V-groove plasmonic waveguides fabricated by NanoImprint Lithography

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Surface plasmon polaritons (SPPs), are quasi two-dimensional electromagnetic waves propagating along a dielectric-metal interface. They have recently generated a lot of interest, triggered by the progress in the fabrication of *nano-structured metal surfaces*, which allows tailoring the properties of the SPPs. For the miniaturization of photonic circuits, metallic structures can provide unique ways of manipulating light at length scales smaller than the wavelength.

Recently, v-shape grooves made in noble metal film have demonstrated plasmon coupling in the bottom of the groove (strong field enhancement) [1]. The structure used for this demonstration was made in silver by Focused Ion Beam (FIB), resulting in a sharp v-groove, but showing rough sidewalls. FIB is suitable for single groove fabrication, but not for large volume applications, (i.e., biosensors).

In this work we present a new process for the fabrication of the v-grooves in metal, based on **NanoImprint Lithography (NIL)**. By our imprinting method, v-grooves with smooth surfaces fabricated in a silicon stamp, are replicated in a metal. Furthermore, in a single step we obtain multilevel structures: few microns deep v-groove waveguides, and ~300 µm deep channels – to place optical fibers for the optical characterization. Figure 1 shows the steps of the whole fabrication process:

(a) The stamp is designed and fabricated in silicon. Each stamp contains 120 v-grooves, placed between deep channels (300 µm deep, 200 µm wide), where the optical fibers will be placed. The grooves have been made by anisotropic wet etching of silicon (KOH), resulting in v-grooves with and angle of 72º, and smooth sidewalls. Each stamp contains grooves with different lengths (from 100 µm to 500 µm), and different widths (5 µm, 7 µm and 12 µm).
(b) The stamp is imprinted in a PMMA sheet.
(c) A 200 nm thick film of **gold** is deposited on the imprinted PMMA.
(d) The structures are filled with a UV curable polymer (Ormocomp®, provided by Micro Resist Technology[2]). The polymer is cured to act as a support for the thin gold film. The gold film has shown better adhesion to the cured material than to PMMA.
(e) The PMMA sheet is dissolved, using acetone, whereby the smooth grooves in the silicon stamps are replicated in the gold film.
(f) Final structures show the same geometry of the initial silicon stamp, but transferred to different materials (200 nm film of gold, on top of cured Ormocomp).

Figure 2, (a) and (b), shows some examples of the final structures, v-grooves fabricated in gold.

We have enhanced the sharpeness of the grooves by **wet oxidation** of the silicon stamp. First, simulations were performed to find the optimal conditions for the oxidation. Then, the stamp was oxidized at these conditions (1150 ºC, 6 h). Figure 3 shows the results of the simulation (top row), and SEM images of the oxidized silicon stamp (bottom row). Figure 3 a and d correspond to the initial groove, and figure 3 (b, e, c and f) show the results for the oxidation of grooves of different geometries (12 µm wide in (b and e), and 5 µm wide in (c and f)). The shape of the 5 µm wide grooves is the most interesting for plasmon confinement, because the angle in the bottom of the groove is improved from 72º to 50º.

Finally, the stamp was imprinted, and the grooves transferred to gold on Ormocer, as described above. Figure 4 shows some examples of the final structures. In the SEM images, the shape of the grooves is shown to be improved. SNOM measurements will be performed in these structures, to study light propagation.

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[1] S. I. Bozhevolnyi, V. S. Volkov, E. Devaux, T. W. Ebbesen, Phys. Rev. Lett. 95, 046802 (2005)

[2] Micro resist Technology – GmbH, Berlin. http://www.microresist.de/

Figures:

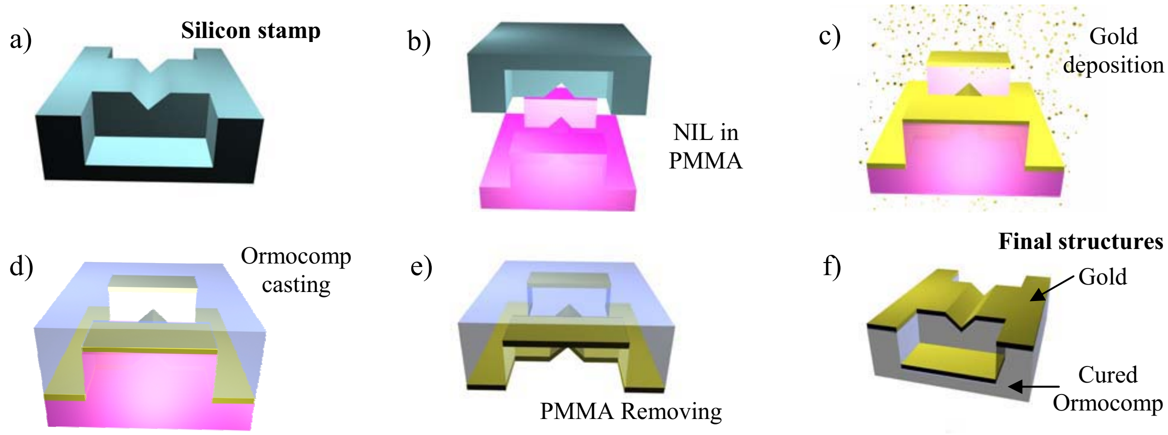

***Figure 1*. Scheme of the fabrication process**: *(a) silicon stamp, containing the v-grooves. (b) NanoImprint process, to transfer the features to PMMA. (c) a 200 nm thick film of gold is deposited on the PMMA structures. (d) casting of a UV curable polymer (Ormocomp, by micro resist technology) on the structures, and UV curing. (d) PMMA is dissolved in acetone. (f) scheme of the final structures, showing the same geometry of the initial stamp, but made in gold on top of Ormocomp.*

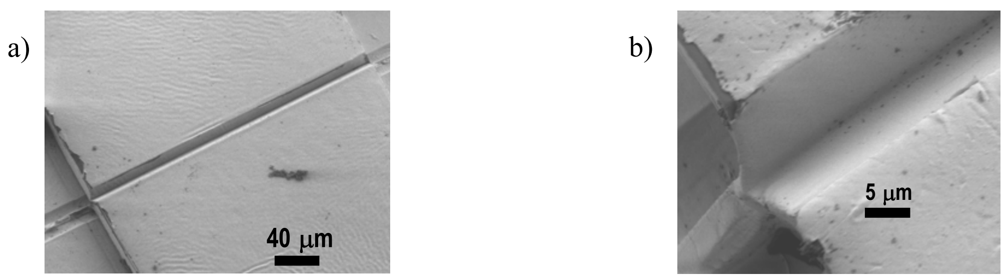

Figure 2. *SEM images of the* ***final structures fabricated in gold*** *(figure 1 f). (a), the groove and the deep channels. (b) a detail of the v-groove, showing the smoothness of the sidewalls.*

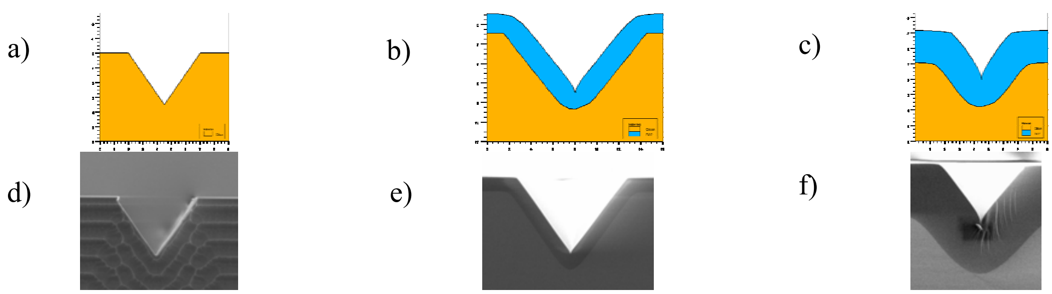

Figure 3. *Results of* ***simulations*** *(top row) and SEM images of the* ***results*** *(bottom row) of wet oxidation of the silicon v-grooves at 1150 ºC during 6 h. (a,d), non-oxidized silicon groove; (b,e), 12 um wide oxidized groove; and (c,f), 5 um wide groove. Agreement between simulation and oxidized sample is shown. The shape of the 5um wide grooves is the most interesting for plasmon confinement. The angle in the bottom of the groove is improved from 72º to 50º.*

Figure 4. *SEM images of the* ***final structures in gold*** *(scheme in figure 1, f), using the oxidized stamp shown in figure 3. The shape has been improved, as can be seen in (a), and especially in (b).*