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Enhanced formation and morphological stability of low-resistivity $CoSi_2$ nanodot arrays on epitaxial $Si_{0.7}Ge_{0.3}$ virtual substrate

S.L. Cheng[a,*], C.Y. Yang[a], S.W. Lee[b], H.F. Hsu[c], H. Chen[a]

[a] Department of Chemical and Materials Engineering, National Central University, Chung-Li City, Taoyuan, Taiwan, ROC
[b] Institute of Materials Science and Engineering, National Central University, Taiwan, ROC
[c] Department of Materials Science and Engineering, National Chung Hsing University, Taichung, Taiwan, ROC

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ABSTRACT

We report here the first successful growth of large-area, low-resistivity cobalt disilicide ($CoSi_2$) nanodot arrays on epitaxial (0 0 1)$Si_{0.7}Ge_{0.3}$ substrates by using the nanosphere lithography (NSL) technique with an interposing amorphous Si (a-Si) thin film serving as the sacrificial layer. For the Co/a-Si bilayer nanodots array on $Si_{0.7}Ge_{0.3}$ samples after annealing, polycrystalline $CoSi_2$ appears to form as the only silicide phase at an annealing temperature as low as 500 °C The a-Si interlayer with appropriate thickness was found to effectively prevent Ge segregation and maintain the morphological stability in forming $CoSi_2$ nanodots on $Si_{0.7}Ge_{0.3}$ substrate. The size, interparticle spacing, and triangular shape of the $CoSi_2$ nanodots remain almost unchanged even after annealing at 950 °C. For the Co/a-Si nanodot samples further annealed at 1000 °C, amorphous SiO_x nanowires, 15–35 nm in diameter, were observed to grow from $CoSi_2$ nanodot regions. The observed results present the exciting prospect that the NSL technique in conjunction with a sacrificial a-Si interlayer process promises to be applicable in fabricating periodic arrays of other low-resistivity silicide nanocontacts with controlled size, shape, and periodicity on $Si_{1-x}Ge_x$ substrates.

1. Introduction

Recently, metal-silicide/$Si_{1-x}Ge_x$/Si heterostructures have been the subject of great interests due to their potential applications in high efficiency photodetectors and high-speed electronic nanodevices [1,2]. Among the various metal silicide contacts, the low-resistivity cobalt disilicide ($CoSi_2$) possesses many favorable properties and was widely adopted as a contact material for silicon ULSI devices [3–5]. However, previous studies have shown that direct formation of metal silicide contacts on $Si_{1-x}Ge_x$ substrate by thermal annealing would lead to Ge segregation, junction degradation, and silicide film agglomeration [6–8]. Therefore, as the dimensions of Si-based devices continues to scale towards the nanometer regime, issues related to the formation of sub-100 nm scale, high-quality $CoSi_2$ nanocontacts on $Si_{1-x}Ge_x$ substrate have become critical to the performance and reliability of SiGe nanodevices.

To produce nanoscale periodic metal contacts on Si-based substrates, a variety of patterning techniques have been developed [9–11]. Among these approaches, colloidal nanosphere lithography (NSL) is one of the most efficient and cost-effective nanopatterning techniques. In the colloidal NSL technique, a series of periodic colloidal sphere (such as polystyrene and silica) arrays are formed on diverse substrates via a self-assembly process and served as the templates for fabricating well-ordered nanostructures without complex lithography [12–14]. Recent studies have demonstrated that various periodic nanoparticle arrays with well-defined shape, size, and spacing were successfully produced on the single-crystalline Si substrates by the NSL technique [15–18]. However, the formation of two-dimensional (2D) ordered arrays of metal and silicide nanocontacts on $Si_{1-x}Ge_x$ substrates using this technique has not yet been demonstrated. Since the silicidation reactions in microelectronic devices are restricted to selected, laterally confined contact areas, the investigation on the interactions of sub-100 nm scale metal contacts with $Si_{1-x}Ge_x$ substrates is demanded. On the other hand, a previous study has shown that incorporation of a silicon interlayer in Co/$Si_{1-x}Ge_x$ reaction has beneficial effects on the formation of $CoSi_2$ thin films on blank $Si_{1-x}Ge_x$ substrates [19]. As a result, in order to eliminate the aforementioned drawbacks of direct reactions of metal thin films with $Si_{1-x}Ge_x$ substrate, and take advantage of the Si interlayer in the enhancement of $CoSi_2$ formation, we propose a new nanodot structure – Co/Si bilayer nanodot array on (0 0 1)$Si_{0.7}Ge_{0.3}$.

