DENSITY MEASUREMENTS OF ION IMPLANTED AMORPHOUS SILICON

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ABSTRACT

The density of amorphous Si was measured. Continuous and buried amorphous Si films were produced by 0.5–8 MeV Si implantation through a steel contact mask. Surface steps of amorphous Si stripes with initial thicknesses from 0.9 to $\sim$ 5.0 μm were measured using a surface profilometer. For implants up to 5 MeV, the amorphous Si is constrained laterally by the surrounding crystal and deforms plastically. The density of amorphous Si deduced from the surface step heights is 4.91×10^{22} cm^{-3}, 1.7 ± 0.1 % less than the density of crystal Si (5.00×10^{22} cm^{-3}).

INTRODUCTION

Many basic properties of amorphous Si (a-Si) are not known despite the continuing technological and scientific interest. The density of amorphous Si relative to the crystal value, for example, has been a source of much debate. Experimental values range from as much as 10 % to 1.7–2.3 % below that of crystal silicon (c-Si).[1-3] Computer models of the structure of a-Si and molecular dynamics (MD) simulations of a-Si formed by a high temperature, disordered Si phase both suggest an a-Si density greater than that of c-Si.[4,5] Recently, it has been observed that as implanted a-Si is in an unrelaxed state and that substantial enthalpy is released upon low temperature annealing. Experiments on this relaxation indicate that the process is dominated by the annihilation of point defect complexes.[6] Here we report measurements of the density of self-implanted amorphous Si layers over a wide range of thicknesses, regrowth and relaxation conditions. Data indicate that a-Si is 1.7 ± 0.1 % less dense than c-Si for both relaxed and unrelaxed states. The density is independent of the implant conditions used to produce the a-Si.

EXPERIMENTAL

Alternating stripes of a-Si ($\sim$ 300 μm wide, 0.9 to 5 μm thick) and c-Si ($\sim$ 100 μm) were produced by series of Si implants between 0.5 and 8.0 MeV through a steel mask into (100) Si on the National Electrostatics 1.7 MeV Tandem accelerator at AT&T Bell Laboratories. In addition to continuous a-Si layers, buried a-Si layers were also fabricated by implantations at at 0.5 and 1.5 MeV. The irradiations were performed at either liquid nitrogen or room temperature, with the samples heat-sunk with vacuum grease to a copper block. A wider range of thicknesses were obtained by partially recrystallizing the thick layers at 580°C in a vacuum annealing furnace with a base pressure of $\sim 10^{-7}$ Torr. In addition, a section of each was thermally relaxed by annealing for one hour at 500°C.

The thicknesses of the a-Si layers were measured by Rutherford Backscattering Spectroscopy (RBS) in the channeling configuration. The maximum observable depth is limited by dechanneling in the overlying a-Si to $\sim$ 2.8 μm. The conversion of energy loss to layer thickness was made using Ziegler's stopping powers.[7] For a-Si layers thicker than 2.8 μm, RBS can not directly measure the thickness. To obtain an estimate of the layer thickness, these layers were partially recrystallized to less than 2.8 μm by thermal annealing at 590°C for a known time. The original thickness is then calculated to be the sum of the partially recrystallized thickness plus the known distance regrown during the anneal.

Surface profiles of the alternating a-Si and c-Si regions were obtained from each sample using a Tencor Instruments Alpha-step 200. A 2000 μm lateral scan, covering approximately 5 repeat periods, was obtained with data points every 1 μm. This digital data was transferred to a computer for further baseline subtraction and step height calculation. The contribution to the step height from the total implanted dose was subtracted from the measured step heights. Since the a-Si plastically deforms during irradiation, and the vertical strain is much larger than

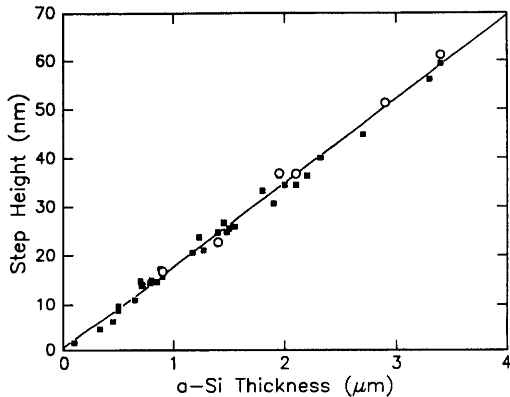

FIG 1. Net step height versus a-Si layer thickness for as-implanted samples (open circles) and annealed samples (filled squares) of all implant series from 0.5 to 5.0 MeV. The solid line shows the step height expected for a 1.7 % density difference. Layer thicknesses greater than 3 μm are extrapolated from observed solid phase epitaxy behavior.

the in-plane strain,[8] the density change is given simply by the ratio of net step height to a-Si thickness.

RESULTS

The net step height data from samples implanted up to 5 MeV are shown in Fig. 1 as a function of a-Si thickness. As implanted samples are shown by the filled squares, and annealed samples by open circles. No differences were found due to implant temperature or annealing treatments. For implant energies greater than 5 MeV, the c-Si matrix is plastically deformed resulting in a lower step height than expected; these data are not shown here.

The best fit line through all data points indicates a density decrease relative to c-Si of 1.7 ± 0.1 %. Fitting only the as-implanted samples (*i.e.* unrelaxed), the density decrease is 1.8 ± 0.1 %. Any density change associated with relaxation is consequently too small to be measured with this technique. The fit to the entire set has an intercept of 0.5 ± 0.5 nm confirming that the subtraction of the implanted material is valid.

In conclusion, we have measured the density of self-implanted a-Si films between 0 and 3.5 μm thick to be 1.7 ± 0.1 % less than the density of c-Si, with the major source of error being uncertainty in the absolute a-Si thickness This value is opposite in sign to that predicted by computer modeling of a-Si structures, but consistent with other experimental measurements on clean a-Si. There are no discernible effects due to structural relaxation. For thicker layers the stresses generated during formation of the a-Si lines eventually leads to plastic deformation of the surrounding c-Si, leading to a smaller surface step than expected.

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