Two-dimensional study on the effects of nonamorphizing silicon implantation damage on phosphorus diffusion

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A new experimental study is performed to determine the lateral extent of silicon implantation damage on diffusion in silicon. The experimental technique is designed to allow easy comparison between damaged and nondamaged areas to facilitate specific measurements. Junction depth is measured under stripes of varying widths that protect from implantation damage as well as at points that receive the full amount of implantation damage. A roughly exponentially decaying profile of junction depth as a function of increasing stripe width is observed. Good correlation between measured and SUPREM-IV predicted values is observed.

The common use of ion implantation for the fabrication of modern devices introduces the problem of enhanced diffusion effects on subsequent steps of the fabrication process. With the geometries of modern devices continuingly shrinking, it also becomes important to understand what lateral effects the introduction of excess point defect might produce.

There have been several studies on the effects of nonamorphizing damage on dopant diffusion.[1–3] Park and Law [1] studied the one-dimensional effects of silicon implantation damage on phosphorus diffusion in silicon by comparing diffusion profiles at damaged and nondamaged points. Park found that significantly enhanced diffusion occurred in the damaged areas as compared to the nondamaged areas. The enhanced diffusion was attributed to excess point defects introduced by the nonamorphizing silicon implantation damage.

Griffin and Plummer[4] performed a two-dimensional study of oxidation enhanced diffusion effects on diffusion. They used a series of stripes having widths ranging from 2 to 200 μm that marked areas free of the oxidation. Their study showed a roughly exponential decay of junction depths as a function of increasing strip widths. They state that the narrowest stripes exhibit the maximum oxidation enhancement and the thickest stripes exhibit little or no enhancement. Additionally, a good correlation between their measured results and SUPREM-IV predictions was reported.

An implantation enhanced diffusion experiment was designed in order to examine the two-dimensional effects of the implantation enhanced diffusion. This experiment combined the experimental work of Park[1] and Griffin and Plummer.[4] A 250 Å layer of dry oxide was grown on three ⟨100⟩ orientation p-type wafers. A phosphorus implantation was performed with a dose of 2×10^{13} cm^{-2} and an energy of 60 keV. A 15 min furnace anneal at 900 °C was then done to remove any implantation damage caused by this initial implantation.

In order to provide a means of contrasting the damaged and nondamaged areas, a series of stripes ranging in width from 1 to 32 μm were fabricated on the wafers. A 200 Å thick layer of nitride was deposited on top of the existing screen oxide followed by a photolithography step and a plasma etch designed to create the stripe patterns. Figure 1 shows a cross section of the wafer. Varying width stripes of nitride form a marker for the subsequent anneals. A combination nitride/photoresist mask protects the stripes from the implantation damage. A silicon implantation with a dose of 10^{14} cm^{-2} and an energy of 60 keV was then performed to create nonamorphizing damage in the areas not protected by the stripes. Finally, furnace anneals were performed to drive in the dopant and thereby examine the extent of diffusion both in the damaged areas and the nondamaged areas under the stripes. At 800 °C furnace anneals were done for 10, 15, 30, and 60 min. At 900 °C there were 10 and 20 min anneals performed.

The measurement process of this experiment required the ability to measure the junction depth of the phosphorus at several locations between the stripes as well as at the center of each stripe. A very small angle (~17 min) of the sample was beveled away perpendicular to the strip pattern, resulting in a cross section of all the stripes. The sample was then stained with a copper based stain in order to determine the boundary of the n-type dopant diffusion. The measured results for the 800 °C 30 min sample can be seen in Fig. 2. The vertical axis shows the junction depth in μm while the horizontal axis shows the width of the stripes in μm. The measured data are presented by the darkened circles and include error bars. The results clearly show that as the stripe width widens, the junction depth tends to decline. The resulting

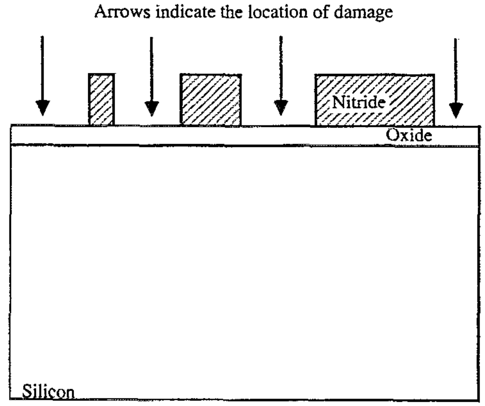

FIG. 1. Cross section of the wafer showing the stripe structures used in the experiment.

