Sub-nanometer gap fabrication using transfer printing by flexible Polydimethylsiloxane (PDMS) substrates

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Recent years, fabrication techniques have progressed to 11 nm node and it is becoming more and more difficult and expensive to approach to smaller ones especially down to sub-nanometer. However, many applications actually don't require such small arbitrary patterns. In fact, one of most useful sub-nanometer structures is the nanogap structure and currently there are still many demands of precisely controllable nanogaps in many applications such as Photocatalyst, Surface-enhanced Raman Scattering, Single Electron Transistor and Quantum Tunneling Junction.

In our previous work, we demonstrated a technology to fabricate large-area nanogap array with gap down to 0.8 nm and atomic-precision gap size control using collapsible nanofingers[1]. However, those nanogaps are sit on high aspect ratio nanofingers, hence, can only be used for limited applications. Therefore, we develop a fabrication technique to produce nanogaps on arbitrary substrates using transfer printing.

Our fabrication approach is described in Figure 1, the fabrication process of nanofingers is based on nanoimprint lithography. Reactive Ion Etching (RIE), Metal Evaporation and lift-off processes were utilized to pattern Cr etching mask, afterwards uncovered resist was etched by anisotropic RIE recipe. A release layer was coated outside to separate the Cr etching mask and upper metal nanoparticles. Subsequent Atomic Layer Deposition (ALD) were performed to define the nanogaps, after soaking samples into ethanol, nanofingers were driven to collapse due to capillary force and the collapsed nanofingers are shown in Figure 3(c). Among many transfer printing mediums, PDMS was used and the transfer procedure is demonstrated in Figure 2. Firstly, top nanogap structures were preserved in a 100 μm thick PDMS film which could be easily peeled off after curing because of the release layer. After applying PDMS film on a thin UV-curable resist and UV exposure, the original nanogap structures were anchored in resist. Then, PDMS and resist could be removed by RIE to expose the underneath pattern.

Thin PDMS films have been examined to successfully peeled off from collapsed nanofingers and a thin PDMS film bonded with nanogap structures is shown in Figure 3(d). More details will be presented in the conference.

1. Song, B.; Yao, Y.; Groenewald, R. E.; Wang, Y.; Liu, H.; Wang, Y.; Li, Y.; Liu, F.; Cronin, S. B.; Schwartzberg, A. M.; et al. Probing Gap Plasmons Down to Subnanometer Scales Using Collapsible Nanofingers. ACS Nano 2017, 11, 5836−5843.

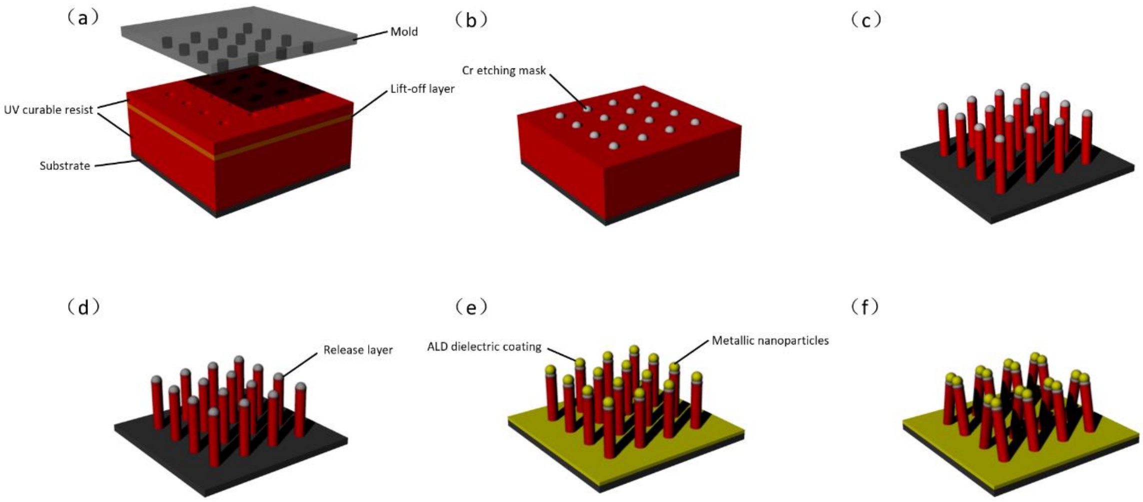

Figure 1. Schematic of nanofinger fabrication process: (a) Two layers of UV-curable resist and one lift-off layer on a silicon wafer and Nanoimprinting by a pillar array mold. (b) After etching residual layer, metal evaporation and lift-off, Cr etching mask was left on the bottom UV-curable resist. (c) Etching uncovered resist. (d) Deposition of a release coating. (e) Metal deposition and ALD deposition of dielectric coating. (f) Soaking into pure ethanol to collapse the nanofingers.

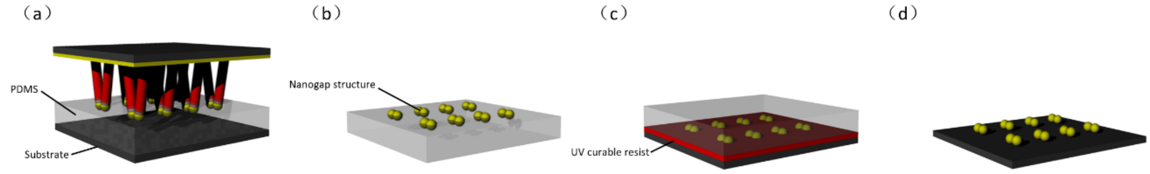

Figure 2. Schematic of pattern transfer process: (a) Spin coating PDMS, pressing nanogap structure into it and then curing. (b) Peeling PDMS film off. (c) Sticking PDMS film on a thin UV-curable resist. (d) Etching PDMS and UV-curable resist by using RIE.

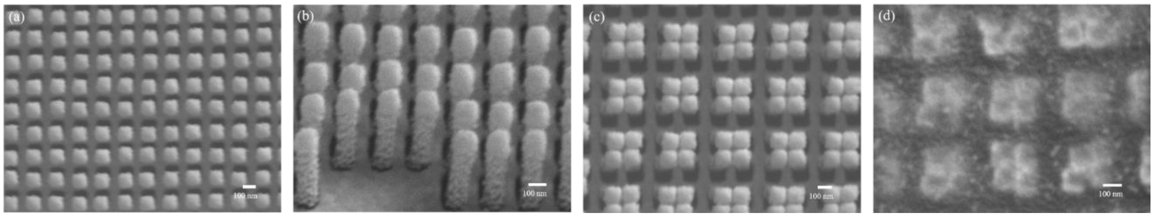

Figure 3. (a, b) SEM images of nanofingers before collapse (c) SEM images of nanofingers after collapse (d) SEM images of PDMS film with nanogap structure