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Growth dynamics of low-dimensional $CoSi_2$ nanostructures revisited: Influence of interface structure and growth temperature

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ABSTRACT

The growth of cobalt silicide nanostructures on clean Si(001) was studied using scanning tunnelling microscopy and transmission electron microscopy. Two types of $CoSi_2$ nanostructures, flat and ridge-type islands, were formed when 0.1 ML Co was deposited onto clean Si(001) between 500 °C and 800 °C. These islands form elongated islands along [110] directions and grow into the Si-substrate within the temperature range. The formation of the two types of islands arises primarily due to the type of $CoSi_2\{111\}$–Si{111} interface formed between the island and the substrate. Flat islands are bound by $CoSi_2\{111\}$–Si{111} Type-A interfaces such that $CoSi_2(001)$//Si(001) and $CoSi_2[001]$//Si[001]. Ridge islands, on the other hand, are bound by a "twinned" $CoSi_2\{111\}$–Si{111} Type-B interface such that $CoSi_2(221)$//Si(001) and $CoSi_2\left[1\bar{1}0\right]$ //Si$\left[1\bar{1}0\right]$. This leads to the formation of three less energetically-favourable interfaces: $CoSi_2\left(\overline{111}\right)$–Si$\left(11\bar{5}\right)$, $CoSi_2\left(\overline{112}\right)$–Si$\left(11\bar{2}\right)$, and $CoSi_2\left(\overline{115}\right)$–Si$\left(11\bar{1}\right)$. Analysis of the interfacial energies through dangling bond counting per interfacial area for each interface shows that the formation of the Type-B interface is energetically more favourable compared to the rest of the interfaces. As a result, the island elongates preferentially along the Type B interface leading to the formation of long nanowires with large length–width aspect ratio of 20:1. However, this formation is only achieved at high growth temperatures due to the presence of corner-barriers constraining the growth at low temperatures. Conversely, flat islands are slightly elongated at low growth temperatures with aspect ratio reaching 7:1 at 650 °C. As temperature increases towards 760 °C, they are brought closer to equilibrium and hence become less elongated with aspect ratio reduced to 1.6:1.

1. Introduction

The formation and growth of low-dimensional nanostructures (e.g. nanowires) through the bottom-up approach offers a plausible alternative route to the current lithographic approach in electronic-device fabrication. However, recent studies reveal different accounts describing the growth behaviour of nanowires on different substrate surfaces. The formation of Ag nanowires on Si(001), for instance, was shown to be a consequence of strain-induced shape transition [1]. In other material systems, anisotropic mismatch allows the formation of hexagonal rare-earth nanowires on Si(001) [2–5] as well as $Fe_{13}Ge_8$ on Ge(001) [6]. In the former case, the islands elongate along the lower-mismatch direction while minimising the parts of islands that are more strained. In the latter, the growth of the nanowires has been attributed to kinetic constraints arising from the presence of island corner-barriers and ledge diffusion-barriers. These kinetic constraints have also been used to account for the formation of 2D fractal shape islands [7] and the anisotropic growth of Cu nanowires on Pd(110) surface [8]. Thus, apart from energetically driven strain-induced growth processes, the formation and shape evolution of islands on a surface can also be attributed to kinetic growth processes.

$CoSi_2$ has been widely used in the microelectronics industry because of its low resistivity, low formation temperature and low lattice mismatch to Si [9,10]. Despite the low mismatch, the growth of epitaxial $CoSi_2(001)$ thin films on Si(001) is difficult due to the competition of grains forming at different epitaxial orientations with good interface matchings [11]. At submonolayer–monolayer growth regime, low-dimensional $CoSi_2$ structures such as elongated islands and nanowires have been reported to form on Si(100). However, the reasons accounting for the growth of these silicide nanowires remain controversial. In the work by Brongersma et al. [12], the shape transition of a $CoSi_2$ square island to a wire at 950 °C was reported to be a consequence of a stress induced shape transition as proposed by Tersoff and Tromp [1]. Stress in the $CoSi_2$ islands can occur when $CoSi_2$ grows epitaxially on Si(001) since there is a lattice mismatch between Si and $CoSi_2$ (~−1.2%). The presence of strain or stress in other material systems has also been demonstrated to influence the equilibrium shapes of the islands [13–16]. Conversely, in the

