Highly Reliable Nano-gap Electrodes for Single Molecule Evaluation

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1. Introduction
The concept of single molecule devices was first proposed [1] and a photonic device was demonstrated [2] about 35 years ago. Today, they are believed to have remarkable possibilities in realizing high performance information processing systems, high efficiency photonic devices, single molecule sensors, and so forth [3]. However, conduction characteristics of single molecule are not quite reproducible [4], as the semiconductor devices were in the early stage of development several decades ago [5]. The major reason for the phenomenon is usually attributed to uncontrollable molecule-electrode contact and uncontrolled electrode gap distance [6]. Here, fabrication technology of highly reliable nano-gap electrodes is reported, which would be the platform for characterizing single molecule devices for future information processing, photonic systems, single molecule sensors and other applications.

2. Nano-gap Electrode Structure
The nano-gap electrode fabricated in this study is schematically shown in Fig. 1, where the gap length measures around 20 nm, as indicated in Fig. 1 (a) by a plane view. The electrode was fabricated on a (100) oriented silicon substrate, with a 200 nm thick thermally grown silicon dioxide layer, as shown in Fig. 1 (b) by a cross-sectional view. The electrodes consist of a 20 nm thick gold layer.

3. Nano-gap Electrode Fabrication Technologies
Fabrication technologies of nano-gap electrode are explained using schematic cross section shown in Fig. 2. A silicon wafer, with a 200 nm thick thermally grown silicon dioxide layer, was used as substrate. Electron beam sensitive resist (1) and (2) were applied to the substrate surface by a spinning method to thicknesses of 40 nm and 80 nm, respectively (a). Then, focused electron beam exposed the resist layers using Elionics 7700 electron beam lithography system, followed by immersion development (b). A 20 nm thick thin gold layer was then deposited onto the double resist system using electron beam evaporation machine (c). Finally, the resist layers (1) and (2) were removed to fabricate the nano-gap electrode structures, depicted in Fig. 1.

Fig. 1 Schematic plan view (a) and cross sectional view (b) of the nano-gap electrodes fabricated in this study

Fig. 2 Schematic cross sectional view of the nano-gap electrode fabrication process: (a) resist (1) (2) application on the substrate, (b) electron beam exposure and development of the resist layers, (c) electron beam evaporation of gold layer on the substrate.
4. Fabricated Nano-gap Electrode

Photomicrographs and an SEM micrograph of the fabricated nano-gap electrode chip are shown in Fig. 3, where, a 10 mm square chip contains 6x6=36 subchips, each containing 12 pairs of nano-gap electrodes, thus, total of 432 nano-gap electrode pairs are accommodated in a chip. The designed gap lengths were between 17.5 nm and 20 nm, and resulting ones were around 18 nm and 20 nm, as depicted in Fig. 4, which suggests the very accurate control of the gap length down to sub-20 nm region. In addition, the yield of the nano-gap electrodes well exceeded 80%, which indicates that the nano-gap electrode can be called as “evaluation platform for single molecule characteristics”. Current-voltage (I-V) characteristics of the fabricated electrodes were evaluated, and the results are shown in Fig. 5. It is clearly indicated that the leakage current is below pA level up to 5 V, suggesting that the chip can be applied for evaluating single molecules with resistance of less than 1 T (10^{12}) ohms.

5. Conclusions

Fabrication technology of highly reliable nano-gap electrode is reported, which would be the platform for characterizing single molecule devices for future information processing, photonic systems single molecule sensors and other novel applications.

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References