maximum measured total play is in the range of ±14 µm to ±19 µm, when the theoretical one is in the range of ±3 µm to ±11.5 µm.

This difference of range is mainly due to the damage caused during the Delay Masking Process for the realization of the pin/hole alignment of the mother board, which dimension m.b increases of 10 µm during the process.

However, these results remain compatible with the required value given by the difference between the size of the movable mirror and the size of the optical fiber mode, ±19 µm. For the mechanical point of view, this result valids the proposed 3DM packaging.

The electrical part of the 3DM has been tested by characterizing the optical filter.

V. OPTICAL CHARACTERIZATION

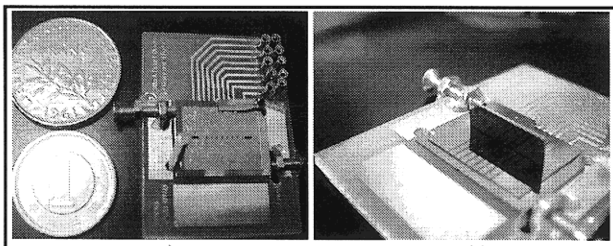
To be able to manipulate and to characterize the 3DM, it has been integrated on a circuit board. In Figure X, a photo of the 3DM mounted on the circuit board is shown.

The optical characterizations are performed with a white light source, an optical spectrum analyzer and two cleaved monomode fibers.

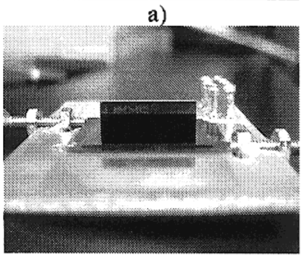
Figure XI shows the relative transmission coefficient of the 3DM with 0 and 50 V as bias voltage. The reference (0 dB) is given by theresponse without the filter, for the two optical fibers in closed contact.

It can be noticed that the resonance peaks are broad because the final purpose of the filter is the switching between 1.3 µm band and 1.5 µm band with silicon mirrors for the Fabry Perot cavity

For this first realization that is not yet optimized, the 3DM exhibits a clear tuning effect and insertions losses less than 6 dB, which confirms the proposed packaging concept.



a) b)



c)

Figure X : Integration of the 3DM on a circuit board, for the manipulation and characterization.

a) the mother board alone, b) and c) the 3 silicon submodules

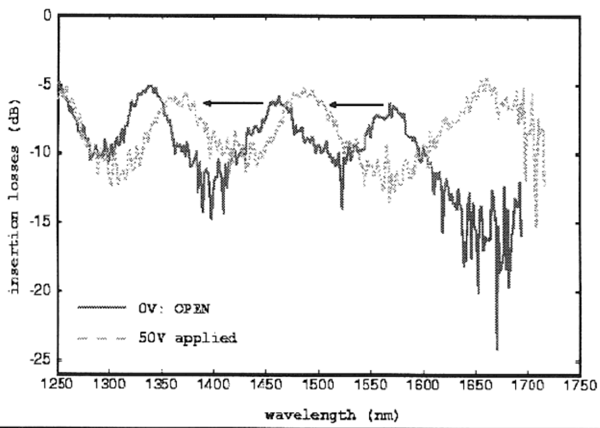


Figure XI: Optical Characterization of the 3DM

VI CONCLUSION

A 3 Dimensional Microsystem has been realized combining optical alignment and electrical actuation of 8 WDM filters. For the application presented in this paper, the microsystem has been realized fully in silicon.

The four pieces needed for this 3DM have all of them either receptacle holes or patterned edges precisely fabricated with ICP-RIE. It allows them to assemble byinserting one in each other. The necessary optical alignement between the WDM filters board and the optical fibers, placed inside the V-grooves of the V-grooves board, is insured by mechanically alignedboards through the mother board. This mechanical alignment reached a measured maximum range play of ±14 µm to ±19 µm. These values are compatible with the maximum play allowed by the mirror width: ±19 µm.

The electrical actuation is realized through microconnectors. For the optical characterization, the 3DM exhibits a clear tuning effect and insertions losses less than 6 dB, which confirms the proposed packaging concept.

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