Plasmonic Devices Based on Collapsible Nanofingers

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Nano-gap structure has attracted great scientific interests. For example, plasmonic nanostructures with nano-gaps concentrate light to a small volume, which can lead to many potential applications. While it is theoretically predicted that the optimal plasmonic hot spot is a gap of less than 1 nanometer between two metallic particles, there is still no manufacturing technology to reliably fabricate it with high-precision and controllability at practical cost. In this work, we present a novel fabrication technique that combines both top-down and bottom-up process to produce large-area nanogap structures with atomic-precision gap size control. The fabrication approach is described in Figure 1. First, two layers of photoresist and one liftoff layer were spin-coated on substrates, then Nanoimprint (NIL)[1], Reactive Ion Etching (RIE) and Metal Deposition were utilized to achieve desired metal patterns. Afterwards, uncovered areas were etched by RIE to form high aspect ratio nanofingers and Atomic Layer Deposition was used to grow selected thin dielectric layer outside nanofingers. After dripping ethanol onto samples, high aspect ratio nanofingers would be driven to collapse by capillary force during ethanol evaporation. By manipulating nanofinger heights and dielectric thicknesses, gap size down to 0.8 nm can be precisely defined after finger collapsing and such structure can be utilized as an ideal platform to study the rich sciences of plasmon and quantum effect. For example, we experimentally demonstrated that tunneling barrier height across the gap can be adjusted by using appropriate gap spacer materials and gap sizes.[2] As a result, plasmonic enhancement can be strongly affected since the electron tunneling mechanism is the most essential part in determining the plasmonic enhancement factor. It was found that as the tunneling barrier height is decreased, the enhancement of electron tunneling manifests itself in a wider optimal gap, a redshift of the plasmon frequency with increasing gap size was also observed when the gaps narrowed to sub-5 nm range[2]. Moreover, many photonic applications have been studied and implemented intensively based on our controllable nanogap structures. Those include plasmonic enhanced fluorescence (figure 2), single-molecule label-free sensing by SERS[3] and plasmonic enhanced photocatalysis.

Reference:

[1] S. Y. Chou, P. R. Krauss, P. J. Renstrom, Appl. Phys. Lett. 1995, 67, 3114.

[2] B. Song, Y. Yao, R. E. Groenewald, Y. Wang, H. Liu, Y. Wang, Y. Li, F. Liu, S. B. Cronin, A. M. Schwartzberg, S. Cabrini, S. Haas, W. Wu, Acs Nano 2017, 11, 5836.

[3] F. Liu, B. Song, G. Su, O. Liang, P. Zhan, H. Wang, W. Wu, Y. Xie, Z. Wang, Small 2018, 14, 1801146.

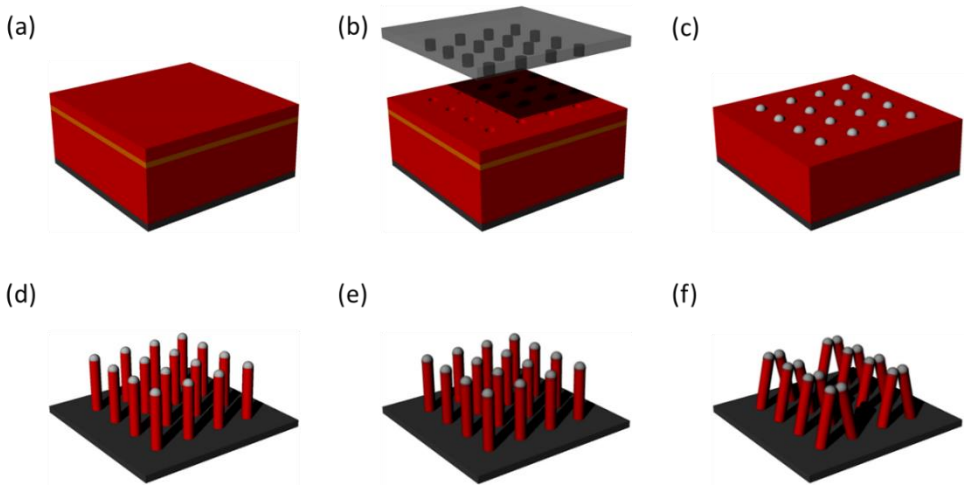

Figure 1. Schematic of nanofinger fabrication process: (a) Two layers of UV-curable resist and one lift-off layer spin-coated on a silicon wafer. (b) Nanoimprinting by a pillar array mold. (c) After etching residual layer, metal evaporation and lift-off, metal etching mask was left on the bottom UV-curable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

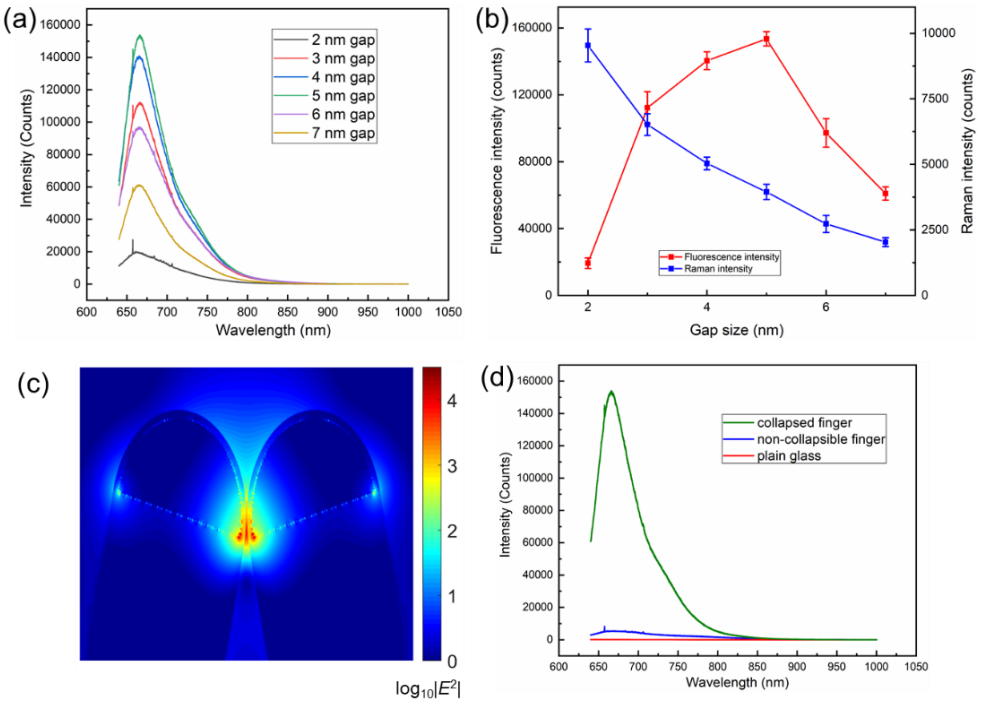

Figure 2. (a) Fluorescence intensity of Nile blue on collapsed nanofingers with different Al_2O_3 gap sizes. (b) The measured fluorescence intensity and the measured 592 cm^{-1} signature Raman intensity of Nile blue for different values of gap size. (c) FDTD calculation of local field enhancement in collapsed nanofingers with 5 nm Al_2O_3 gap. (d) Fluorescence intensity of Nile blue on collapsed nanofingers with 5 nm Al_2O_3 gap, non-collapsible nanofingers with same Al_2O_3 coating and plain glass.