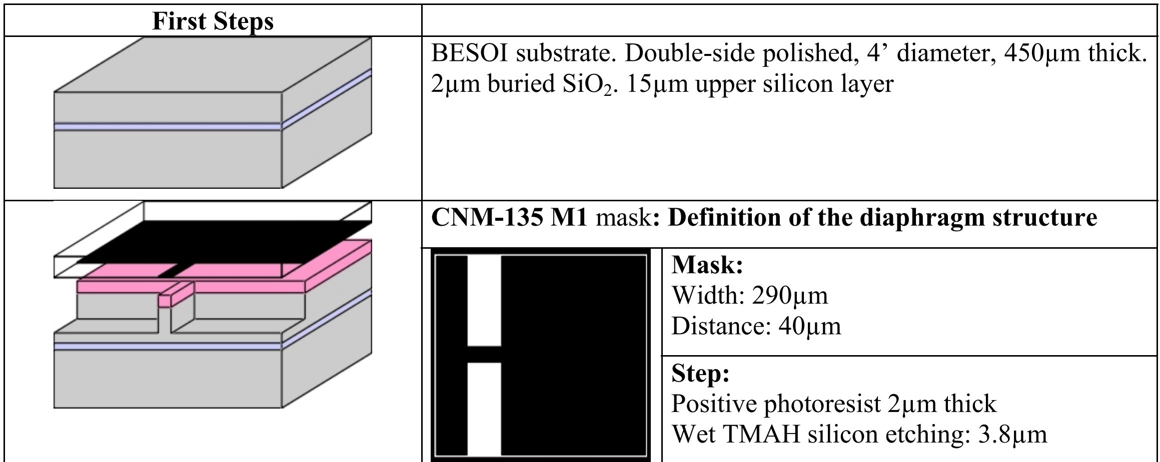
5.8 Diaphragm Uniaxial Optical Accelerometer

Optical accelerometers are based on the BESOI (*Bond and Etch back Silicon On Insulator*) wafers, supplied by *Shin-Etsu* with (100) orientation, 4' diameter and total thickness of 450±25μm. The thickness of the buried silicon oxide layer is 2μm and the upper silicon layer is 15μm thick, with a dispersion of less than 0.5μm in the wafer an less than 1μm between the wafers of the same set. This accurate control on the silicon thickness allows controlling the beam thickness, responsible of the appropriate working range of the accelerometer. Although the price of these wafers is much higher as compared to standard wafers, the buried silicon oxide layer permits defining complex mechanical structures in a relatively simple manner.

