Nano Scale Disruptive Silicon-Plasmonic Platform for Chip-to-Chip Interconnection

Fabrication of compact optical filters and first generation beam shapers

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Executive Summary

This document reports completion of the fabrication of the compact optical filters and first generation beam shapers.

Change Records

Version	Date	Changes	Author
0.1 (draft)	2013-05-15	Start	Dries Van Thourhout
1 (submission)			Dries Van Thourhout

Contents

1. Introduction

This milestone document reports on the completion of the fabrication of the optical filters and first generation beam shapers. This milestone follows up on MS27 (design of devices) and will feed in deliverable D5.3 (report on first generation filters and beam shapers, month 21) where the characterisation results will be discussed in detail.

2. Optical filters

Various optical filers were fabricated, in several processing runs. All devices were fabricated on 200mm wafers using imec's standard passive waveguide platform, starting from SOI-wafers (SOITEC) with a 220nm thick silicon layer. Patterns were defined using 193nm DUV lithography and subsequently etched using a dry etching process (ICP-based). Two etching steps were used:

- A 220nm deep etch to defined the fully etched waveguides
- A 70nm shallow etch to define grating couplers and transition regions between deeply etched regions and slab regions.

Following fabrication wafers were diced for characterisation.

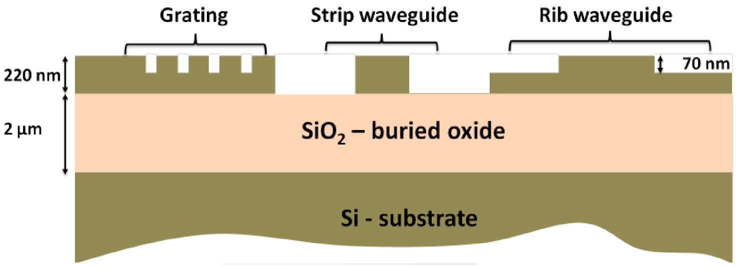


Figure 1 The different photonic components fabricated in IMEC on the SOI structure; the deep etch of 220 nm is used in fabricating the strip wave- guides whereas the shallow etch of 70 nm is used in making the rib waveguides and the gratings.

3. Optical beam shapers

The optical beam shapers were fabricated using the same process as the one used for the optical filters. However, since the optical beam shapers need to be free hanging, such that they can be moved electrostatically an underetching process had to be developed, to remove the oxide below the moving parts of the beam shapers. Typically a wet etch process would be used for that.

However, removal of the water from the liquid etchant results in a meniscus (liquid-air interface) that often pulls movable structures into contact via capillary forces. Once in contact, even after drying, the surfaces often remain in contact due to various types of adhesion forces (e.g. capillary, van Der Waals, electrostatic due to trapped charge) resulting in a stuck, or stiction-like failure as shown in Figure 2.

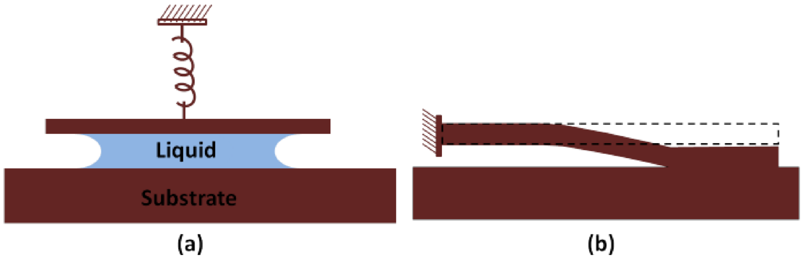


Figure 2 Schematic illustration of: (a) the formation of a liquid meniscus during the the sacrifical etch, and (b) sticking of the released parts due to surface tension at the final phase of evaporation.

