Chapter 5

Summary and Future Work

5.1 Summary

In summary, we have performed experiments to characterize the effect of ion implantation damage on boron diffusion after low temperature annealing. The emphasis of the experiments has been on implantation damage above the amorphization threshold. A special test structure using low temperature silicon epitaxy has been used to grow buried boron marker layers. The test structures have been designed to isolate the effect of implant damage alone on boron diffusion. The major findings of our experiments are listed below.

1. Dislocation loops generated at amorphous silicon/single-crystalline silicon interfaces absorb excess interstitials injected during subsequent oxidation or ion implantation. Although, the dislocation loops absorb significant fractions of the injected interstitials, not all of the injected interstitials are absorbed.
2. For moderate ($1x10^{14}$ cm^{-2}) to high ($1x10^{16}$ cm^{-2}) silicon implant doses, the enhanced diffusion of the boron marker layer is independent of implant dose for short-anneal times.

3. For long anneal times, the enhanced diffusion of the boron marker layer is lower for implant doses above the amorphization threshold as compared to implant doses below the amorphization threshold. The lower enhancements are believed to be due to dislocation loops, present only for the high-doses, which reduce the interstitial supersaturation.
4. For high-dose implants, the enhanced diffusion of the boron layer exhibits two time transitions. Initially, the enhancement in diffusivity is very large but decays very rapidly to a moderate value at which point the second transition begins.
5. The inert boron diffusion coefficient in the epitaxially grown layers used in this work is the same as the inert boron diffusion coefficient in FZ material indicating that the epitaxial material has a low oxygen content.

The ability of existing diffusion models in SUPREM-IV to simulate the effects listed above has also been investigated. When necessary, new models have been implemented into SUPREM-IV. The major improvements to SUPREM-IV are listed below:

1. A one-dimensional model for the growth of dislocation loops has been added to SUPREM-IV. This model has been used to simulate the reduced OED observed at 900ßC for 2 hours in a wet ambient. An activation energy for dislocation loop growth of 0.12 eV was extracted based on agreement between the simulation results and SIMS data as well as TEM data. The ability of the dislocation loop model to model uphill dopant diffusion has also been shown.
2. A nondilute equilibrium pair diffusion model has been implemented as the new full.cpl model in SUPREM-IV. To model the experimental data presented in this work, the two.dim model is sufficient. However, the new full.cpl model may still be important in modeling the effects of self-implants as well as dopant diffusion during very short time and very low temperature annealing.
3. The dislocation loop model has been modified to mimic interstitial cluster dissolution. By using this model for cluster dissolution along with the

two.dim diffusion model, the two time transitions in enhanced diffusion due to moderate and high-dose implant damage can be modeled.

5.2 Future Work

Although we have made considerable progress in understanding the interaction between implantation damage and dopant diffusion, there are still many issues which need to be resolved. Here, we suggest a few possible directions for future research.

1. In order to extract a more accurate value for the activation energy of dislocation loop growth, the blocking experiment could be repeated at various temperatures. However, careful control on the conditions of the amorphizing implant are necessary to ensure that only full dislocation loops are nucleated and that the formation of half-loops is minimized.
2. Currently, the model for dislocation loop growth only accounts for interaction with interstitials. Silicon nitridation, which is the direct complement of silicon oxidation in that nitridation injects vacancies rather than interstitials, can be used along with an antimony buried layer to determine whether or not a vacancy component needs to be added to the model for dislocation loop growth.
3. In this work, silicon was used to create implantation damage without the introduction of an electrically active species. In real device structures, silicon is rarely implanted. Instead B, P, As, Sb, and BF_2 are typically used. The experimental structure used in this study can be easily extended to investigate the effect of different ion species to create the implant damage.
4. BF_2 is commonly implanted to introduce boron into devices at an effectively lower implant energy to further reduce junction depths. The effect of the fluorine on gate oxide integrity for MOS devices has been extensively studied. However, the effect of fluorine on local point defect concentrations and dopant diffusion has not been as widely studied. We have performed a preliminary experiment that indicates the presence of fluorine results in reduced IED. An understanding of the interaction

between fluorine and point defects could result in additional applications for fluorine in semiconductor processing.

5. A very good test for future models of IED would be to combine the IED model with the model for dislocation loop growth and simulate the reduced IED when dislocation loops are present.
6. In Chapter 4 of this thesis, the focus was on modeling the time and temperature dependencies of IED while the dose and energy dependencies were not directly addressed. Since the enhanced diffusion was found to be independent of implant dose for moderate to high-doses, once a parameter set and initial condition have been optimized for one dose, the same parameters are used to simulate other damage doses of the same energy. To account for the dependence on implant energy, the scaled +1 concentration is allowed to vary. Currently, physical explanations for the dose and energy dependencies of enhanced diffusion are still lacking. Any theoretical calculation or numerical simulation which provides insight into either of these phenomena would be helpful.
7. Finally, the development of an experimental tool that can be used to characterize point defects and point defect clusters in the silicon crystal would be extremely valuable. Currently, our understanding of the physical processes that occur on an atomic scale during implantation is limited. We can only postulate on the initial point defect concentrations after implantation and the types of defects that form during annealing. Understanding which defects are important and how they interact with each other (in particular with point defect concentrations) are keys to unraveling the complex dependence of dopant diffusion on implantation damage.