Ultrasmooth, 3D Nanostructured Gold Films for Enhanced SPR Detection by Nanoimprint Lithography and Template Stripping

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Surface plasmons (SPs) propagating on thin gold films are highly sensitive to subtle refractive index changes at the metal-dielectric interface and have been widely explored to detect the presence or binding kinetics of many biological species including DNA, proteins and peptides. Structuring these metal films on the nanoscale can enhance this plasmon response and increase detection sensitivity [1]. Here we demonstrate fabrication of a variety of ultra-smooth, three-dimensional gold nanostructures with critical dimensions as small as 15nm by nanoimprint lithography (NIL) and template striping (TS) techniques based on the low adhesion force between gold and silicon [2].

We use NIL as a low-cost solution for large area nanofabrication [3] to pattern re-usable silicon molds for template stripping of thin gold films. Gold evaporated onto the smooth crystal surfaces of the silicon templates initially conforms to the nanostructured surface. By inverting the structured film using template stripping, the side of the film originally in contact with the silicon template becomes the top functional surface for binding studies and can be patterned with critical dimensions as small as the typical grain size of as-deposited gold.

Figures 1a and b show 50nm thick gold films studded with smooth 3D gold nano-pyramids centered on 200nm pitch square arrays. The inverse-pyramid silicon template (Fig. 1c) was fabricated by imprinting a thermal imprint resist (Nanonex 1025) spun on a 200nm thick thermal silicon dioxide. Holes were opened in the oxide by reactive ion etching and used as a mask for KOH/IPA anisotropic wet etching of the Si (100) wafers. Gold films were deposited on the silicon templates by both e-beam evaporation and sputtering. The gold layers were transferred by TS to glass, silicon and flexible plastic substrates using various adhesives including scotch tape, PDMS, epoxy and by cold welding to flat Au/Cr films. The smoothness of the gold nanostructures is evident when contrasted to the original top surface of the as evaporated gold film (Figure 3d).

Rounded gold structures were also fabricated using both EBL and holographic imprint molds. The thermal imprint resist was then used as an RIE mask to transfer nanopatterns into the underlying silicon substrate. By controlling the etch depth, the relief of the final gold structures can be tuned to optimize the SPR response and enhance the sensitivity. Figures 3a-d show the different possible feature heights alongside the corresponding silicon templates.

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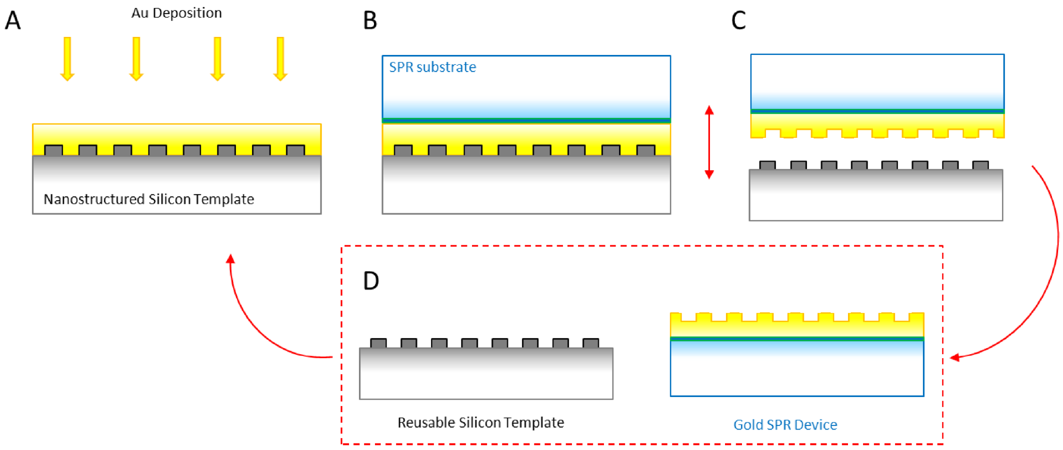

Figure 1: After NIL and patterning of the silicon template gold films are deposited by e-beam evaporation or sputtering. The side of the gold film initially in contact with the silicon template is smooth. After transfer of the film to the device substrate by template stripping (epoxy, tape or cold welding) the smooth side becomes the top device layer and the silicon template can be re-used.