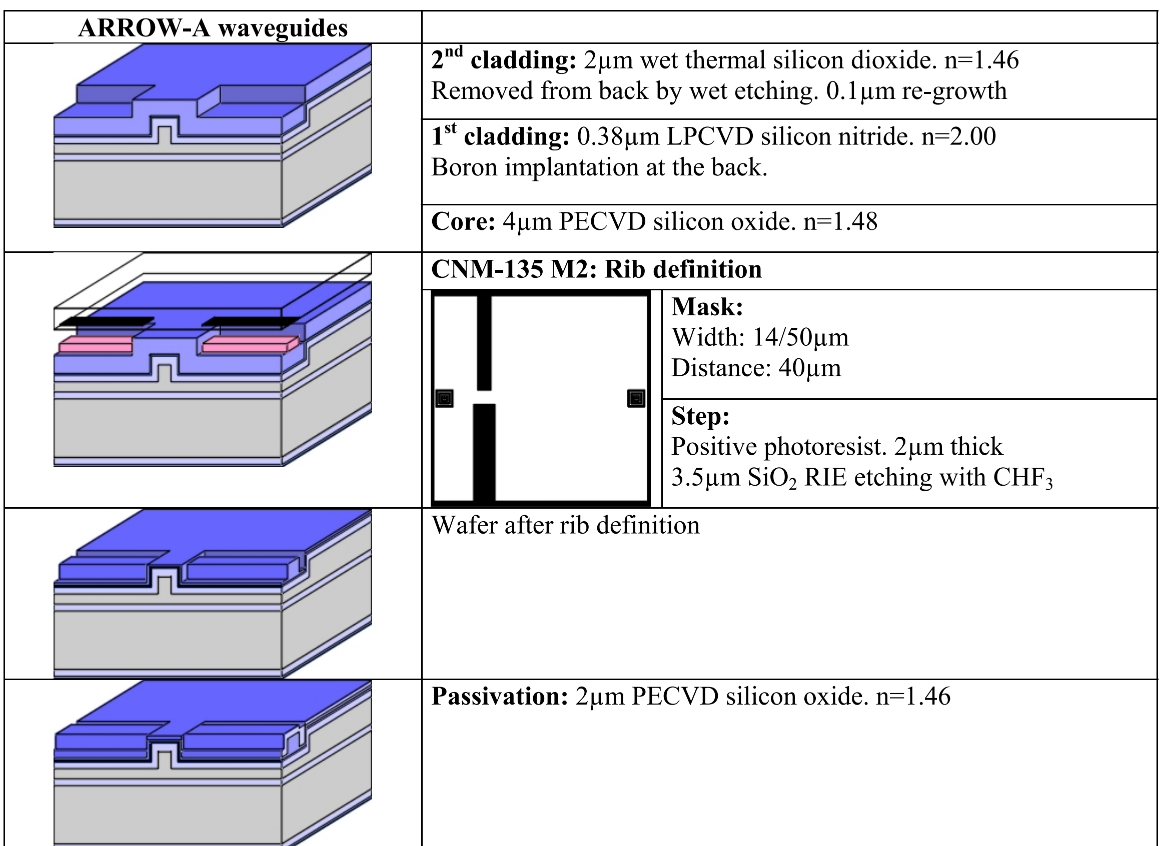
First steps on the fabrication head towards aligning the bridge with the future waveguides (table 5.13). With that objective, a thin silicon oxide layer is deposited on the entire wafer and, after the first photolithographic step, it is removed by RIE from the regions where waveguides have to be defined. Remaining silicon oxide acts as a mask during the wet silicon etching, which has been done with TMAH due to the fact that its selectivity against SiO_2 is much higher and, it is CMOS compatible, that is, wafers can still be treated as non-contaminated after this process (This would not be so if KOH was used, since K^+ ions could contaminate furnaces or reactors). Silicon etching has been fixed at a depth of 3.8μm. Thus, the diaphragm will be aligned with the center of the waveguide. As can be seen in table 5.13, etching has been done where waveguides should be located, but its initial thickness remains unchanged at the diaphragm zone.



First Steps		
	BESOI substrate. Double-side polished, 4' diameter, 450μm thick. 2μm buried SiO_2. 15μm upper silicon layer	
	CNM-135 M1 mask**: Definition of the diaphragm structure**	
		Mask: Width: 290μm Distance: 40μm
		Step: Positive photoresist 2μm thick Wet TMAH silicon etching: 3.8μm

Table 5.13: Diaphragm definition on the uniaxial diaphragm optical accelerometer.

Secondly, ARROW-A waveguides are defined following the steps described in section 5.3.1 However, the thermal silicon oxide causes excessive mechanical stresses on the back of the wafer and it is completely removed from this side. Afterwards a new thin silicon oxide layer of 0.1µm is grown. It will be the mask during the anisotropic etch (table 5.14). This small oxidation does not cause significant changes on the components side of the wafer due to the fact that there still are 2µm silicon oxide and the growth in a furnace is not linear, but has a logarithmic behavior. The silicon nitride that acts as the 1st cladding in an ARROW-A waveguide is also used as a mask for the KOH etching. However, in order to reduce mechanical stresses on the back, it has been Boron-implanted. After the deposition of the core, a 3.5µm RIE etching is performed in order to define the rib ARROW structure, obtaining input and output waveguides of 14 and 50µm, respectively. Finally, 2µm PECVD silicon oxide is deposited for passivation

