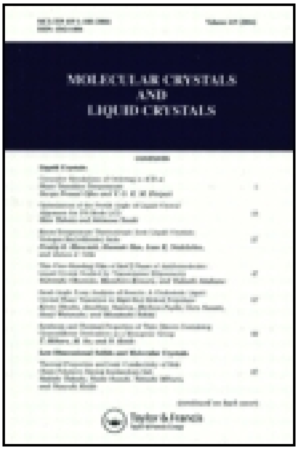

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Preparation of Nanogap Electrodes of Silicon by Chemical Etching

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Preparation of Nanogap Electrodes of Silicon by Chemical Etching

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We have prepared nanogap electrodes of silicon by chemical etching. The substrate used was silicon(001)-on-insulator (SOI). A metal film used as an etching mask was fabricated on SOI by a conventionally lithographic process. The direction of the mask patterns with respect to the crystal axes of silicon is a key factor for anisotropic chemical etching. The substrate was, then, immersed in a KOH aqueous solution to etch the (001) plane selectively, which resulted in the formation of the electrodes with the shape of square pyramid.

Keywords: anisotropic etching; nanogap electrodes; silicon-on-insulator (SOI)

INTRODUCTION

Fabrication of nanogap electrodes for the electrical characterization of single molecules has recently been intensively studied [1]. The well-defined shape and the atomically flat surface are essential for

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the electrodes of single molecular devices. The nanogap electrodes of metals prepared so far have the shape like a cliff with a rough surface. In order to overcome this difficulty in preparation of electrodes, one of the most promising ways is to use semiconductors with the use of nano- and micro-fabrication techniques [2]. There have been, however, few reports of fabrication of nanogap electrodes of semiconductors including silicon. Fabrication of silicon nanogap electrodes by partly removing the oxide from a silicon-oxide-silicon stack by using a selective oxide etchant has been demonstrated [3,4]. In this study, we have fabricated silicon nanogap electrodes by electron beam lithography and KOH anisotropic etching of a silicon-on-insulator (SOI) wafer.

EXPERIMENTAL

Figure 1 shows a perspective view of the fabrication process of the silicon nanogap electrodes. The electrodes were fabricated on the [001] oriented n-doped silicon top layer of a SOI wafer. This silicon layer was 1.2 μm in thickness and insulated from the bottom silicon by a 1 μm buried silicon oxide layer. Square-shaped mask patterns of Au(50 nm)/Cr(20 nm) were prepared by a conventional e-beam lithography with a careful alignment with respect to the crystal axes of silicon. The substrate was then immersed in 1% hydrofluoric acid to remove the native oxide, followed by immersion in 20%(w/w) KOH aqueous solution to etch the (001) plane selectively [2,5]. After etching, the substrate was washed in water using ultrasonic cleaning and pad patterns for the electrical contact were fabricated by a photolithographic process and vacuum evaporation.

The topographic image was taken using a tapping-mode atomic force microscope(AFM) with Si_3N_4 coated silicon cantilevers (spring constant 4.5 N/m) at room temperature in ambient condition.

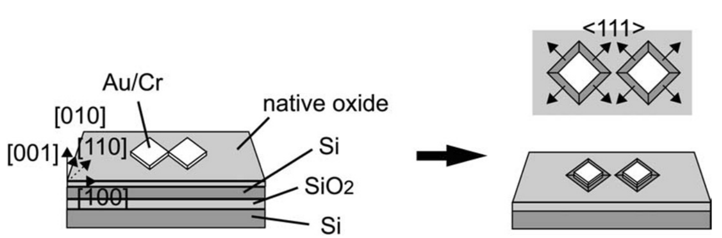


FIGURE 1 Schematic view of the fabrication process of the silicon nanogap electrodes.

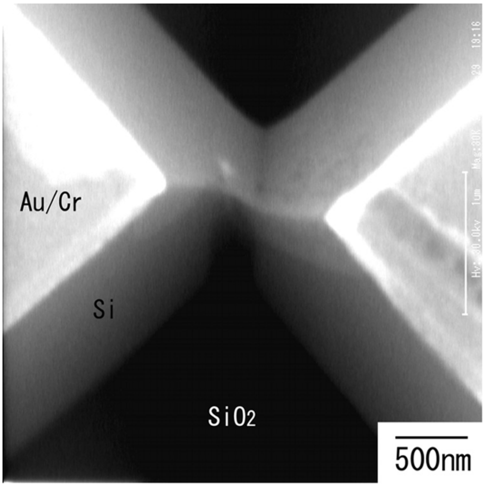


FIGURE 2 SEM image of the electrodes after the KOH anisotropic etching for a few tens of hours.