In this study, we report the first successful fabrication of large-area periodic arrays of low-resistivity $CoSi_2$ nanodots on epitaxial $Si_{0.7}Ge_{0.3}$ substrates by using the colloidal NSL technique in conjunction with the use of a sacrificial Si interlayer. The phase transformation and structure evolution of the sub-100 nm scale

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

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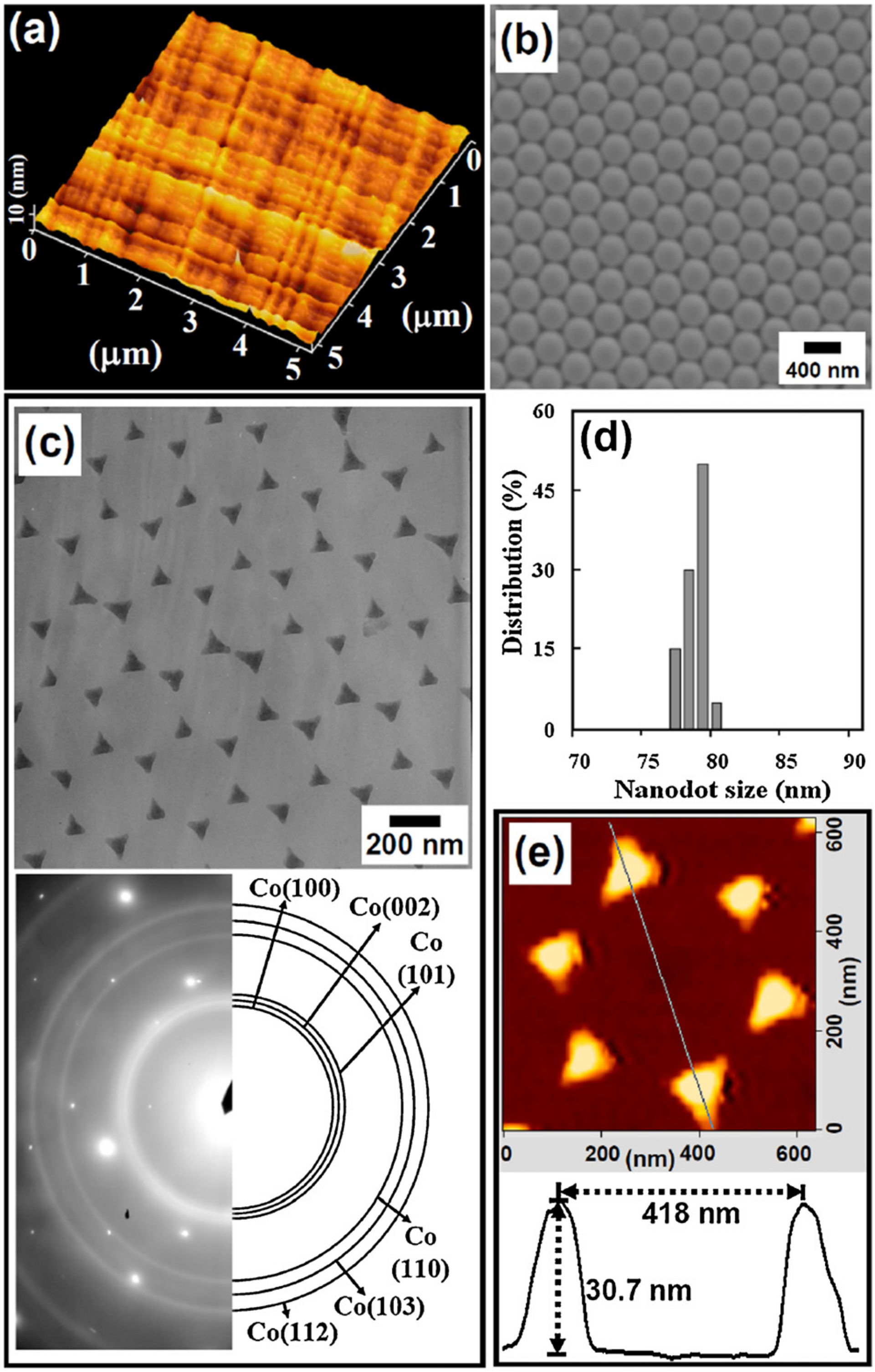

Fig. 1. (a) Tilt-view AFM image of the surface of a (0 0 1)$Si_{0.7}Ge_{0.3}$ substrate. (b) SEM image of a close-packed monolayer of 340-nm-diameter PS spheres on (0 0 1)$Si_{0.7}Ge_{0.3}$. (c) Planview TEM image and indexed SAED pattern and (d) the corresponding size distribution histogram of an as-deposited Co/a-Si bilayer nanodot array. (e) AFM image and corresponding line-scan profile of a typical Co/a-Si nanodot array.

Co/Si bilayer nanodots on (0 0 1)$Si_{0.7}Ge_{0.3}$ samples after different heat treatments are discussed.

2. Experimental procedures

Single crystal (0 0 1), oriented silicon wafers with low-temperature Si buffer layer and epitaxial $Si_{0.7}Ge_{0.3}$ layer grown by molecular beam epitaxy (MBE) were used as the virtual substrates in this study. Monodispersed suspensions of polystyrene (PS) spheres with mean diameter of 340 nm were diluted with an aqueous solution of sodium dodecylsulfate (SDS) surfactant, and then used to fabricate nanosphere lithography templates on $Si_{0.7}Ge_{0.3}$ virtual substrates by the drop-casting method [20]. The concentrations of PS spheres and the surfactant SDS in this mixed solution were 0.5 wt% and 0.005 wt%, respectively. Prior to the drop-casting process, the (0 0 1)$Si_{0.7}Ge_{0.3}$ substrates were cleaned chemically by a standard procedure followed by dipping in a dilute HF solution to remove the native oxide layer. Subsequently, appropriate amounts (~10 μL) of the mixed PS spheres/SDS suspensions were pipetted onto the cleaned (0 0 1)$Si_{0.7}Ge_{0.3}$ substrates and then dried in