Germanium seeded crystallisation of α-Si for application in 3D integration

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Key words to describe the work: Seeded crystallisation, 3D integration

Key Results: Effect of α-Si thickness and doping on Ge induced lateral crystallisation of α-Si is investigated

How does the work advance the state-of-the-art?: Ge-seeded crystallisation allows crystallisation of α-Si at 550°C, and gives grains/single-crystal regions up to 1.49 μm in size. Dopant and thickness dependence of the Ge induced lateral crystallisation is investigated, which will improve the understanding of the crystallisation and nucleation behaviour of α-Si for 3D integration.

Motivation (problems addressed): To achieve a CMOS compatible metallic contamination free technique to realize grain boundary controlled single crystal silicon in desired areas for 3D integration.

Introduction

The growing demand for increased functionality and complexity of modern VLSI chips has highlighted the requirement for 3D ICs where transistors are arranged in multiple layers instead of a conventional single layer [1]. 3D ICs can be built by wafer bonding or by fabricating transistors in deposited layers of silicon. The wafer bonding approach has the limitation of lack of precision alignment, whereas the latter approach faces processing temperature limitations in order to preserve the underlying layers and devices. Crystallisation of α-Si by LASER irradiation or epitaxial growth from a single crystal seed from the open window have been realised in the past [2, 3]. These processes are not very attractive for 3D integration due to the involvement of high temperatures. Solid phase crystallisation (SPC) of α-Si provides an alternative low temperature process, but devices fabricated in such films have low performance due to the random distribution of grain boundaries. For grain boundary control metal induced lateral crystallisation has been studied in the past, using such metals as Ni [4]. Unfortunately, the integration of such a process into a CMOS technology is problematic due to the deleterious effect of Ni on device performance. Most recently a novel crystallisation technique to achieve lateral crystallisation using Ge as a crystallising agent has been proposed for CMOS technology [5]. In this work Ge seeded crystallisation is studied for application in 3D CMOS; the effect of α-Si thickness and doping on the Ge induced lateral crystallisation is described.

Experimental details

To simulate the intended device application this study was done on oxidized silicon wafers. α-Si with thicknesses 400 nm, 200 nm and 100 nm was deposited by LPCVD at 560°C from SiH_4. Some of the wafers were doped with B^+ with a dose of 8×10^{14} and energy 15 keV which gives a projected range of 56 nm. On these Si films, 300 nm LPCVD (LTO) SiO_2 was deposited for use as a sacrificial layer. Seeding windows of different shapes were opened in this layer. The wafers were dipped in a 100:1 HF solution to remove the native oxide from the α-Si, and this was followed by LPCVD Ge deposition at 520°C, 2T with a 200 sccm GeH_4 flow. Under these conditions, the Ge was deposited as polycrystalline material. Immediately after Ge deposition the wafers were annealed in argon at 550°C for 20 hours to crystallize the films. After crystallisation the remaining Ge was removed in RCA solution and the sacrificial oxide was removed in HF. The samples were then etched in a $HF:H_2O:HNO_3:CH_3COOH$=1:9:50:50 for 40 seconds. The etchant etches α-Si selectively over poly-Si with a selectivity of over 100:1 and the etch time gives complete etching of the 100 nm α-Si film. After defect etching scanning electron microscope (SEM) was used to observe the material structure in the crystallized films.

Results and discussion

Fig. 1 shows an SEM micrograph of 100 nm and 200nm defect etched boron doped silicon films annealed at 550°C for 20 hours. In the 200 nm film some sparse laterally crystallized grains originating from the circular seed point are observed, whereas in the 100 nm silicon films uniform lateral crystal growth from the seed point is clearly evident.

Fig. 2 shows an SEM micrograph of defect etched 200 nm and 100 nm undoped silicon films annealed at 550°C for 20 hours. For 200 nm silicon films no lateral crystallisation from the seed point is seen but some randomly crystallized grains are observed both in seeded and unseeded region. In contrast,

100 nm undoped silicon films show lateral crystallisation from the seed point along with some random crystals in between the seeds.