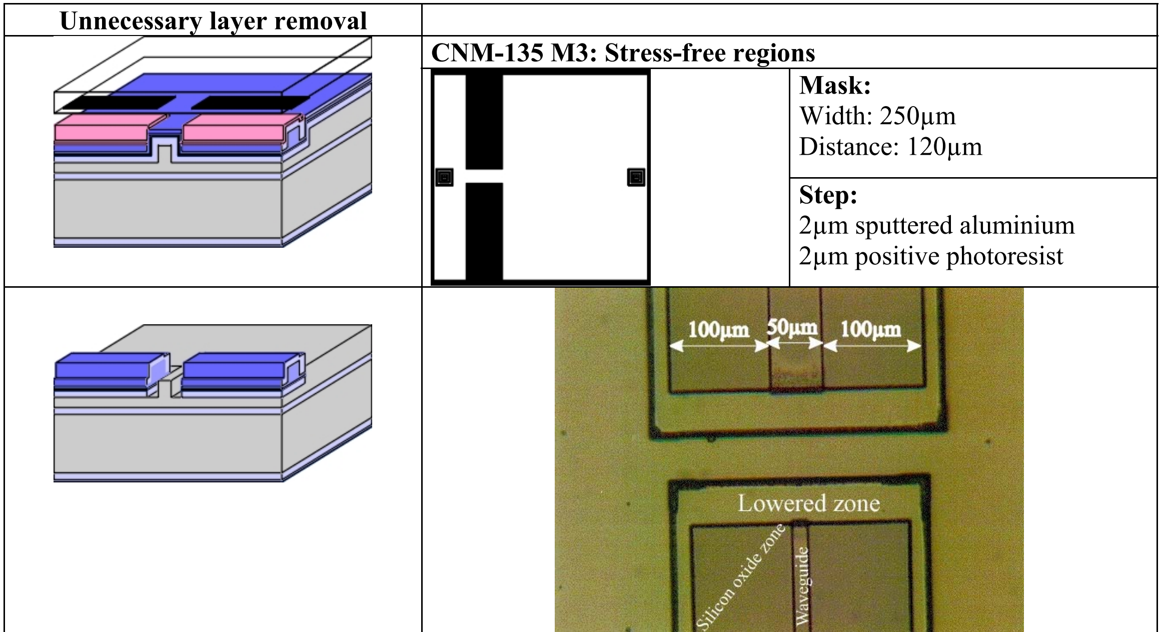


ARROW-A waveguides		
	2nd cladding: 2µm wet thermal silicon dioxide. n=1.46 Removed from back by wet etching. 0.1µm re-growth	
	1st cladding: 0.38µm LPCVD silicon nitride. n=2.00 Boron implantation at the back.	
	Core: 4µm PECVD silicon oxide. n=1.48	
	CNM-135 M2: Rib definition	
		Mask: Width: 14/50µm Distance: 40µm
		Step: Positive photoresist. 2µm thick 3.5µm SiO_2 RIE etching with CHF_3
	Wafer after rib definition	
	Passivation: 2µm PECVD silicon oxide. n=1.46	

Table 5.14: Wafer status during the waveguide fabrication steps.

The following steps, shown in table 5.15, is the complete removal of all the ARROW layers except in the zone where the rib has been defined. Concretely, the third mask has been designed so as to leave the ARROW structure only at 100µm in distance from the rib. This has been done for preventing the accelerometer from suffering the so-called bimetal effect, that is, bending of the structures due to the different expansion coefficient of two or more adjacent layers. Thus, it is essential to remove al silicon oxide and silicon nitride in the region where the mechanical structure has to be defined.

Layer thicknesses to be etched are significantly thick. This force using a material able to stand such a long etching time: first attempts with thick photoresist did not provide with satisfactory results and it was decided to use aluminium as mask. The main advantage of this material is the capability of this layer to resist the deep etching required. However, deposition of a metal on the wafer causes to be treated as a contaminated wafer, being forbidden to be processed in the CMOS line afterwards.