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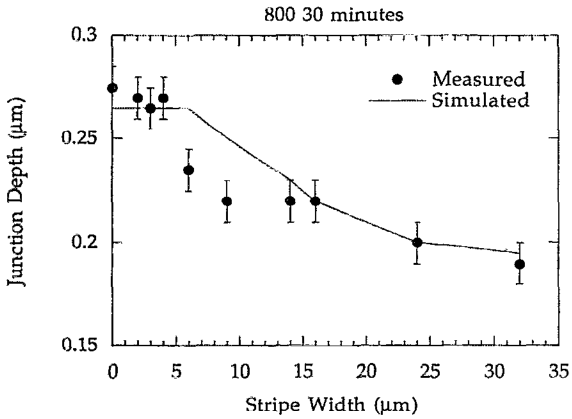

FIG. 2. Measured and simulated junction depths as a function of the stripe width.

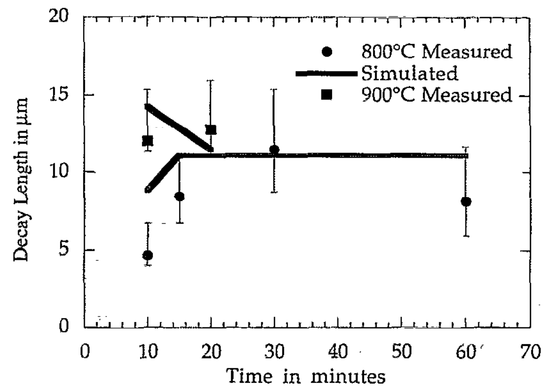

FIG. 3. Extracted decay length from measurement and simulation as a function of anneal time and temperature.

curve is roughly an exponential decay as a function of increasing stripe width. The results are similar to those found by Griffin and Plummer[4] for their two-dimensional oxidation enhanced diffusion study. Another interesting point in Fig. 2 is the difference between the junction depth measured at 0 μm stripe width which corresponds to the middle of a damaged area and the 32 μm stripe width measured value which is unaffected by the implantation. The difference in junction depth between these two points was found to be 85 nm which clearly shows that enhanced diffusion is occurring where the excess point defects from the implantation are located. This result agrees with the study performed by Park[1] on one-dimensional implantation enhanced diffusion. The results discussed above were similar to those at other anneal conditions.

The results of the SUPREM-IV simulation for the 800 °C 30 min samples at each stripe width can be seen in Fig. 2. The simulated data correlate well with the measured data and for the most part fall within the measurement error. The roughly exponential decay of junction depth as a function of increasing stripe width is clearly evident in the SUPREM-IV simulations. Griffin and Plummer[4] reported similar results for their oxidation enhanced diffusion study. Since the model used in SUPREM-IV[5] in this study was similar to that used by Griffin and Plummer, it follows that the model accurately describes both implantation enhanced and oxidation enhanced diffusion in two dimensions.

Figure 3 presents the measured and simulated results for the decay lengths of the phosphorus. As Fig. 2 shows, the change in junction depth is roughly exponential as a function of stripe width. The decay lengths in Fig. 3 are the characteristic length of the exponential decay. The horizontal axis shows the anneal time while the vertical axis shows the extracted decay length. The points marked by darkened squares show the measured 900 °C data along with the corresponding error estimates. The line between these two points denotes the simulated data for 900 °C. Similarly, the 800 °C measured data are marked by the darkened circles and the line passing across those points is the simulated data from SUPREM-IV for 800 °C. As Fig. 3 clearly shows there is a good correlation between the measured and the SUPREM-IV values. With the exception of the 10 min anneal data at 800 °C, the SUPREM-IV simulation values fall within the error bars of the measured values.

In conclusion, there are several interesting results from this experiment. First, the findings by Park[1] with regards to one-dimensional implantation damage diffusion enhancement were confirmed. Second, a roughly exponential decline in junction depth as a function of increasing stripe width was observed. This finding was similar to that found by Griffin and Plummer[4] for oxidation enhanced diffusion and confirmed that point defects caused by implantation damage have far reaching effects in a lateral as well as a vertical direction. Finally, the results from this study showed a good correlation between the measured data and the predictions of SUPREM-IV simulations. Additionally, since the model used in SUPREM-IV for this study was identical to that used by Griffin and Plummer[4] for their study of oxidation enhanced diffusion, the results show that the model is accurate for describing the effects of excess point defects in silicon.

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