Applied Surface Science 343 (2015) 88–93

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Fabrication and characterization of periodic arrays of epitaxial Ni-silicide nanocontacts on (1 1 0)Si

S.L. Cheng*, L.H. Chang, C.F. Chuang, H. Chen

Department of Chemical and Materials Engineering, National Central University, Chung-Li City, Taoyuan, Taiwan, ROC

ARTICLE INFO

Article history:
Received 10 October 2014
Received in revised form
24 December 2014
Accepted 11 March 2015
Available online 19 March 2015

Keywords:
Self-assembly
Ni silicide
Nanosphere lithography
(1 1 0)Si
Epitaxy
Nanocontact

ABSTRACT

In this study, we report on the fabrication and characterization of periodic Ni and Ni-silicide nanocontact arrays on (1 1 0)Si substrates. From transmission electron microscopy and selected-area electron diffraction analysis, it is found that the epitaxial $NiSi_2$ is the first and the only silicide phase formed in the nanoscale Ni contact/(1 1 0)Si sample after annealing at a temperature as low as 300 °C, demonstrating that the nanoscale Ni contact is more favorable for the epitaxial growth of $NiSi_2$ phase on (1 1 0)Si. The orientation relationship between the epitaxial $NiSi_2$ nanocontacts and the (1 1 0)Si substrate is identified as $[1\,1\,0]NiSi_2//[1\,1\,0]Si$ and $(\bar{1}\,1\,\bar{1})NiSi_2//(\bar{1}\,1\,\bar{1})Si$. For the samples annealed at higher temperatures, all the epitaxial $NiSi_2$ nanocontacts formed on (1 1 0)Si are anisotropic in shape and elongated along the crystallographic $\langle 1\,\bar{1}\,0 \rangle$ directions. The observed results can be attributed to the higher surface area to volume ratio of Ni nanocontacts and the faster growth rate along the $\langle 1\,1\,0 \rangle$ directions than along other directions. The size and periodicity of the nanocontacts can be readily controlled by adjusting the diameter of the colloidal nanosphere template. The self-assembled approach proposed here will provide the capability to fabricate other highly-ordered metal silicide nanocontact arrays and may offer potential applications in constructing silicide-based nanodevices.

1. Introduction

As the critical dimensions of devices are scaled down to the nanometer range, there is a great increase in the parasitic series resistance of source/drain conductors and gate electrodes, resulting in a degradation of device performance. The above-mentioned problem has been solved by the introduction of metal silicides as the source/drain and gate contact electrodes [1]. Of the various metal silicides, nickel silicides have many unique and desirable properties, including low resistivity, low silicidation temperature, low contact resistance, and high compatibility with current SALICIDE processing technology, that make them the most promising materials for contacts in ultra-large-scale integrated circuit devices [2–4]. In practical Si-based IC devices, metal silicide contacts are usually formed within laterally confined regions. Thus, much research effort has been devoted to the investigation of the interfacial reactions between metal contacts and Si substrates at the nanoscale.

Recently, several studies have demonstrated that the reduction of contact region sizes has a significant effect on the morphology and phase of the Ni silicides that form during solid-state silicidation processes [5–7]. However, it is worth noting that most of these studies were carried out on (0 0 1)-oriented Si substrates. Studies investigating the formation of nanoscale Ni-silicide contacts on differently oriented Si substrates are relatively rare. In some advanced Si-based nanodevices (for example, 3D IC devices), silicide formation on a Si substrate with different surface orientations is required. Furthermore, for p-channel MOSFET devices, the hole mobility on a (1 1 0)Si substrate has been found to be higher than that on a (0 0 1)Si substrate [8,9]. Therefore, it is of much interest to investigate the interactions of well-ordered arrays of nanoscale Ni metal contacts with (1 1 0)Si substrate under different heat treatments.

There are several template-patterning techniques that have recently been developed for the fabrication of well-ordered nanostructures on the desired substrates. One of the most promising high-throughput nanopatterning approaches is the so-called nanosphere lithography (NSL) [10–13]. In this technique, a close-packed monolayer of colloidal nanospheres with uniform diameters is self-assembled on a flat substrate and then used as a shadow mask for the deposition of thin films. After metal thin film deposition and subsequent lift-off of the colloidal nanosphere template, a large-area, highly-ordered metal nanostructure array with controlled size, morphology, and interspacing

* Corresponding author. Tel.: +886 3 4227151x34233; fax: +886 3 2804510.
E-mail address: slcheng@ncu.edu.tw (S.L. Cheng).

