

Fabrication of Silicon Nanowires Using Atomic Layer Deposition

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ABSTRACT

Growth of silicon nanodots at temperatures 550-625°C by thermal decomposition of silane in a low pressure chemical vapor deposition reactor is reported here. This procedure uses short periods of deposition time in the early stages of polysilicon growth. Atomic Force Microscopy was used a primary technique to investigate the growth of the silicon nanodots on three different substrates. The substrates used are clean silicon, silicon dioxide (SiO₂) substrate and dilute hydrofluoric acid treated silicon dioxide substrate. The analysis reveals that for a 1 min deposition time on a hydrofluoric acid treated substrate, the mean size of the nanodots obtained range between 5-10 nm in height and 20-30 nm in diameter. However, the size of the nanodots obtained is different for the three substrates used.

Keywords: silicon quantum dots, lpcvd, nanodots, silane decomposition

1 INTRODUCTION

The emerging field of nanotechnology offers possibilities for studying fundamental chemical and physical principles at nanoscale and provides avenues to new technologies such as nanodevices and nanosensors. Nanoscale structures have been extensively studied due to their unique properties that display important size-dependent quantum effects. These structures offer extremely attractive physical features and have a great potential for nano-scale applications since they can function both as active devices and interconnects. The quantum size effects and the coulombs blockade phenomenon make them extremely attractive to use in functional devices such as resonant tunneling device, single electron transistor and p-n junction transistors [1-3]. However, one current challenge is the fabrication and interconnection of these devices on semiconducting surfaces such as a Si wafer. We must precisely control the physical properties of these structures; thus, it is necessary to control with atomic precision their morphology, structure, composition and size. To realize silicon (Si) quantum effect devices, we desire to develop a simple technique to fabricate high-quality crystalline nanowires using Atomic Layer Deposition (ALD) technique. The method will enable control over several important aspects of the growth, including control of the nanowire diameter, length and structure. In this work, we

present the first step to our approach – the formation of the Si nanodots that act as seeds to grow nanowires.

Low Pressure Chemical Vapor Deposition (LPCVD) has been widely used in the field of ultralarge-scale integrated circuits to form poly-crystalline Si films. Several groups have reported the formation of Si nanocrystals on insulators such as SiO₂ [4, 5], sapphire [6] and silicon nitride [7, 8] by controlling the early stages of LPCVD deposition. Here, we show that the Si dot density can be controlled by monitoring the surface properties and that the size can be controlled by varying the time and the temperature of deposition of silane.

2 EXPERIMENTAL

To study the nucleation process on Si, SiO₂ and hydrofluoric acid (HF) treated SiO₂, a clean hot-wall LPCVD system was used. The LPCVD system consisted of a quartz tube heated by a resistance furnace. The temperature was varied from 550 – 650° C and the partial pressure of silane was constant at 0.2 Torr. The p-type Si(100) substrates were chemical cleaned and some of the substrates were oxidized in dry oxygen at 1100° C to form an oxide layer of 15 nm thick. A few of these oxide layers were then treated with dilute HF solution (10%) for 60 s to form hydroxyl groups on the surface. Silicon nanodots were self-assembled on all the three substrates by LPCVD of pure silane. The deposition times for this study were short compared to the usual polysilicon deposition time.

In order to investigate the nucleation, growth and coalescence of the nanodots, the areal density and dimensions of the particles were probed and measured using AFM. The density of the particles was calculated using the “particle analysis” Nanoscope DI software.

3 RESULTS

Figures 1 (a), (b), and (c) show the top view image for SiO₂ substrates treated with HF with deposition times 1, 2 and 6 min, respectively, at 625°C and 0.25 Torr pressure. The hemispherical shaped nanodots vary in both diameter and height. Figure 1 also shows that several of the nanodots coalesce to form dots with larger diameter for longer deposition times. The mean size and size distribution of these nanodots with respect to both diameter and height on the three different substrates used is shown in figure 2. As the deposition time is increased not only do the diameter

and the height of the dots increase but the dots tend to coalesce. Nakajima et.al. [4] speculate that this coalescence could be due to the Brownian migration of the particle. Si dots of about 10 nm are mobile on SiO₂ substrate. It should be noted from Figure 3 that though the size of the Si dots increases the density of the dots on the surface decreases with deposition time. The decrease in density is more significant on substrate treated with HF when compared to SiO₂, while the density of dots on clean Si substrate essentially remains constant. It is also evident from Figure 1 and that the dots are not only coalescing but also new Si dots are seen to be formed. The size distribution of the dots formed with deposition time (Figure 2) suggests the formation of new nucleation sites over a period of time. The lower limit of the size distribution essentially remains constant.