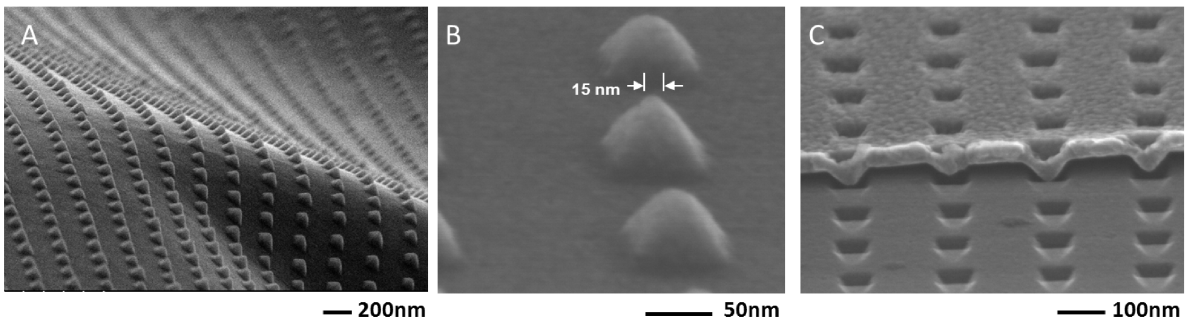

Figure 2: Smooth-topped gold films with protruding 3D nanostructures (also gold) were templated from inverse pyramids wet-etched into a silicon crystal substrate (c). Low adhesion force between gold and silicon allows the ~50nm thick films to be transferred by template stripping to an SPR bio-detection substrate.

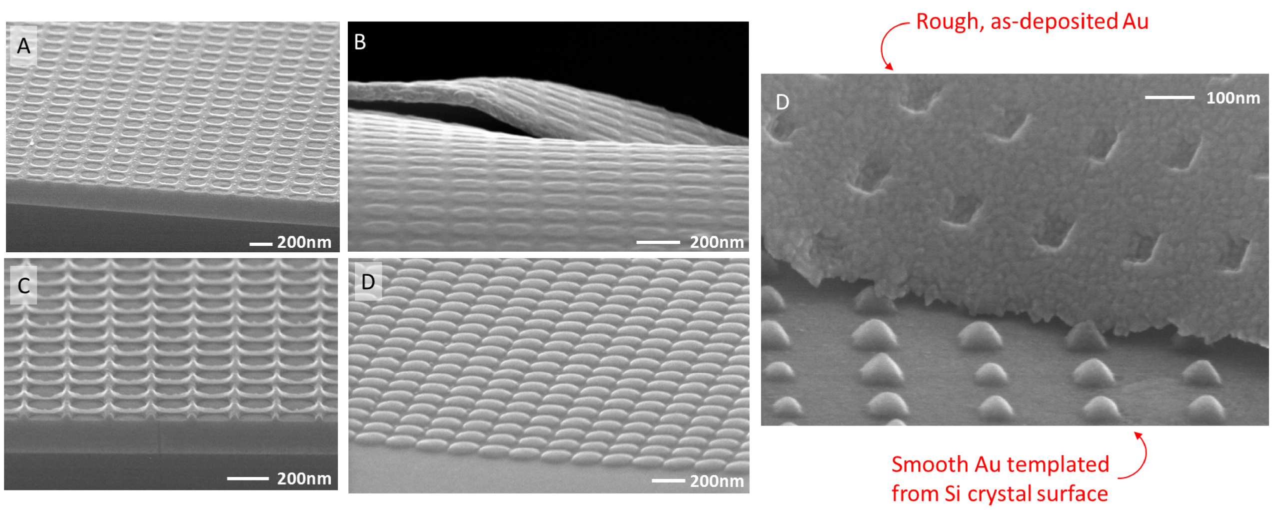

Figure 3: Rounded protrusions with optimized relief heights can also be fabricated by controlled RIE etching of the silicon substrate. d) Detailed view contrasting the smooth gold nanopyramids with the granular backside of the as-deposited gold film (gold was peeled back on itself by scratching the surface.)