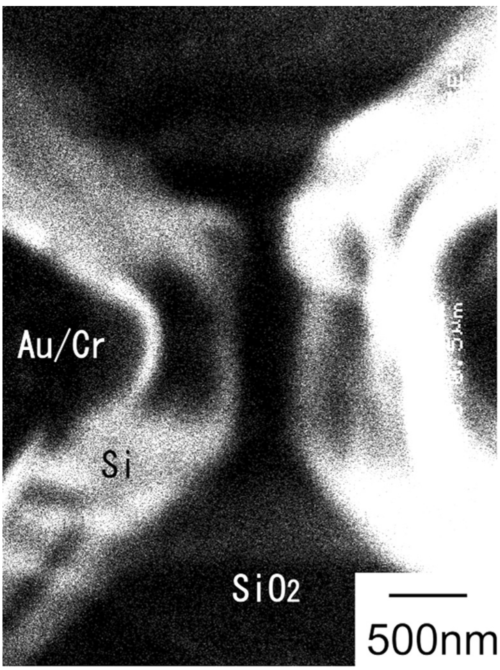
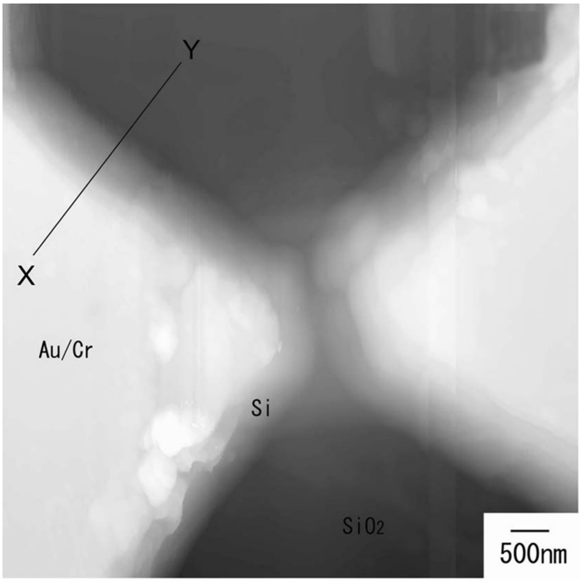
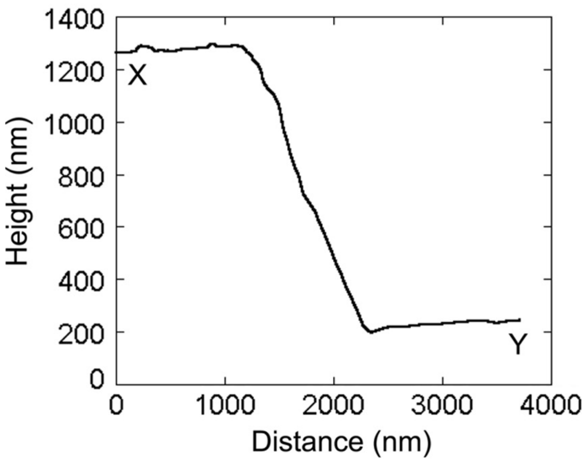


FIGURE 3 SEM image of the silicon nanogap electrodes prepared by KOH anisotropic etching for several tens of hours.



(a)



(b)

FIGURE 4 (a) Topographic AFM image of the silicon nanogap electrodes. The image size is 7.5 μm × 7.5 μm; (b) Cross section profile along the line X-Y in Figure 4(a).

RESULTS AND DISCUSSION

Figure 2 shows a SEM image with accelerated voltage of 30 kV of the electrodes fabricated by KOH anisotropic etching for a few tens of hours. At this stage, the gap had not yet been formed. It was found that the sides of the electrodes were etched diagonally. In the central region of the electrodes, the silicon isle with the V-shaped groove made up of {111} planes due to the selective etching was formed. Metals bridging over silicon electrodes were broken by washing in water using ultrasonic cleaning after etching. Figure 3 shows a SEM image with accelerated voltage of 2 kV of the electrodes fabricated by etching more for several tens of hours. The electrodes with the gap width about one hundred nanometers were fabricated. Figures 4(a) and 4(b) show the topographic image and the cross section view of the electrodes, respectively. From the cross section view, the electrodes had the slope of an angle of about 55° with respect to the surface. This proved that the electrodes were bound by {111} planes. The triangular section is also an advantageous for bridging a small number of molecules between the electrodes. In addition, the surface of the electrodes etched is hydrogen-terminated after the KOH aqueous solutions [6]. It is known that the molecules having C=C double [7] or C≡C triple bonds [8] at their terminals react with hydrogen-terminated silicon surfaces. The gap width was controlled by the immersion time and temperature of etchant.

In summary, we prepared the nanogap electrodes of silicon having a slope in the edges by e-beam lithography and KOH anisotropic etching. The electrodes are available for molecular bridging through Si−C covalent bonds since their surfaces are hydrogen-terminated silicon ones to which molecules having C=C double or C≡C triple bonds at their terminals react.

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