It has been suggested that a point imperfection is composed of silicon bonds [7]. In the case of HF treated SiO₂ substrate, the surface Si-O bonds dissociate creating dangling bonds [9]. At the thermal decomposition temperature of silane, the SiH₂ precursor reacts with the surface "OH" groups. Miyazaki et.al. have reported this reaction scheme based on variation of the concentration of surface "OH" groups achieved by annealing the surface for different times [9]. The Si dot distribution became significantly narrow with increasing concentration of the "OH" groups on the surface. In the case of SiO₂ substrate, the strain induced in the Si-O-Si bond due to oxidation is responsible for the Si dot nucleation sites. However, due to the stronger bond energy of Si-H (299 kJ mol⁻¹) the nucleation density on Si substrate is much smaller than that on SiO₂ and HF-treated SiO₂ substrates.

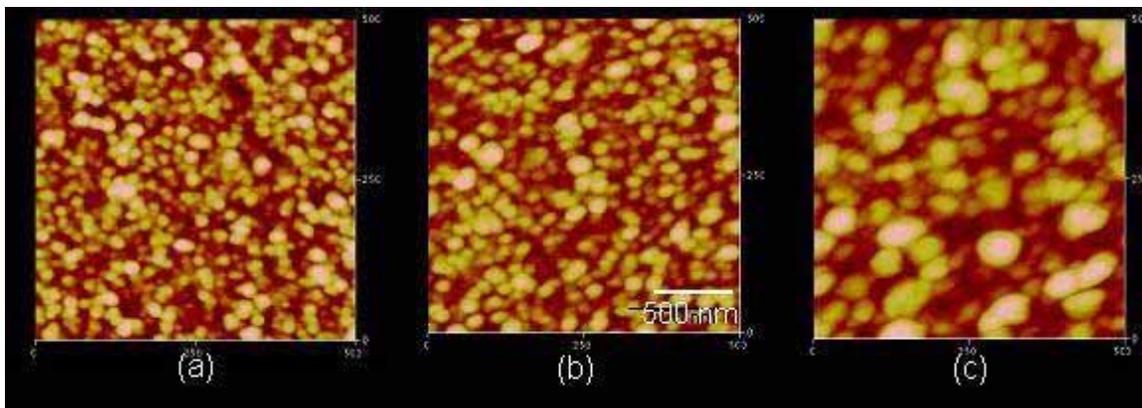


Figure 1: The evolution of Si dot density and size after a deposition time of (a) 1 min, (b) 2 min and (c) 6 min.

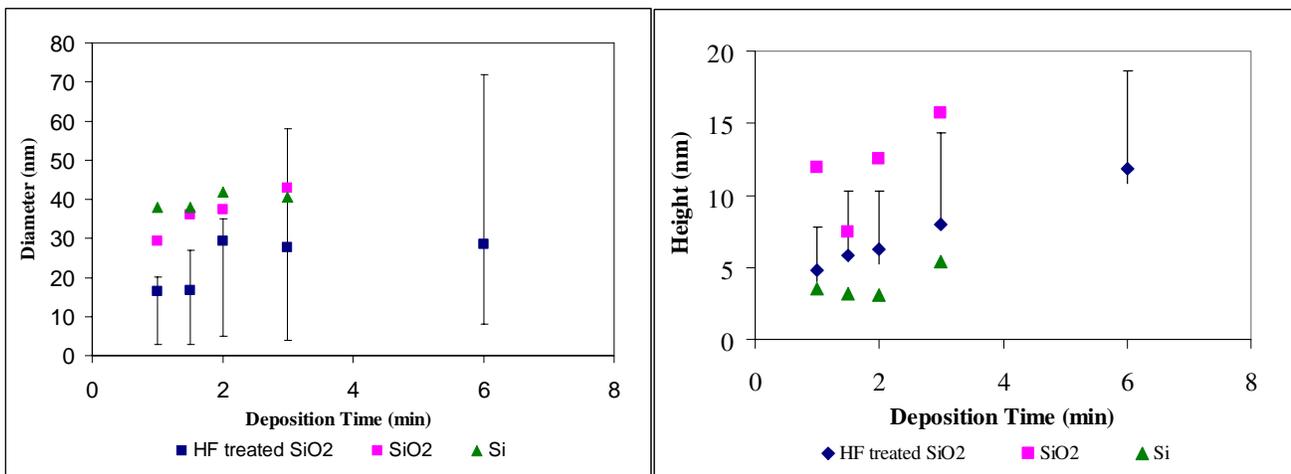


Figure 2. Evolution of Si size with time on Si, SiO₂ and HF-treated substrates. This figure also shows the size distribution of the Si dots on HF treated SiO₂ substrate.

The size and the density of the Si dots formed on Si substrates remain nearly the same. This suggests that the growth of the silicon dots is very slow and there is no evidence of Brownian motion on of Si dots on the clean Si surface.

