

The Kinetics of Solid Phase Epitaxy in As-Doped Buried Amorphous Silicon Layers

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Introduction

Ion implantation is the principal method used to introduce dopants into silicon for fabrication of semiconductor devices. The damage which accumulates during ion implantation may lead to amorphisation of the silicon over the depth range of the ions. To activate the dopants and make a useful device the damaged or amorphous material must be crystallised by thermal annealing. In the case of amorphous silicon layers, crystallisation can be achieved by a solid-state process called solid phase epitaxy (SPE) in which the amorphous layer transforms to crystalline silicon (c-Si) layer by layer using the underlying c-Si as a seed. Unlike liquid phase epitaxy, SPE occurs under conditions where the atomic mobility is comparatively low and crystallisation occurs by highly localised bond breaking and rearrangement processes. The bond breaking process is thought to be mediated by a defect which is present at the amorphous/crystalline (a/c) interface, however, the exact nature of this defect is unknown. One of the key observations which may lead to identification of the defect is the fact that moderate concentrations of dopants enhance the SPE crystallisation rate while the presence of equal concentrations of an n-type and a p-type dopant (impurity compensation) returns the SPE rate to the intrinsic value. This provides crucial evidence that the SPE mechanism is sensitive to the position of the Fermi level in the bandgap of the crystalline and/or the amorphous silicon phases and may lead to identification of an energy level within the bandgap that can be associated with the defect.

The crystallisation via solid phase epitaxy of a-Si surface layers formed by self-ion implantation into single-crystal (c-Si) substrates has been studied extensively [1, 2] and various models have been proposed to explain the SPE growth process and its observed dependence on parameters such as substrate orientation [3], impurity type and concentration [4] and pressure [5]. The studies of dopant-enhanced SPE are of particular importance because they provide insight into the fundamental mechanism responsible for the crystallisation process [1]. Significantly, the experiments of Walser and co-workers showed that for dopant concentrations less than ~ 0.1 at.% the SPE rate increases linearly with concentration [6] and several different models of the SPE process that can accommodate this observation have been proposed [5-8]. However, Olson and Roth [9] have shown that the SPE rate in thin (< 4000 Å) surface a-Si layers like those used by Walser et al. is affected by the presence of hydrogen even when the measurements are performed in vacuum. They found that H present in the surface oxide infiltrates the a-Si layer during annealing and that for thin layers this results in a nearly constant H concentration of $\sim 2 \times 10^{19}$ cm $^{-3}$ at the amorphous/crystalline (a/c) interface throughout the SPE process, causing retardation of the growth rate. They also showed that the intrinsic SPE rate can be obtained by using a-Si layers several microns thick and measuring the growth rate during the early stages of crystallisation before significant concentrations of H have penetrated to the a/c interface [1]. However, thick amorphous surface layers are not very convenient for studies of dopant-enhanced SPE and the degree of H infiltration must always be considered. Recently, we have shown that buried a-Si layers provide an alternative environment in which the intrinsic [10] and dopant-enhanced [11] growth kinetics of a-Si can be studied free from the rate-retarding influence of H and that a two laser time resolved reflectivity technique can be used to measure the instantaneous crystallisation rates in these layers. The overlying

crystalline Si layer provides a barrier to H infiltration. This paper gives details of SPE measurements in As-doped buried a-Si layers and discusses the implications of these data for models of the SPE process.

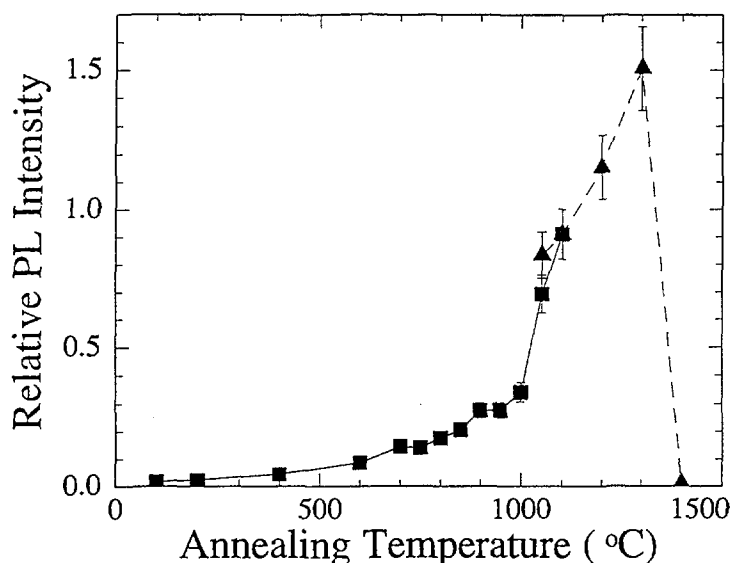


Figure 1: (a) Schematic representation of the reflected signals for the 632.8 nm laser used in the TRR measurements. (b) TRR trace for crystallisation of a buried a-Si layer at 580°C.

Experiment

For the dopant-enhanced SPE studies, uniform concentration profiles were produced over the depth range $\sim 0.4\text{--}0.7\ \mu\text{m}$ by implantation of As ions at four different energies in the range 450–1200 keV with the substrates held at 77 K. Following As implantation, the samples were annealed at 580°C, 1 hr under UHV conditions in the implantation chamber to fully crystallize the implanted layer. Buried a-Si layers were then formed using self-ion implantation [10]. The SPE rates were determined in air by mounting the samples on a resistively heated vacuum chuck and using time resolved reflectivity at wavelengths of $\lambda = 1152\ \text{nm}$ and $\lambda = 632.8\ \text{nm}$ to measure the a/c interface motion during crystallisation. Further details of the experimental procedure are given elsewhere [10, 11].

Results

Figure 1(a) shows a schematic representation of the laser reflections from the sample interfaces for the 632.8 nm laser used in the TRR measurements of the SPE rates in the buried a-Si layers. During crystallisation, the front and back a/c interfaces of the buried amorphous layer approach each other with growth rates represented by v_f and v_b . For much of the crystallisation process, the 632.8 nm reflectivity signal is only sensitive to motion of the front a/c interface because the laser light is strongly absorbed in the amorphous layer. Figure 1(b) shows a typical 632.8 nm TRR trace collected during SPE of a buried a-Si layer at a temperature of 580°C in air. During SPE, the front a/c interface recedes from the surface region and the

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