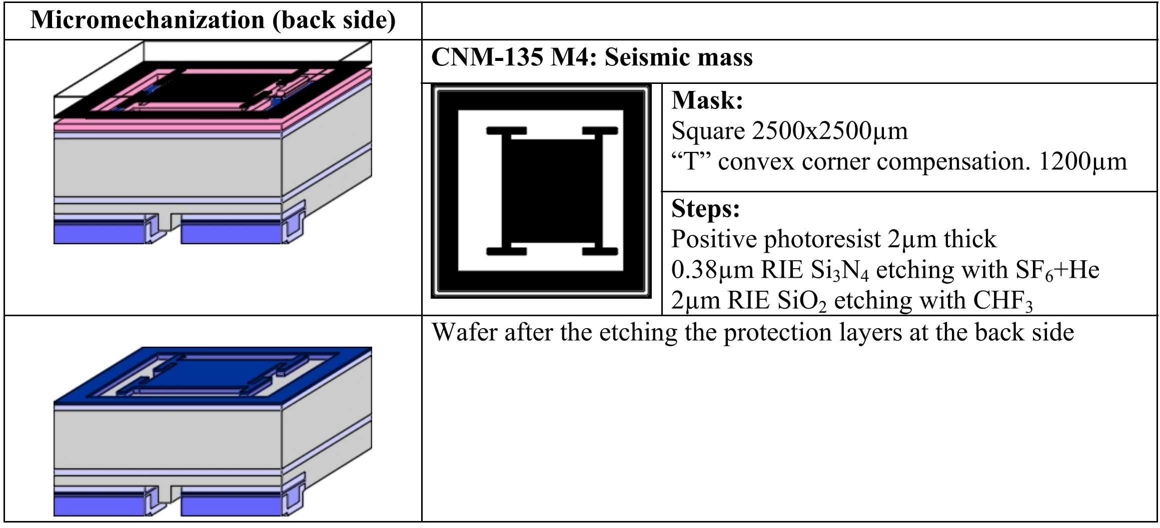
Unnecessary layer removal		
	CNM-135 M3: Stress-free regions	
		Mask: Width: 250µm Distance: 120µm
		Step: 2µm sputtered aluminium 2µm positive photoresist

Table 5.15: Removal of unnecessary layers and final appearance of the sensing region where it can be observed the thinner input waveguide (bottom) the zone where the diaphragm will be defined and the output waveguide (top).

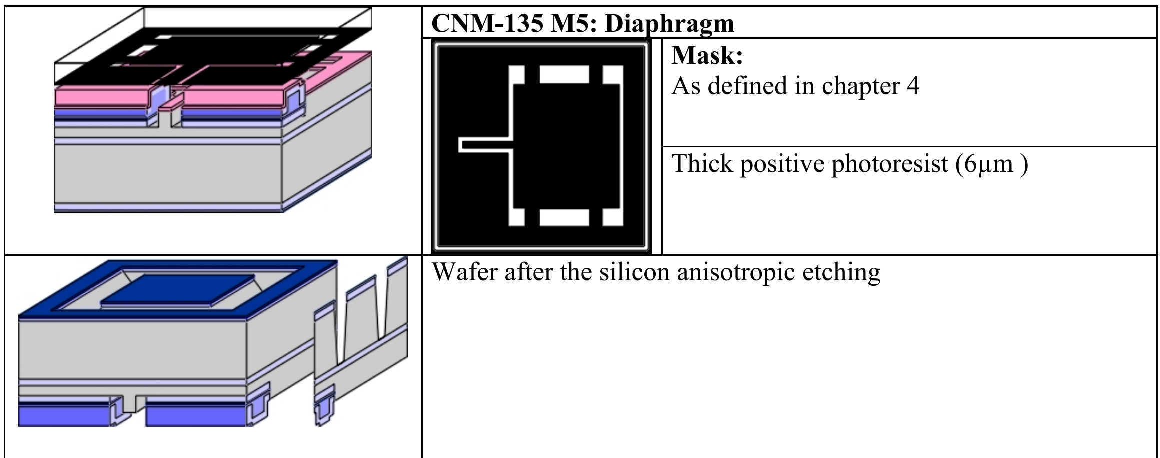
Once the optical part has been successfully defined, the next issue is the definition of the mechanical part, that is, the wafer micromechanization. It has been done in two steps, firstly, an anisotropic etching has been produced at the back of the wafer so as to define the three dimensional structure. Once this point has been fulfilled,

a second etching, being in this case RIE etching, has been used in order to free the structure.

