Nickel Silicide Electrodes Pattern Fabricated by Resistless Electron-beam Lithography Process

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abstract

A new method for microfabrication and nanofabrication is developed by using focused electron beam localized heating the nickel film which is deposited on a silicon surface. After heating the Ni_2Si silicide pattern is formed on the Si substrate. The difference in etch rates for the unexposed Ni and Ni_2Si silicide is sufficient for obtaining a selective etch. The factors that determine the temperature which causes the transformation Ni into Ni_2Si silicide are the beam current and the dose density. As an example, a silicide single electron tunneling device pattern is fabricated by this kind of direct write resistless of electron beam lithography process.

1. Introduction

Direct patterning methods for microfabrication and nanofabrication are more interested for last a few years. For example, Dagata *et al.* [1,2] reported the chemical modification of hydrogen-passivated n-Si(111) surfaces by a scanning tunneling microscope. Snow and Campell [3] showed the fabrication of Si nanostructures which were lithographed by an atomic force microscope. Matsumoto *et al.* [4] fabricated a single electron transistor made by the scanning tunneling microscope nano-oxidation process for the TiOx/Ti system. Recently, Drouin *et al.* [5] demonstrated a novel direct write resistless lithography technique for producing platinum structures on a silicon surface with achievable linewidths below 50 nm.

Metal silicides have been great potential for shrinking IC electronics, since their low resistivities, immunity for electron-migration due to covalent bonding and moderate temperatures forming properties. Moreover, the silicides form reproducible Schottky barriers to the surrounding silicon which, in many cases, will adequately confine the carriers with no need for additional isolation. The silicide is also a technologically promising material to fabricate solid devices such as permeable base transistor of $Si/CoSi_2/Si$ heterostructures [6]. The silicide device may offer the possibility for an ultrafast device. Among metal silicides, nickel silicide is known for the being best epitaxial film because the lattice misfit to silicon is small. In this paper, we report a nickel silicide electrodes pattern fabricated by a direct write resistless of electron beam lithography process.

2. Experiment

The Ni silicide fabrication process sequence is shown in Fig.1. The samples were prepared by n-type silicon (100) with high resistivities of 1 -10 Ω cm and cleaned in acetone, methanol for 10 min in ultrasonic and NH_4-buffered HF solution of 1 ml 46% HF + 30 ml 40% NH_4F + 8 ml 28% NH_3 with pH 8 for 4 min. After rinsing in the methanol to reduce the exposure of the freshly prepared surface to atmospheric humidity, the samples were transferred into vacuum system of the evaporator. The nickel layer of 20 nm was

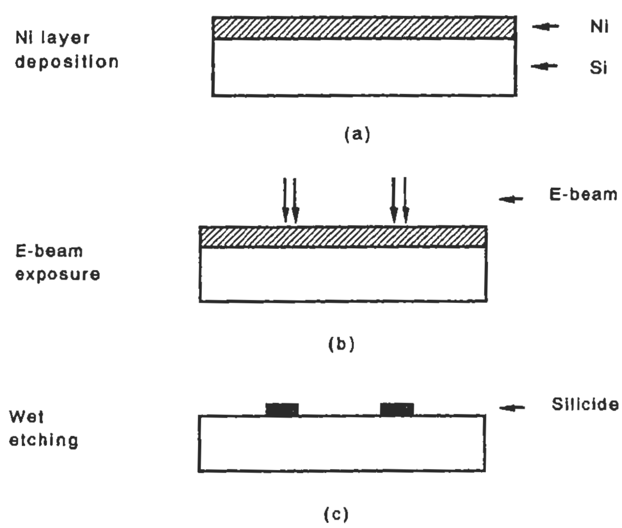

Fig.1 The fabrication sequence of the nickel silicide pattern.

evaporated on clean Si substrate using an electron-beam evaporator with an evaporation rate of 0.1 nm/s. Then, the Ni layer was locally heated by 3KeV focused electron beam which was conducted using a modified JSEM-5410 (JEOL Ltd.) scanning electron microscope (SEM) equipped with a pattern generator. To determine the absolute electron dose, the beam-current was measured using a Faraday cup attached to the sample holder.

After localized heating, the heated parts will form a nickel-silicide pattern. The unexposed Ni was removed from the silicon surface using the solution of HNO_3: CH_3COOH: H_2SO_4:H_2O = 5:5:2:5. An etch time of 2minutes was used. The difference in etch rates for the unexposed Ni and nickel-silicide is sufficient for obtaining a selective etch.

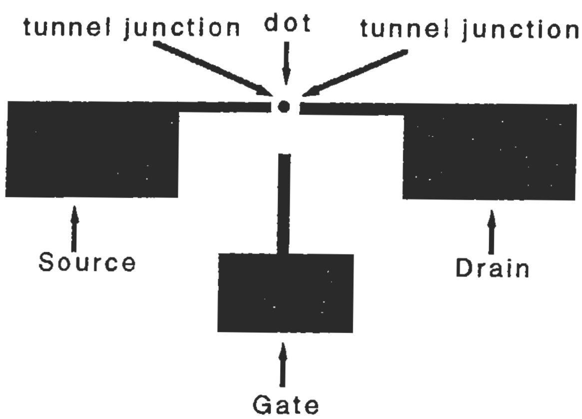

Fig.2 The configuration of a single electron tunneling device.

