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Influence of an epitaxial Si capping of Ge islands on Si(0 0 1) and Si(1 1 0) by LPCVD

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Abstract

The influence of the Si overgrowth in the Ge/Si(001) and Ge/Si(110) systems has been studied. Rutherford backscattering spectroscopy analysis pointed out a reduced number of Ge atoms in capped samples performed on Si(110). Atomic force microscopy and transmission electron microscopy allowed us to propose a model to explain this behaviour. A way of explanation is given to clarify why such a phenomenon does not take place in the samples realized on Si(001).

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1. Introduction

The growth of Ge islands on Si(001) has attracted a large interest in the last few years. In this work, we consider growth of Ge islands on an other surface, Si(110). Only a few studies have been carried out on this surface especially for the growth by low pressure chemical vapour deposition (LPCVD). So, it is interesting to know how the different properties of the Si(110) surface compared to the Si(001) surface affect the growth of Ge and particularly what is the influence of an epitaxial Si capping layer of Ge islands.

2. Experimental

Experiments were performed in a LPCVD reactor at 0.12 Torr with SiCl_2H_2 and He-diluted GeH_4 as source gases for silicon and germanium epitaxy, respectively. After the growth of a Si buffer layer at 800°C during 60 min, a Ge film is deposited at 700°C with a constant pure GeH_4 flow of 1 sccm. The same growth conditions were used on Si(001) and Si(110) in order to compare the growth on these two surfaces. Then, a second set of samples was prepared under the same conditions and a Si cap layer has been added at 700°C.

3. Results and discussion

For each sample, the Rutherford backscattering spectroscopy (RBS) analysis gave us a total

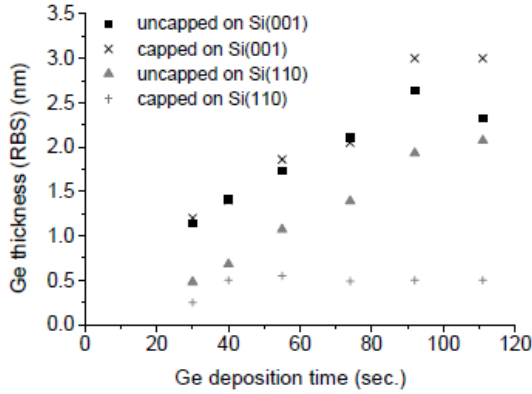


Fig. 1. Ge thicknesses determined by RBS of uncapped and capped samples grown on Si(001) and Si(110) as a function of the nominal Ge deposition time. The lower values of Ge thicknesses found on Si(110) reveal a smaller growth rate on this surface.

number of Ge atoms contained in the structures. Fig. 1 represents a graph of these Ge amounts converted to equivalent Ge thicknesses as a function of the nominal Ge deposition time. We remark that the experimental values of the uncapped and capped samples grown on Si(001) and the uncapped samples grown on Si(110) follow the same trend. In this investigation time range, the Ge growth rate is approximately constant since the Ge thickness linearly increases when the Ge deposition time rises. For the capped samples on Si(110), the same behaviour occurs until a Ge deposition time around 50 s. After this value the Ge thickness remains constant to about 0.5 nm. Therefore, the Si overgrowth of Ge islands on Si(001) has no effect on the Ge growth rate under our growth conditions, whereas on Si(110) the growth of the Si cap layer is associated with a reduction of the number of Ge atoms in the structure.

In order to clarify the mechanism which takes place during the growth of the Si cap layer in the Ge islands/Si(110) system, we performed investigations using atomic force microscopy (AFM) and transmission electron microscopy (TEM). Then, we focus the discussion on two samples grown on Si(110) with a Ge deposition time of 92 s. One is uncapped and was used to perform AFM investigations, while the second one was studied by TEM. The data are displayed in Table 1.

Table 1

Results of AFM and TEM characterizations to uncapped and capped samples, respectively. The values are given for a growth on a Si(110) substrate. The island height and diameter for the uncapped sample are average values. They were determined by Gaussian fits to the height and diameter distributions extracted from AFM images. For the capped sample, a range of values has been determined by measuring the island height and diameter on several cross-section TEM micrographs. The island area density has been estimated from AFM images and plan-view TEM micrographs for uncapped and capped samples, respectively

	Island height (nm)	Island diameter (nm)	Island area density (μm^{-2})
Uncapped sample (AFM)	27.3	121.1	45
Capped sample (TEM)	2–7	35–80	~ 30

It results that when a Si cap layer is added, the island height and diameter are strongly reduced and the island density is decreased by 30%. A loss of materials is then clearly identified. In Ge/Si(001) system, several authors report shape changes of buried islands [1–3]. A Si capping leads to the dissolution of Ge island apex and reduced island height. Moreover, the smallest islands shrink or even disappear. This phenomenon is explained by a Si-induced destabilisation of island apex which produces the formation of a (001) stable facet on the island top and an increase of the island base area by atoms migration [3]. On Si(110), this scenario is not sufficient to explain the island height reduction. Moreover, the island diameter does not increase but is clearly reduced. Another mechanism is then involved.

SiCl_2H_2 is used as source gases for silicon epitaxy. Near the surface, SiCl_2H_2 decomposes to produce HCl. Furthermore, GeCl_2 is the only major Ge-containing gaseous species in the equilibrium Si–Ge–Cl–H system under our conditions [4]. Then, during the formation of the Si cap layer, HCl can react with the Ge atoms at the surface as $\text{Ge} + 2\text{HCl} \rightarrow \text{GeCl}_2 + \text{H}_2$ [5]. This Ge etching reaction is inefficient as soon as the Si overgrowth becomes faster. The competition between these two mechanisms is driven by the surface properties. The difference of surface energies and nucleation kinetics between the (001) and (110) surfaces, and the smaller growth rate on Si(110) revealed by Fig. 1 lead to the

conclusion that the etching reaction is favoured on Si(1 1 0) surface.

4. Conclusion

The epitaxial Si capping of Ge islands on Si(0 0 1) has no effect on the Ge growth rate under our growth conditions, whereas on Si(1 1 0) a reduction of the number of Ge atoms in the structure occurs.

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