

## Self-Assembled $\text{TiSi}_x$ Nanostructures Formed by Chemical Vapor Deposition

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With ever decreasing feature sizes of advanced integrated circuits, the cost of photolithography is rapidly becoming a limitation to further advances of IC technology. Using self-assembly techniques to form the smallest features may allow practical continuation of IC technology scaling.

One method of forming self-assembled structures is to employ epitaxial deposition of one material on another material with a different lattice constant. Although the first few atomic layers may deposit uniformly on the substrate, the stress resulting from the lattice mismatch increases with increasing layer thickness. Once the stress increases beyond a critical value, three-dimensional structures may form to reduce the stress. When the stress is the same in two dimensions, the resulting structures tend to be equi-axed.

The formation of Ge islands on Si has been extensively studied and reported [1-3]. The 4% lattice mismatch between Ge and Si strongly influences the size of the islands formed. To obtain smaller islands, a set of materials with a larger lattice mismatch is needed. In addition to appropriate lattice mismatch, using a material compatible with Si IC technology is especially advantageous. Titanium silicide is one attractive candidate material because it is widely used in integrated circuits and, with proper precautions, is compatible with IC fabrication facilities.

Titanium silicide can be formed by reacting chemically vapor deposited Ti with Si from the substrate or with Si simultaneously added from the vapor phase. This paper reports a study of titanium silicide nanoislands formed by depositing Ti from the precursor  $\text{TiCl}_4$ , with the Si coming from the substrate or from added gas-phase  $\text{SiH}_4$  or  $\text{SiH}_2\text{Cl}_2$ .

For nanoisland formation, only monolayer amounts of Ti are to be deposited. The amount of Ti deposited can be controlled by varying the deposition temperature within the reaction-rate controlled regime of deposition. Temperatures between 630 and 690°C are especially useful. At these temperatures, Ti layers containing  $10^{14}$  – mid- $10^{15}$  atoms  $\text{cm}^{-2}$  can readily be formed. The low temperature limits reaction with the substrate, and very small, probably sub-stoichiometric islands form with composition  $\text{TiSi}_x$  with  $x \leq 2$ . After deposition, the number of islands varies only weakly with the amount of Ti deposited, but the number of atoms per island varies more strongly. Within the range

investigated, the number of Ti atoms in an island varies from about 800 to about  $2 \times 10^4$ . The linear dimension of a  $\text{TiSi}_2$  cube containing the same number of Ti atoms varies from 3 to 10 nm.

When the layers are annealed at temperatures above 800°C, the Ti reacts with the substrate to form stoichiometric  $\text{TiSi}_2$ . Significant mass transport of the Ti causes the number of islands to decrease and their size to increase, as shown in Fig. 1. After annealing, the island size depends only weakly on the amount of Ti in the layer, while the number of islands varies more strongly.

Three different types of islands are formed after annealing. The dominant island type is a nearly equi-axed, flat-top island that has been studied in detail by scanning tunneling microscopy (STM) and by transmission electron microscopy (TEM) [4]. The properties of the islands vary considerably. The islands catalyze the decomposition of subsequently introduced silicon-containing gas, with one of the minor island types being especially effective. The catalytic decomposition of a silicon-containing gas allows formation of nanowires; these nanowires may be virtually defect free and have diameters as small as 20 nm [5].

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