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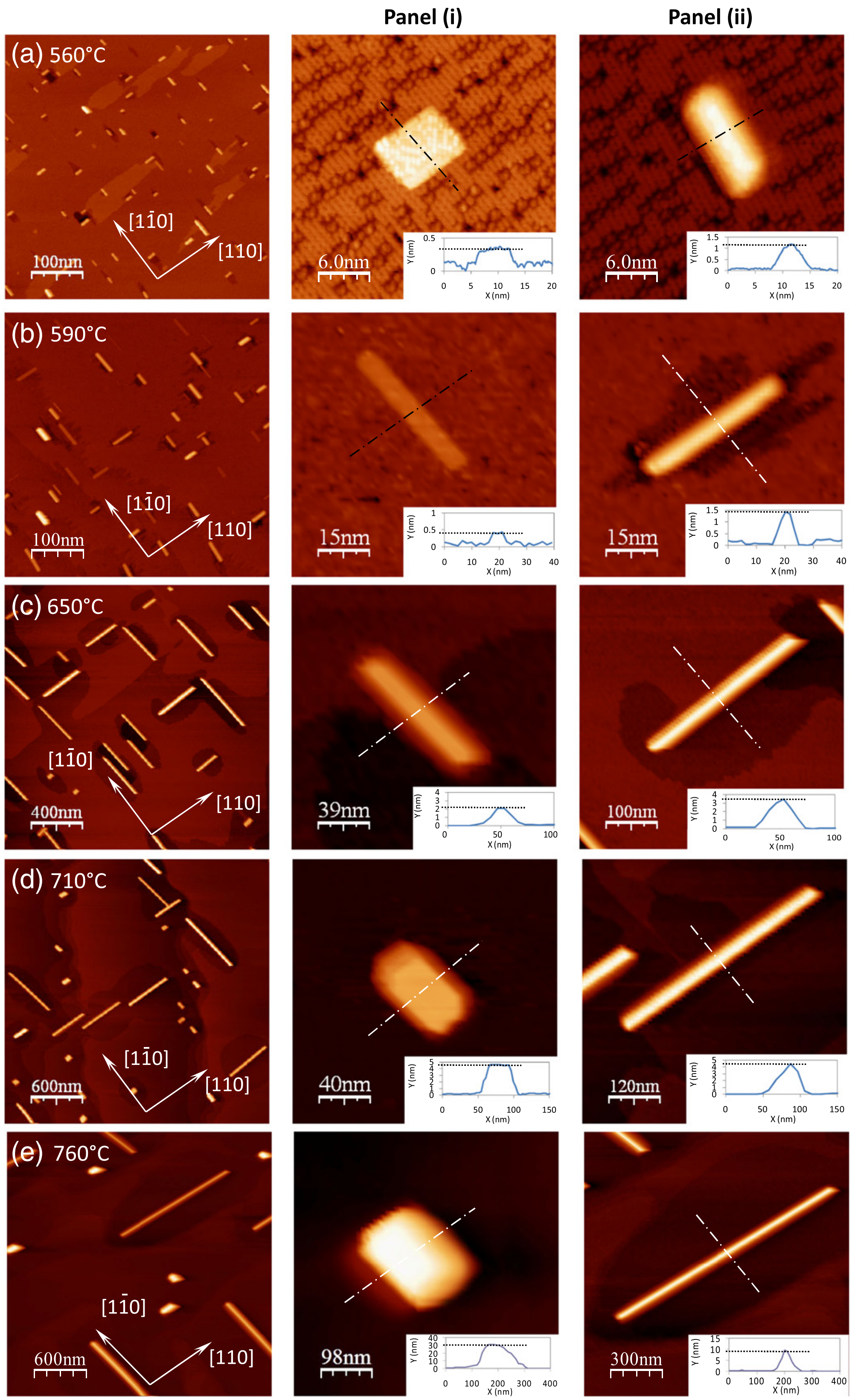

Fig. 1. STM surface morphologies of clean Si(001) deposited with 0.1 ML cobalt deposited at (a) 560 °C, (b) 590 °C, (c) 650 °C, (d) 710 °C and (e) 760 °C. Zoom in images of a flat and a ridge islands are shown in Panels (i) and (ii) respectively with corresponding line-profiles.

work by Goldfarb et al. [17,18], the size of the islands formed at 500 °C on Si(001) was found to have a $t^{0.5}$ dependence and its growth behaviour did not fit the Tersoff–Tromp model [18]. In addition, these islands were shown to become more isotropic (square-like) with increasing anneal time. Their results thus do not agree with those reported by Brongersma et al. [12]. Using finite