The evolution of Si dot density and size with temperature was also explored. Figure 4 shows top view images for HF treated SiO₂ substrate. The deposition temperature affects the size of the Si nanodot formed. On the contrary, the deposition temperature does not seem to influence the density of nucleation of the nanodots. It appears that the size of the nanodots increases with temperature while the nucleation density remains constant. As the temperature increases, silane decomposes faster into

SiH₂ precursor thus increasing the both the diameter and the height of the nanodots formed.

4 SUMMARY

In this study, we investigated the formation of Silicon nanodots on three different substrates. The size and the nucleation density of of Si dots formed were found to be dependent on the nature of substrates used. The HF-treated SiO₂ substrate resulted in higher nucleation rate than that of SiO₂ substrate. On a Si substrate, the nucleation rate did not depend on deposition time. To obtain a high nucleation density and narrow size distribution, high concentration of Si-OH group on the surface maybe required.

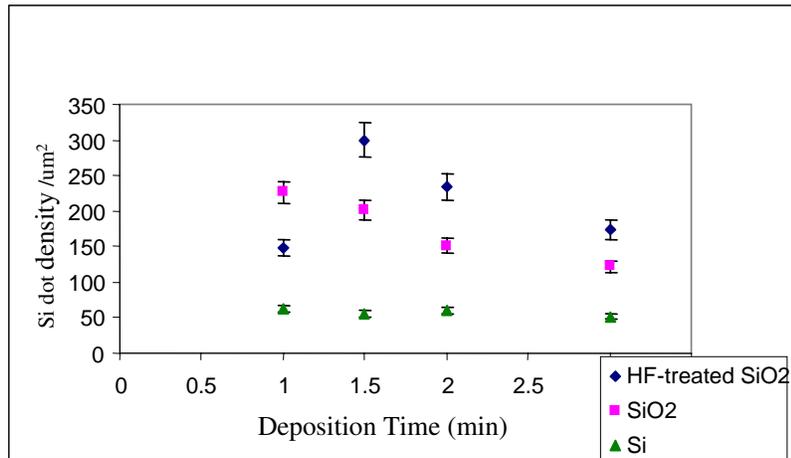


Figure 3. Variation of Si dot density for three different substrates - Si, SiO₂ and HF-treated SiO₂.

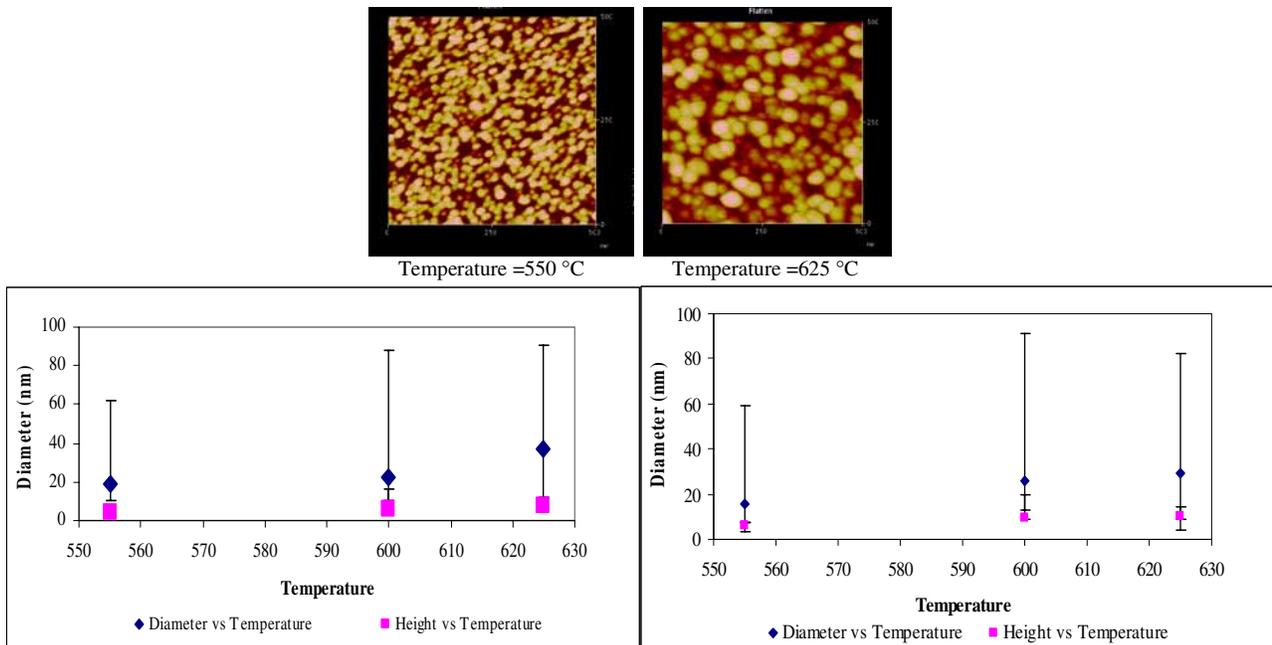


Figure 4. Temperature dependence of nucleation density and size of the Si dots

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