Micromechanization starts by the deposition of a photoresist on the back of the wafer and etch by RIE both the silicon nitride and the silicon oxide in order to open the windows where anisotropic etching will be done. However, before doing the etching, the next photolithographic step, this time in the front side, is done (table 5.16). This step has been done at this time because of the fact that after KOH etching wafers are extremely fragile and would not be possible to do any further photolithographic process. Photoresist used at the front side is 6µm thick because it is needed to cover high steps and stand harsh silicon RIE etching (15µm). Anisotropic etching is done in KOH. As compared to TMAH, the former has a higher selectivity on etching (100) and (111) planes (which provides with a better accuracy on obtaining the expected geometry) and a minor lateral etching (which allows defining smaller convex corner compensation structures). Moreover, due to the KOH selectivity, either in the (111) and silicon oxide etching speed, the etching is automatically stops at (111) planes and/or when the buried silicon oxide layer is reached.



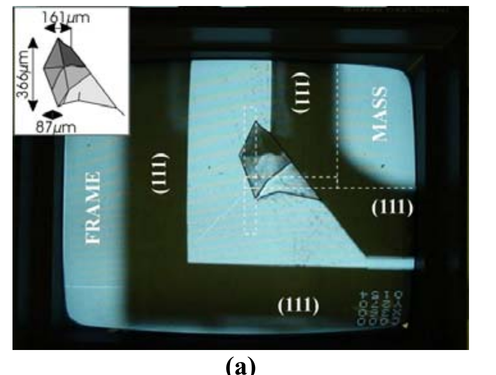
Micromechanization (back side)		
	CNM-135 M4: Seismic mass	
		Mask: Square 2500x2500µm "T" convex corner compensation. 1200µm
		Steps: Positive photoresist 2µm thick 0.38µm RIE Si_3N_4 etching with SF_6+He 2µm RIE SiO_2 etching with CHF_3
	Wafer after the etching the protection layers at the back side	

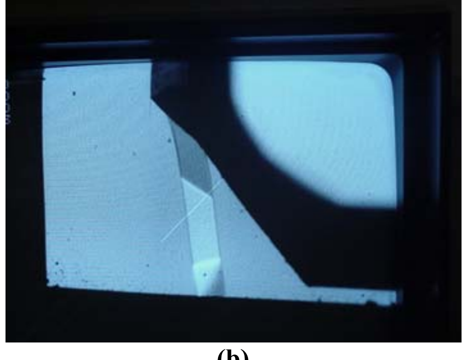


	CNM-135 M5: Diaphragm	
		Mask: As defined in chapter 4
		Thick positive photoresist (6µm)
	Wafer after the silicon anisotropic etching	

Table 5.16: Anisotropic steps that allow defining the three-dimensional structure of the diaphragm optical accelerometer.

For convex corner protection, in chapter 3 it was shown that experimental KOH etching results obtained at CNM required a length of 1300µm in order to fully protect the corners. During the design of the seismic mass of the accelerometers, corners were 100µm subcompensated. This was done so as to cause a small rounding at the corners, trying to avoid salient formation at the bottom of the seismic mass (as shown in fig. 5.28) that could cause malfunctions on the correct behavior of the device. However, its removal could be simply done by overetching the wafers, which would not cause significant variations on the device working range.





(a) (b)

Fig. 5.28: Salient obtained after Convex corner subcompensation etching (a) which has been completely removed after wafer overetching (b).

Layers that still remain in the backside after the steps shown in table 5.16, that is, Si_3N_4 and SiO_2, are removed, by dry and wet etching, respectively, so as to prepare that side for anodic bonding. Then, the accelerometer micromechanization ends with a RIE etching on the front side.