There are several solutions that have been used by researchers and MEMS manufacturers to reduce stiction. One approach calls for coating the substrate surface with a thin hydrophobic layer, thereby repelling liquid from the surface. Another popular technique is to dry surfaces using super-critical CO_2. This removes fluid without allowing the surface tension to form. Still other techniques utilize "stand-off bumps" on the underside of moving parts. These bumps act as pillars, propping up movable parts wherever surface tension may form. However, the most effective method for avoiding stiction is simply to use dry or quasi-dry etching techniques for release wherever possible.

A possible approach is to use a hydro-fluoric acid (HF) vapour phase etching (VPE) system. This enables the removal of silicon dioxide in a vaporous environment rather than in an aqueous solution. The silicon oxide is etched in a quasi-dry method and is never in contact with a liquid. No cleaning or rinsing of the chips is needed.

In this process water acts as initiator of the etching process as well as reactant. This fact suggests that the etching process can be temperature controlled to maintain the amount of water needed to initiate the process and the amount of reactant water in equilibrium.

We used the HF VPE apparatus from IDONUS to release all our MEMS devices. A detailed descriptipon of the working principle of the apparatus and its mechanical realisation can be found on www.idonus.com. In this system, the HF evaporates at room temperature and the etching process starts spontaneously. The etch rate is controlled by the wafer temperature that can be adjusted from 35°C to 60°C. The water film on the wafer is evaporated at moderate temperatures. We experimentally found that the etch rate decreases with increasing temperature and stops completely at temperatures above 52°C when using 50% concentrated HF.

Process optimization: Starting with a clean and dry surface of the samples was the most important pre-condition to obtain a uniform etching rate for successful release of the structural layers. Hence, the separate dies were first cleaned with acetone, IPA and de-ionized water and later dried with N_2. Next, the samples were thoroughly dried at an elevated temperature of 150C for 15 minutes to ensure that no moisture is left on the samples before they were put inside the VPE. Particularly, the metal deposited samples suffered from frequent stiction even after thorough cleaning and drying of the samples before starting the etching process. The situation worsened with any residual resist left on the samples after the lift-off. Additionally, after a long etching time (~ 2-2.5 hrs), we observed peeling of the metal layers deposited on top of the Si structure. Hence, we had to add an intermediate step of rapid thermal annealing of the metal deposited samples at 430°C to enhance the adhesion of the Au films deposited on Si. Even after taking all the precautions, we observed non uniform etching and sticking of the released samples when etched at temperatures lower than 40 °C.

However, we could achieve a stiction free release of our devices when the buried oxide was etched at a temperature of ≥42◦C which resulted in a etch rate of ∼ 5-6 µm/ hr. In this way, we could obtain a reproducible etching process though a few inconsistencies remained.
Figure 3 shows an example where 220 nm thick and 2 µm wide Si cantilevers with length upto 200 µm are released successfully without stiction after remov- ing the 2 µm thick SiO_2 layer. For these devices, we had to go to higher temperature of 43.5C to release the longer cantilevers, which gave us an etching rate of ∼1 µm/ hr.

