TECHNICAL NOTE

RANGE DISTRIBUTIONS OF LOW-ENERGY NITROGEN AND OXYGEN IONS IN SILICON

A. R. Zomorrodian and F. Dehghani

Department of Physics
Faculty of Sciences
Ferdowsi Unviersity of Mashhad
Mashhad, Iran

Abstract The range distributions of low-energy nitrogen and oxygen (2-3 *keV*) ions is silicon are measured and compared with these available in theories. The nitrogen distribution is very close to a Gaussian distribution as predicted by theory. The oxygen profile however, indicates a surface localized peak along with a shoulder and a long tail into the sample. The surface peak is beleived to be the result of radiation induced segregation and the position of the shoulder corresponds to the peak of the theoretical distribution. The peak position in both profiles is very close to those obtained from the theories.

Key Words Silicon, Segregation, Nitrogen

چکیده توزیع یون های اکسیژن و هیدروژن با انرژی کم (۲ تا ۳ کیلو الکترون ولت) در سیلیسیم اندازه گیری و نتایج بدست آمده با محاسبات نظری این توزیع ها مقایسه شده است. توزیع نیتروژن در داخل سیلیسیم خیلی نزدیک به یک توزیع گوسی است که محاسبات نظری پیش بینی می کند. در توزیع اکسیژن در داخل سیلیسیم یک قله در ناحیه سطح با یک ناحیه بازو مانند مشاهده می شود که با دنباله ای بلند به داخل نمونه کشیده شده است. قله ناحیه سطح بدلیل برخورد یون ها با این ناحیه و نفوذ اتم های اکسیژن به طرف سطح از طریق کانال های ایجاد شده به وجود می آید و محل بازو همان موقعیت قله ایست که مطالعات نظری برای قله توزیع گوسی ارائه می دهد. محل قله ها در هر دو توزیع نزدیک به مقادیری است که به طور نظری پیش بینی می شود.

INTRODUCTION

Low energy ion surface interaction has many applications in many areas of thin film technology. These applications include sputter cleaning of surfaces, thin film doping, and reactive ion etching, to name a few[1]. Ion implantation also results in significant improvement on the corrosion and the wears behavior of several metals and alloys [2]. Further, the friction coefficient and wear rate can be reduced using light ion implantation [3]. Finally, with the development of microelectronic technology, semiconductor doping at low energy has become an important technique in very large scale integrated circuits (VLSI).

Although the implantation theory of Lindhard, Scharff and Schiott (LSS) [4] can be used to predict the depth profile of implanted ions, practically it is only a starting point. The ion implantation is a nonequilibrium process and can be affected by many factors such as the temperature and the quality of the target materials. In other word, ion-implanted materials do not always follow the criteria predicted by classical diffusion theory. Phenomena like differential sputtering and surface segregation affect the profile formation of the implanted species, causing the deviation of the

distribution from that of theoretical prediction.

Ion implantation theory, developed by many authors [5-7] predicts a normal distribution for most of the implanted ions inside the solids. These predictions are based on the energy loss mechanisms [8], which basicly are nuclear stopping and electronic stoppoing. Nuclear stopping is a result of implanted ions seeing the interatomic potential and energy loss calculations involve the cross section of the impacts. Nuclear stopping results when implanted ions lose their energies to the electrons of the target materials such that the electrons act as a frictional source for the motion of the ions inside the solids.

The nuclear stopping dominates at low energies (E = 10 to 3000 eV), while electronic stopping, which is mostly responsible for the depth of the implanted ions, is effective at high energies (E>10 keV). In both cases, however, the shape of the distributions is determined by the nuclear stopping. In fact, high energy implanted ions become low energy ions when they are about to stop in their path through the target materials.

For each distribution, one can define the most probable range for the implanted ions called Rp, or the mean value of the projected range which is the peak of the Gaussian distribution. Such distributions are ideal as predicted by theories. Practically, however, such profiles do not form during the implantation due to the effects of many different factors which are active during implantation [9-12].

Despite the development of microelectronic technology, silicon is still the major semiconductor element. In this work we have studied the low-energy nitrogen and oxygen ions implanted in silicon. Experimental data are presented and the distributions are compared with those predicted by available theories.

RESULTS AND DISCUSSIONS

Figure 1 shows the range distributions of 2keV nitrogen and oxygen ions in silicon. Both implantations were performed by 5×10^{15} ions/ cm^2 dose and at room temperature. The depth profiles were obtained by means of Auger Electron Spectroscopy (AES). The inert-gas ion-bombardment stripping technique was used, and a calibrated thickness of the material was removed by bombarding the surface with the probing ion beam. The amount of nitrogen or oxygen remaining in the sample was determined from the nitrogen or oxygen AES peak-to-peak height. The oxygen profile shows a very strong peak of implanted oxygen at the surface together with a weakening, (up to a full disappearance) of the Gaussian peak in the distribution. The nitrogen profile however, follows the theoretical distribution which is very close to a Gaussian one. Both distributions are extended by a long tail into the sample.