http://dx.doi.org/10.1016/j.apsusc.2015.03.058

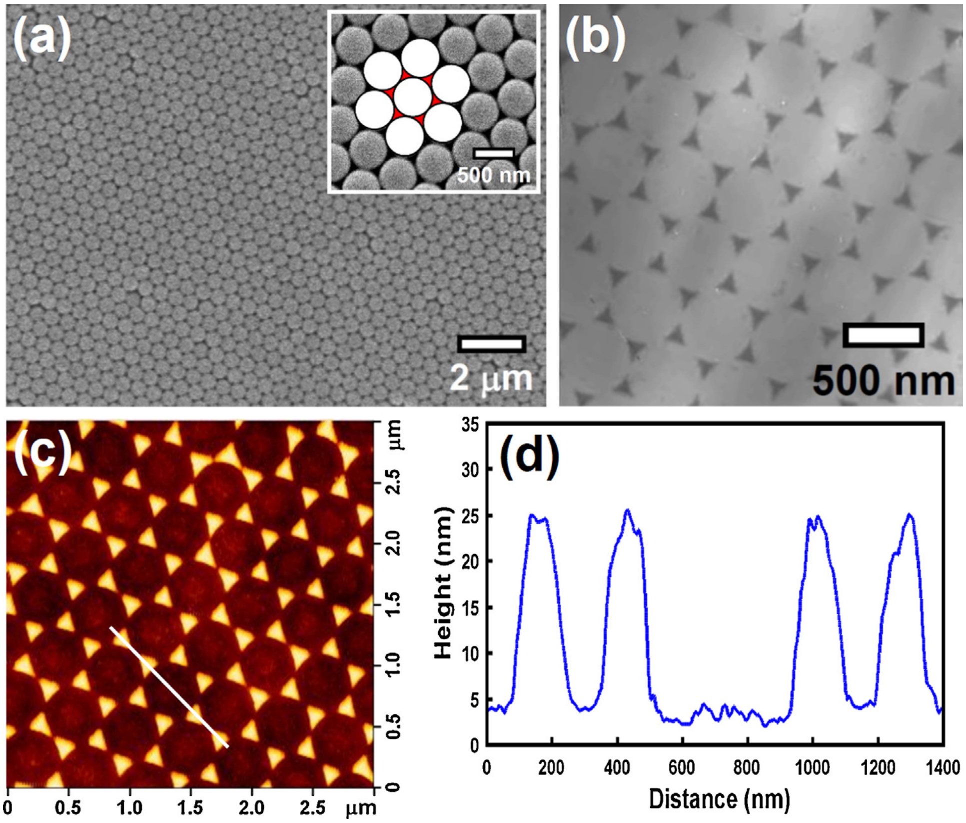

Fig. 1. (a) Top-view SEM image of a self-assembled monolayer of 460-nm-diameter colloidal PS nanospheres. The inset is the corresponding high-magnification SEM image. (b) Planview TEM image of an as-deposited Ni metal nanocontacts array on (1 1 0)Si substrate. (c) AFM image and (d) the corresponding line-scan profile of a periodic triangular-shaped Ni nanocontacts on Si surface.

can be readily produced on the substrate surface [14–17]. No expensive photolithographic equipment and complicated operations are needed during the manufacturing processes. Therefore, in the present study, we propose taking advantage of the colloidal NSL technique to fabricate size-controllable, periodic arrays of nickel metal nanocontacts on (1 1 0)Si substrates. The results from a systematic investigation of the phase transformation, morphological evolution, and atomic crystal structure of periodic nickel silicide nanocontact arrays formed on (1 1 0)Si under different annealing conditions are reported.

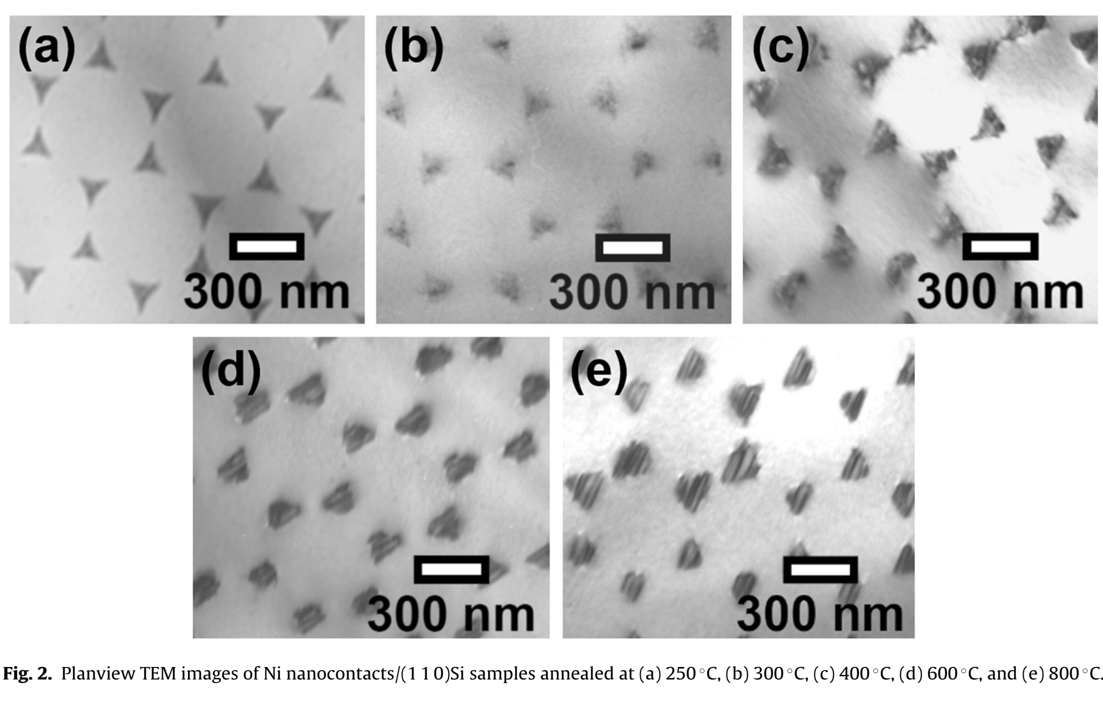

Fig. 2. Planview TEM images of Ni nanocontacts/(1 1 0)Si samples annealed at (a) 250 °C, (b) 300 °C, (c) 400 °C, (d) 600 °C, and (e) 800 °C.