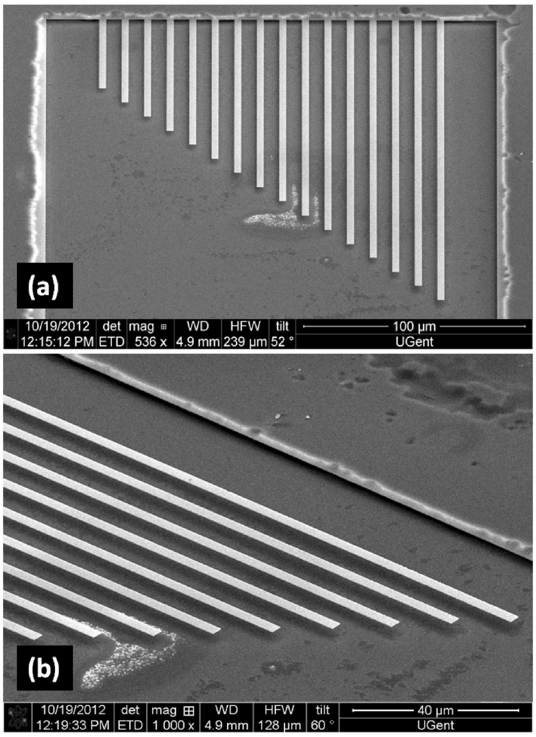


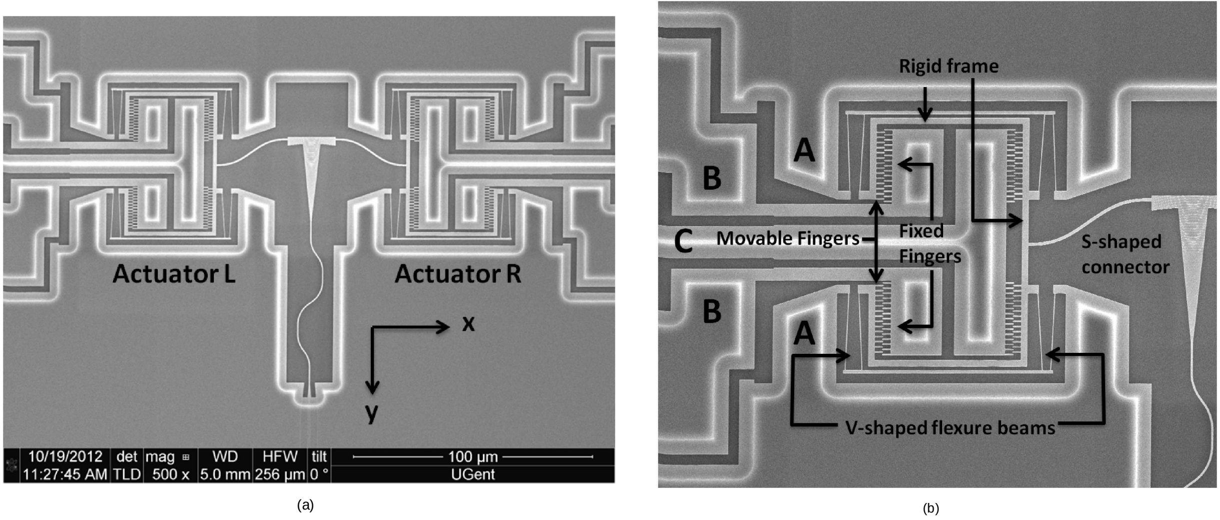
Figure 3 SEM pictures of the successful release of 220 nm thick and 2 µm wide poly-Si cantilevers on top of 2 µm thick SiO_2 without sticking; where the length of the cantilevers varies from 50 µm to 200 µm.

SEM pictures of the in plane moving device are given in Figure 4. The actuator consists of 3 major elements:

1. The first is the focused grating coupler(FGC) which is the principal micro-optical component of the device and the central component of the active region. To decrease the weight of the proof mass (here the FGC) attached to the comb drives, the FGC is cut down from the sides and the top, making it smaller and lighter
2. The second is a system of curved compliant suspension beams. The curved ’S’ shape is designed to convert a unidirectional actuation into a bidirectional displacement
3. The third element comprises of comb-drive actuators where the moving fingers are attached to a rigid frame which is further attached to the fixed parts of the chip by ’V’ shaped springs.

The active FGC along with the movable comb fingers (region A) are always kept at ground potential whereas the two separate fixed comb structures (region B and C) are always maintained either at ground or higher potential respectively depending on the direction of the desired movement. These three regions A, B and C are etched completely through the silicon, allowing for separate electrical actuation.

In our design each of the comb drive actuator consists of 28 pairs of fingers of 300 nm width, 2 μm length and 300 nm gap between each pair. The rigid support is 1.5 μm wide and 56 μm long. The 'V' shaped springs are 120 nm wide and 18 μm long and are connected by another 0.75 μm wide rigid structure. The 'S' shaped connectors are 29 μm long and 0.75 μm wide.



(a) (b)

Figure 4 (a) SEM picture of the top view of the planar moving devices showing the two actuators on both the sides of the FGC (a), and close-up view of the specific actuators and the different components of it (b).