Sub-lithographic Vertical Nanogap Fabrication for Electrical Detection of Protein-Ligand Interactions

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A vertical gold (Au) nanogap can provide a new approach to detect DNA hybridization [1] and protein interaction [2] with high sensitivity. Since the electrode of the previous nanogaps was made of poly-crystalline silicon, there was difficulty in immobilizing DNA or protein on it. There were two types of nanogaps: planar and vertical structure. Both electrodes faced each other horizontally in the planar nanogap while they encountered vertically in the vertical nanogap. The planar nanogap used a spacer lithography [1], which used an oxide deposited by chemical-vapor-deposition (CVD) as a sacrificial layer, and suffered from the process complexity and low process windows to make the nanogaps. Thus, the vertical gold nanogaps which are patterned sub-lithographically are demonstrated with a simple process for the first time.

The fabrication process is shown in Fig. 1. A starting material is an n-type (100) silicon wafer. It was heavily doped by $POCl_3$. This heavily doped n+ region forms ohmic contact between the subsequent Ti and gold. A 10nm thickness of Ti and a 50nm thickness of Au were deposited. For a precise control of the nanogap space with atomic level, 15nm of Al_2O_3 was deposited by an atomic-layer-deposition (ALD) instead of CVD. This ALD-Al_2O_3 will determine the nanogap space. For formation of top gold electrode, another Ti (2nm) and Au (200nm) were deposited again. After electrode patterning, Al_2O_3 was etched by (30:1) buffered HF, and the sub-lithographic vertical nanogap was finally fabricated as shown in Fig. 2. SU-8 negative resist was used to confine a buffer solution including proteins in the designed area as shown in Fig. 1 (e).

In this paper, sub-20nm vertical nanogap is used to detect a protein interaction. It is well known that detection sensitivity enhances as the gap space reduces. After formation of alkanthiol self-assembled monolayer on both gold sides, specific interaction between biotin and streptavidin was detected by an electrical current measurement. Fig. 3 and Fig. 4 show I-V characteristics, which represent streptavidin-linkage on biotin-functionalized surfaces. In this figure, the current increased dramatically in the case of biotin-streptavidin interaction than other two cases: nanogap filled with air and with biotin only. The nanogap device provides a simple and quick analyzing tool to detect protein-ligand interaction electrically with a low cost.

References

[1] Y.-K. Choi et al., "Sublithographic nanofabrication technology for nanocatalysts and DNA chips", Journal of Vacuum Science and Technology B", vol. 21, p.2951-2955, 2003.

[2] D.D. Carlo et al., "Nanogap-based Dielectric Immunosensing", 12th International Conference on Solid-State Sensors, Actuators and Microsystems (Boston), p.1180-1183, 2003

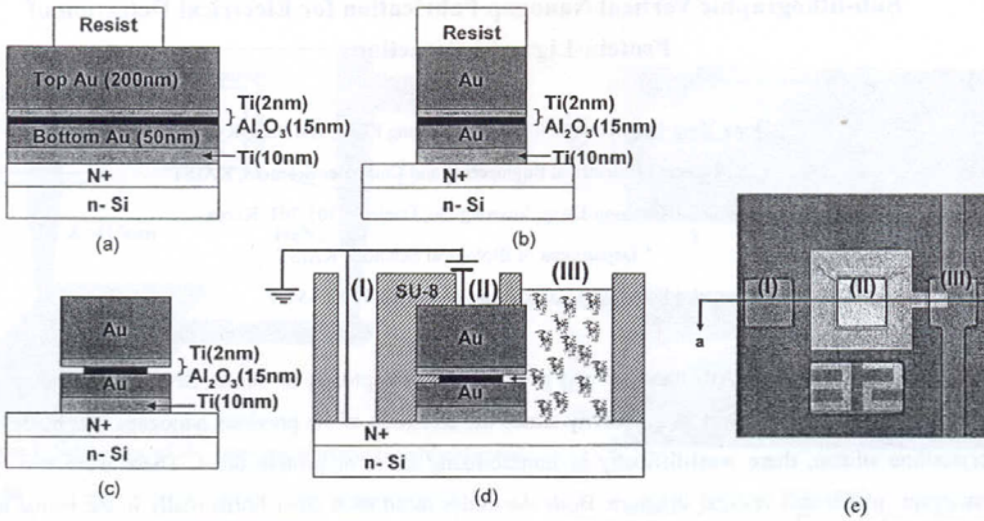

Fig. 1. Schematics of process flow. (a) after thin film deposition and mask for electrode patterning, (b) after electrode patterning, (c) after Al_2O_3 etch by BHF, (d) nanogap with SU-8 container to confine buffer solution, and (e) optical photograph to show a top view of the fabricated nanogap device.

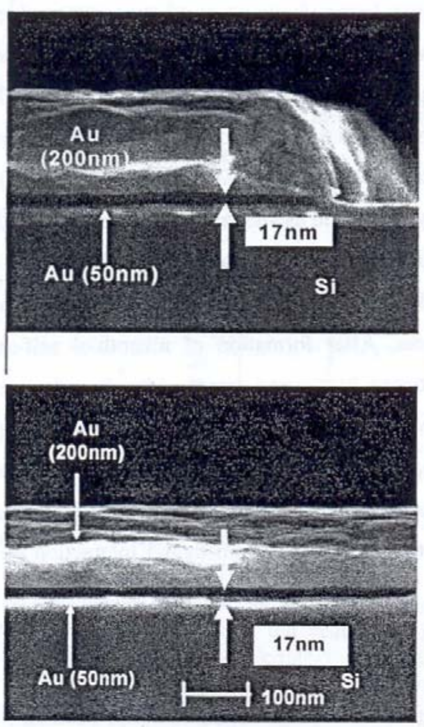

Fig. 2. Cross-sectional (a-a' direction in Fig. 1) SEM photographs of 17nm space of the vertical nanogap.

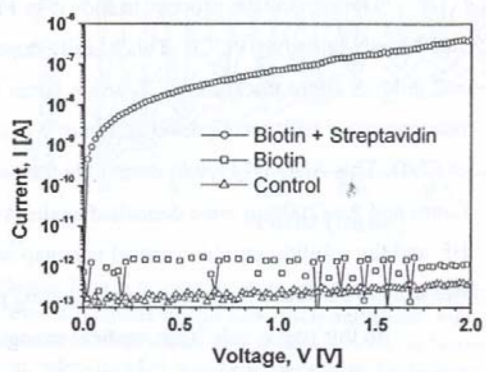

Fig. 3. I-V characteristics for three types of samples. The binding of biotin-streptavidin shows a dramatic increasing of the current.

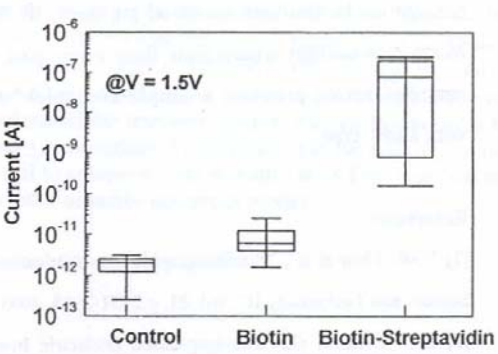

Fig. 4. Turn-on current at 1.5V across the gap.