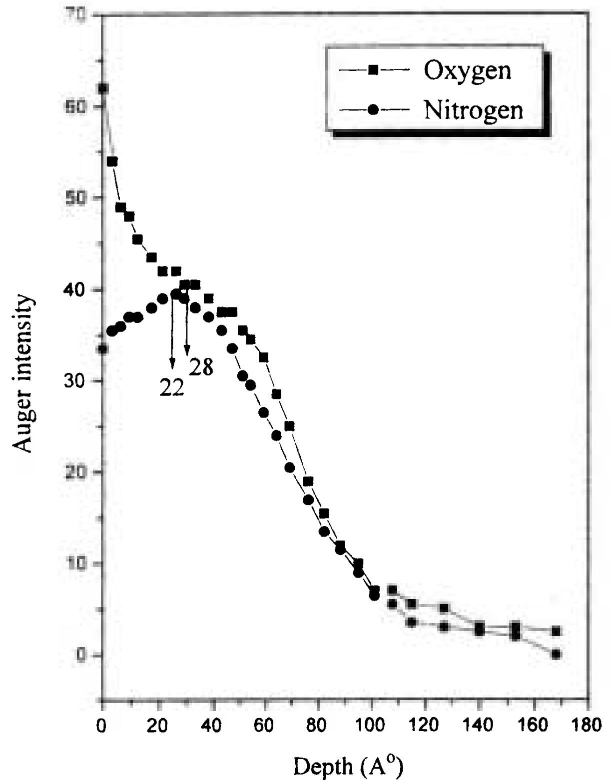

Figure 1. Range distributions of 2keV Nitrogen and Oxygen ions in Silicon.

A shown by others scholars [13], all possible

factors, other than radiation enhanced diffusion (RED), which could eventually lead to such segregation of the implanted species, are not active in the experiments. The creation of defects by implanted ions near the surface region causes the diffusion of the implanted ions to the near surface. The details of these mechanisms are described elsewhere [14,15]. Vacancies normally play the most important role in diffusion. The concentration of vacancies near the surface region is about $N_v \sim 5\times10^{18} cm^{-3}$. With a dose of about 1×10^{15} *ions/cm*^{2}, the concentration of vacancies per host atoms is $C_v \sim 1\times10^{-3}$. Similar experiments of nitrogen and oxygen implanted in silver and copper show the same surface localized peak at low energies [13]. In fact, to check whether the vacancies are responsible for the radiation induced segregation, defects were created by some inert atoms like neon and the diffusion of implanted species were monitored. Again, the surface peak appeared [16]. These findings imply that radiation induced segregation is to be responsible for the surface peak.

The long tail at the end of the distribution is believed to be due to the knock-on effect either during the implantation or during the sputtering where, the already implanted ions are pushed in deeper inside the target by the incident ions.

The peak of the distribution in the case of nitrogen and the position of the shoulder in the case of oxygen correspond to the peak of the Gaussian distribution predicted by theory. Values of Rp calculated by the available theories are listed in Table 1. The experimental values were taken from Figures 1 and 2 and the theoretical values were calculated from Schiott [6]. Considering the area of the error in the experiment, the agreement between the calculated and the experimental values of Rp is satisfactory.

TABLE 1. Calculated and Experimental Values of Rp for 2 and 3 keV Nitrogen and Oxygen in Silicon.

Rp	**Experiment**		**Theory**	
Energy	2keV	3keV	2keV	3keV
Nitrogen	22±4	38.5±4	26.4	39.61
Oxygen	28±4	37.5±4	22.5	33.75

In case of nitrogen, the distribution does not show the surface localized peak, but follow a normal distribution. The radiation enhanced diffusion appears weak in this case. The combination of host atoms with vacancies which results in the migration of implanted species to the near surface, is true if there is no chemical reaction between host and implanted atoms. If the incident ions and target atoms tend to form compounds, i.e., to attach to one another by chemical bonds, new phases may apear which become molecular-like complexes. These molecules are too large to be mobile and hence atomic diffusion is reduced.