3. Results and discussion

For the nanostructure device operation, the flat surface where the device fabricated on is important. In order to obtain atomically flat silicon surface, the NH_4-buffered HF solution was used in clean procedure [7]. After cleaning, the surface of samples were inspected by scanning tunneling microscope. The roughness of the cleaned Si surfaces is within 1 nm in range of more than 100 nm^2.

To form a Ni_2Si silicide layer on Si surface, the temperature range for complete transformation of Ni into Ni_2Si is from 200 to 350℃ [8]. The activation energy to form Ni_2Si is about 1.5 eV, and typical resistivity of Ni_2Si and Schottky barrier height of Ni_2Si on n-type Si are about 25 $\mu\Omega$.cm and 0.66 eV respectively [8].

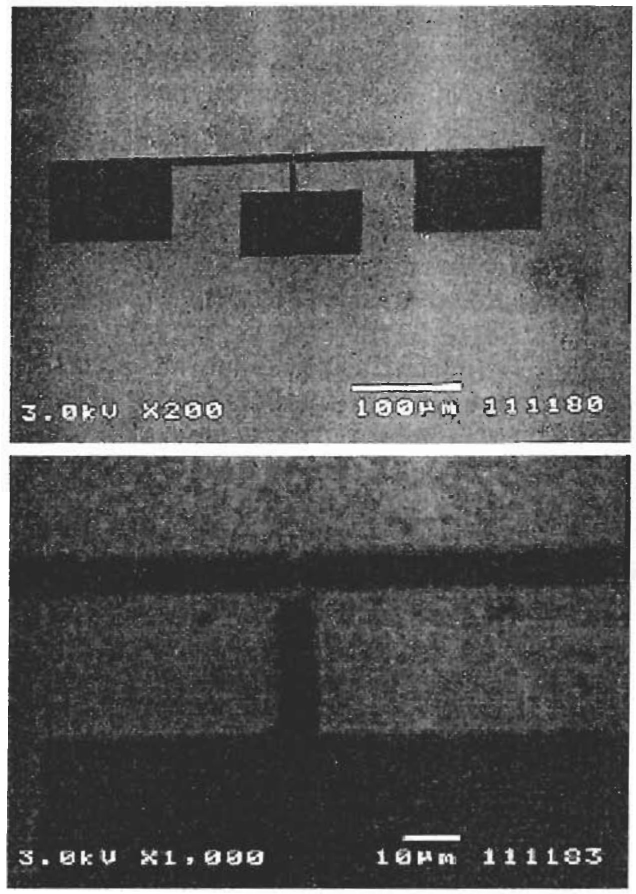

Fig.3 SEM micrograph of the electrodes pattern of a single electron tunneling device fabricated by resistless e-beam lithography. (a) The pattern of device. (b) enlargement of center part of the device.

Fig. 2 gives a single electron tunneling device configuration and Fig. 3 shows the nickel silicide electrodes pattern of a single electron tunneling device fabricated by direct write resistless electron beam lithography technique. The exposed pattern area is about 400×100 μm^2. The factors that determine the tempera-ture rise are the current density and line dose. Experiments have been carried out with a tungsten filament. The current on the sample surface for exposing pattern is 20 nA. The dose density which determines the electron beam exposure time is 0.20 $\mu C/cm^2$. There are a threshold current and line dose for fabricating pattern. If the exposure current is less than 10 nA and dose density is less than 0.10 $\mu C/cm^2$, no silicide pattern was formed on Si surface.

The one of possible formation mechanism of Ni_2Si by directly heating is that after heating the Ni diffuse into silicon surface as the diffusion species and form nickel silicide. The Si atoms do not alter their relative position and only Ni atoms diffuse. Although there are six equilibrium silicide phases for the Ni-Si system, only the Ni_2Si can grow on the silicon surface since other equilibrium phases require higher temperature which beyond the e-beam heating capability. An understanding of forming mechanism by localized heating method still requires more research efforts.

Since a standard tungsten filament was used in used in our e-beam system, the pattern resolution is limited by the beam diameter which is about 400 nm for our system. The resolution can be improved by using a LaB_6 or field emission filament. The two to three order resolution enhancement can be expected.

4. Summary

The nickel silicide electrode patterns have been fabricated by resistless electron beam lithography and wet etch processes. The difference in etch rates for unexposed Ni and nickel silicide is sufficient for obtaining a selective etch. If the resolution of focused electron beam is good enough, the single electron tunneling device can be fabricated by this way. Also the method is suitable to make many microstructure and nanostructures.

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