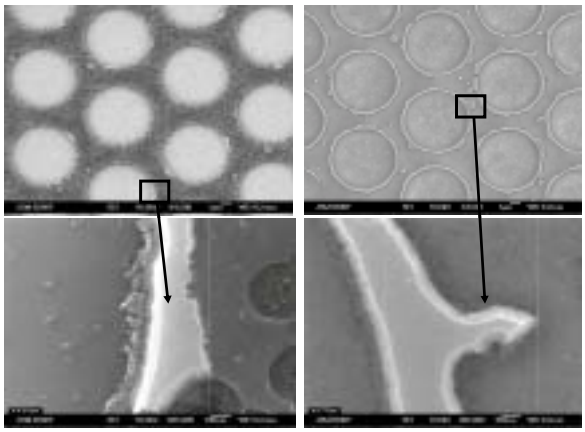

Fig. 1. SEM micrographs of a) 200 nm and b) 100nm defect etched boron doped silicon films annealed at 550°C for 20 hours.

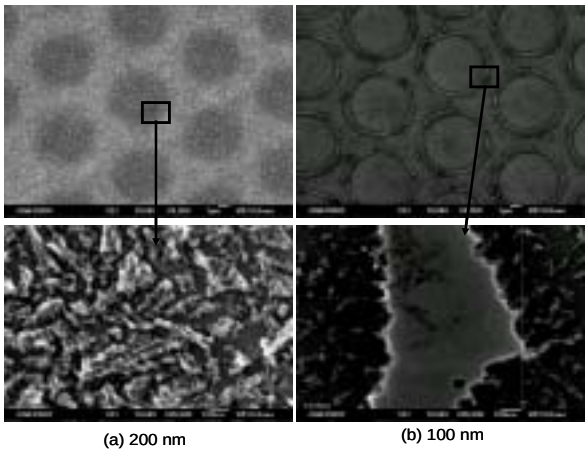

Fig. 2. SEM micrographs of a) 200 nm and b) 100nm defect etched undoped silicon films annealed at 550°C for 20 hours.

SiGe alloys crystallize much more rapidly than pure silicon at any given temperature. In the seeded zone the Ge reacts with the Si to form a SiGe layer at the interface, which in turn nucleates the lateral crystallisation. Fig. 3 shows a higher magnification SEM micrograph of a 200 nm silicon film adjacent to the seeded zone. We see a much higher population of randomly nucleated grains in the seeded zone compared to the unseeded zone, supporting the higher nucleation rate of the Ge covered zone due to the lower temperature crystallisation of SiGe alloy, which in turn induces lateral crystallisation. In the course of time these growing lateral crystals merge with the randomly nucleated crystals, giving a grain boundary. For efficient crystallisation, the seeded zone nucleation rate should be at a higher rate and the nucleation in the unseeeded amorphous matrix should be suppressed so that lateral crystals can grow for a longer time.

Table I summarizes the lateral extent of the α-Si crystallisation found in this experiment. No lateral crystallisation is found for 400 nm and 200 nm undoped films, whereas the undoped 100 nm Si film shows uniform lateral crystallisation behaviour. For doped samples sparse lateral crystals are found in the case of thicker films but the extent of the lateral crystallisation is found to increase with the decrease of film thickness and at all film thickness doped samples show superior lateral crystallisation behaviour than undoped samples.

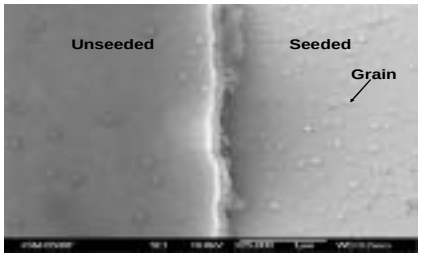

Fig. 3. SEM micrograph of a 200 nm defect etched silicon films annealed at 550°C for 20 hours.

Table I

Film thickness	Lateral crystallization distance	
	Doped samples	Undoped samples
400 nm	Sparse crystals; L_{max}=324 nm L_{min}=0 nm L_{avg}=21 nm	No lateral crystals
200 nm	Sparse crystals; L_{max} =633 nm L_{min} =0 nm L_{avg} =77 nm	No lateral crystals
100 nm	Uniform crystals; L_{max} =1.49 μm L_{min} =227 nm L_{avg} =330 nm	Uniform crystals; L_{max} =1.266 μm L_{min} =142 nm L_{avg} =258 nm

Conclusion

We have studied the effect of α-Si thickness and doping on the Ge induced lateral crystallisation of α-Si. It is found that doping enhances lateral crystallisation and the extent of the lateral crystallisation increases with decreasing film thickness. In the 100 nm Si films we found single-crystal regions up to 1.49 μm in size which is promising for 3D CMOS fabrication.

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