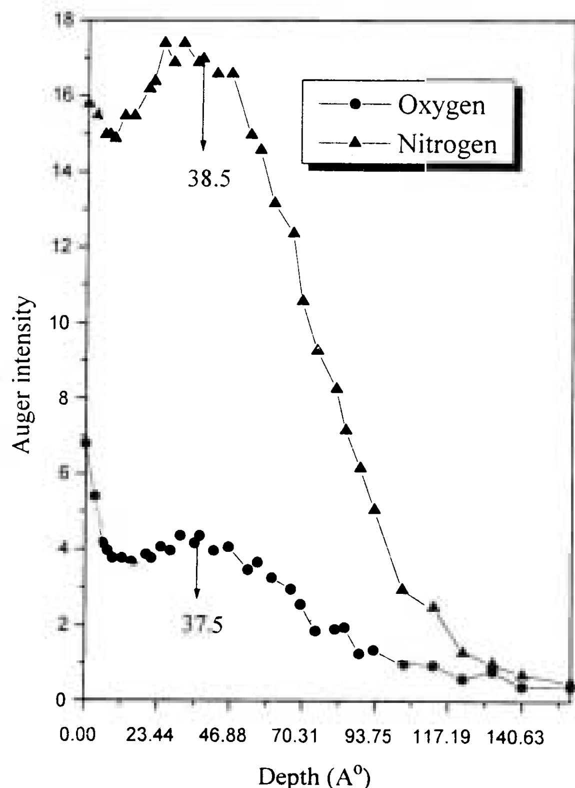

Figure 2. Range distribution of 3 *keV* Nitrogen and Oxygen ions in Silicon.

The formation enthalpies for silicon oxide is -23.8*Kcal/mole* and for silicon nitride is -177.7*Kcal/mole*. These values are related to one atom of O or N in the respective oxide or nitride. These enthalpies may be considered as a measure of the tendency of the metal to form an oxide or nitride specially at low temperatures, where the entropy factor plays an insignificant role.

Two oxides could form where oxygen is implanted in silicon; SiO and SiO_2. The formation of SiO_2 is less likely during ion implantation; the O_2 molecules dissociates upon impact at the surface (the dissociation energy is about 10*eV*) and practically atomic oxygens are implanted. On the other hand, due to low value of formation enthalpy for SiO, the RIS mechanism more likely dominates, resulting the surface localized peak in the distribution. In the case of nitrogen the large and negative value of formation enthalpy for silicon nitride readily causes the formation of this compound during ion implantation. The nitride formation reduces the RIS effect and hence, the distribution looks more or less simillar to a normal distribution.

CONCLUSION

We have studied the range distributions of low-energy light ions of nitrogen and oxygen in silicon. The radiation induced seggregation seems to play a major role in the distribution of oxygen into the silicon; forming a surface localized peak. In the case of nitrogen however, silicon nitride formation during the implantation prevents the diffusion of the implanted species to the near surface and the profile follows a normal distribution as predicted by theory.

ACKNOWLEDGEMENT

Experiments and measurements were performed at the University of Houston, Physics Department, U.S.A. The work was partially supported by R.A. Welch Foundation.

REFERENCES

1. A. H. Eltoukhy and J. E. Greene, *J. Appl. Phys.* **51** (8), (1980), 4444.
2. I. J. R. Baumvol, *Phys. Stat. Sol.* (a) **67**, (1981), 287.
3. S. Mohajerzadeh and C. R. Selvakumar, *J. Appl. Phys.* **81** (7), (1997), 3003.
4. J. Lindhard, J. M. Scharff and H. E. Schiott, K. dan. Vidensk. Selsk. Mat. Fys. Medd., **33** (14) (1963).
5. K. B. Winterbon and J.B. Sanders, "Radiation Effects," **39**, (1978), 39.
6. H. E. Schiott, Radiat. Eff. **6**, (1970), 107 .
7. P. Sigmund, *Rev. Roum. Phys.* **17**, (1972), 969, 17, (1972), 1079.
8. P. D. Townsend, J. C. Kelly and N. E.W. Hartley, "Ion Implantation, Sputtering and their Application.," Academic Press, New York, (1976).
9. D. G. Swartzfager, S.B. Ziemecki and M. J. Kelley, J. *Vac. Sci. Technol.*, **19** (2) (1981).
10. D. F. Downey, R. J. Eddy and S. Mehta, "Nuclear Instrument and Method in Physics Research, "Section B, **74**, (1993), 160.
11. R. S. Averback, M. Ghaly and H. Zhu, Conference "Phase Transition in Thin Films- Thermodynamics and Kinetic Symposium", **160**, (1993).
12. W. Schule, *J. Phys. F: Metal Phys.* **10**, (1980),2345.
13. A. R. Zomorrodian, S. Tougaard and A. Ignatiev, *Phys. Rew. B*, **30**, (1984), 3124.
14. S. Tougaard, A. R. Zomorrodian, L. Kornblit and A. Ignatiev, Surface Science, **152/153**, (1985), 932 .
15. L. Kornblit, A. R. Zomorodian, S. Tougaard and A. Ignatiev, radiation Effects, **91**, (1985), 97.
16. A. R. Zomorrodian, *J. Sci. I. R. Iran*, **7** (4) (1996).