(7A-4)

Two-Dimensional Modeling based on the Fokker-Planck Equation for Ion Implantation

Ikuo Saitoh and Nobuyoshi Natsuaki*
Central Research Laboratory, Hitachi Ltd.
Kokubunji, Tokyo 185, Japan

1. Introduction

The ion implantation technique is widely used in fabricating VLSI devices. To use wafers more efficiently and to integrate many components onto one chip, the components have become extremely small and their shape increasingly complex. Since smaller components have a shallower junction depth and therefore greatly influence device properties, details on not only range distributions but also lateral impurity distributions become very important. Therefore, a theoretical analysis of ion implantation is indispensable for VLSI device design.

To date, several computing techniques for the theoretical treatment of ion implantations have been proposed [1]-[4]. However, with these techniques, treatment of complex or multidimensional targets is insufficient, or requires much calculation time.

To improve on these points, this paper presents a new formulation, in which the Fokker-Planck approximation is applied for the first time to ion implantation and is solved numerically with the finite element method. The LSS theory calculates only a few moments of the distributions of ions, but the distributions cannot be determined from these moments. Using a Monte Carlo method, individual ion trajectories can be calculated but the resulting fluctuations usually need to be smoothed to get a practical distribution. In the so-called Boltzmann transport equation method, ion trajectories are statistically weighted, and the ions are treated like a fluid. These two methods treat details of individual ion movements, and therefore require many calculations.

2. Method

First, the Fokker-Planck equation method is briefly described.

The ion movements are given by the Boltzmann transport equation.

$$\frac{\partial f_a(x,v,t)}{\partial t} + v\cdot\frac{\partial f_a}{\partial x} + \frac{1}{m_a}\sum_b \rho_b f_b S_{ba}(v)\cdot\frac{\partial f_a}{\partial v} = \left(\frac{\partial f_a}{\partial t}\right)_c$$

where f_a is the distribution function and

$$\left(\frac{\partial f_a}{\partial t}\right)_c$$

is a collision term.

Scaling by the mean free path, the collision term of the Boltzmann transport equation is transformed to the Fokker-Planck equation.

$$\left(\frac{\partial f_a}{\partial t}\right)_c = -\frac{\partial}{\partial v}\cdot\left(f_a\frac{<\Delta v>}{\partial t}\right) + \frac{\partial^2}{\partial v\partial v}:\left(f_a\frac{<\Delta v\Delta v>}{2\Delta t}\right)$$

where

$$<\Delta v> = \int d(\Delta v)\Delta v P(v,\Delta v)$$

$$<\Delta v\Delta v> = \int d(\Delta v)\Delta v\Delta v P(v,\Delta v)$$

$P(v, \Delta v)$ is the transition probability during Δt, and the velocity v changes by a small Δv from v.

The Fokker-Planck equation is a diffusion equation in phase space. Therefore, for easier treatment of a complex shaped specimen, the Fokker-Planck equation can be discretized using the Galerkin method and then integrated by the forward Euler method.

As a nuclear potential, the Moliere potential is used and for the electronic stopping power, the Linhard formula, with a correction factor K/KL=1.59 for B, is used

3. Experimental data

(1) B+ ions were implanted using 25 keV to 150 keV energies, and oblique incident beams (6° off Si(100), rotation angle 127°)were used to avoid channeling.

(2) As+ ions were implanted using 10 keV to 50 keV energies, and oblique incident beams (7° off Si(100)) were used. (Nakata [5])

(3) P+ ions were implanted into a trench using an energy of 2.2 MeV followed by 10 min. of annealing at 900°C .

4. Results and Discussion

Comparisons of range distributions between the experiments and the calculations are shown in Fig. 1, and Fig. 2. These distributions are in good agreement with each other. On the other hand, the calculations [6] based on the LSS theory are incorrect. The differences between experiments and calculations at the tail region are due to channeling.

A two-dimensional profile of experimental data (3) is shown in Fig. 3, and the result of the calculation is shown in Fig. 4. In Fig. 3, the white lines represent the contour of impurity concentration on the order of 10^{17} atoms/cm^3 . The result of the calculation, as shown in Fig. 4, is in good agreement with the experimental data. It also shows that for the case of high-energy implantation into a trench, except for the side wall reflexion, which is negligible, invasion from the side wall is not negligible.

*Present address: Device Development Center, Hitachi Ltd. Oume, Tokyo 198.

5. Conclusion

A two-dimensional analysis technique for ion implantation using the Fokker-Planck equation was described for the first time. The results of the calculations were compared with those of experiments. The range distributions show good agreement and the two dimensional impurity concentration profiles show good agreement in both their order of magnitude and their shapes. This method gives very useful imformation for the designers of VLSI devices.

The authors would like to thank Tadashi Suzuki and Tadashi Kamata for their collaboration in these experiments.

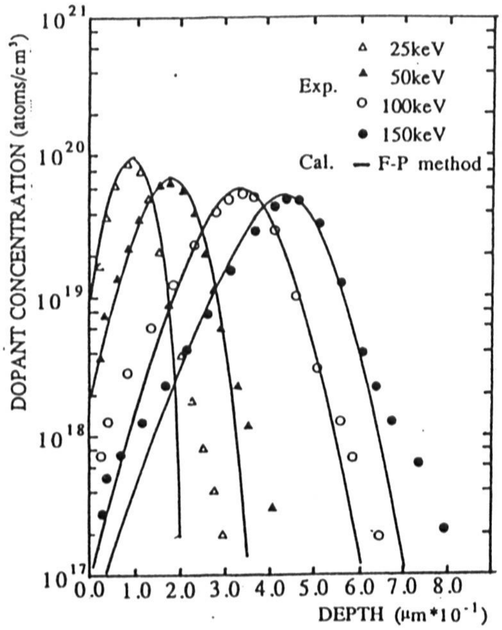

Fig.1. Range distribution comparisons between experimental data and calculations for B

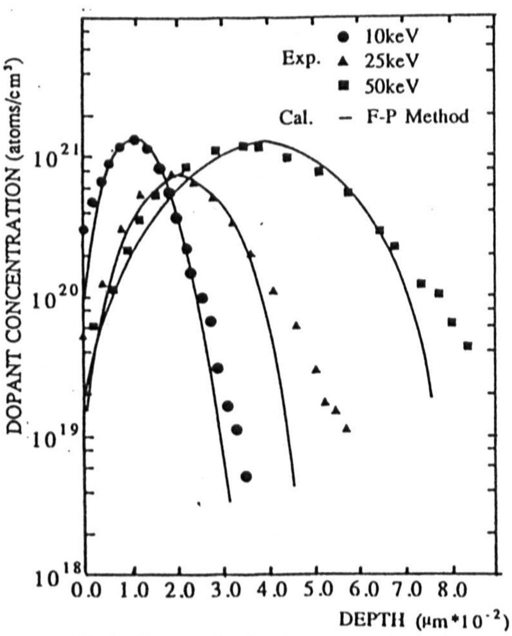

Fig.2. Range distribution comparisons beteen experimental data and calculations for As

6. References

1) J. Linhard, Mat. Fys. Med. Dan. Vidensk selsk, 33, No.14, (1963)
2) M. Makin, J. Nucl. Materials, 68, 161, (1977)
3) T. Ishitani, Phys. Letters, 46A, 487,(1974)
4) T. Takeda, IEEE Trans. EDL-4, 430,(1983)
5) J. Nakata, Japan J. Appl. Phys., 21, 1363, (1982)
6) J.Gibbons, "Projected Range Statistics", 2nd. ed., (Wiley, New York,1975)

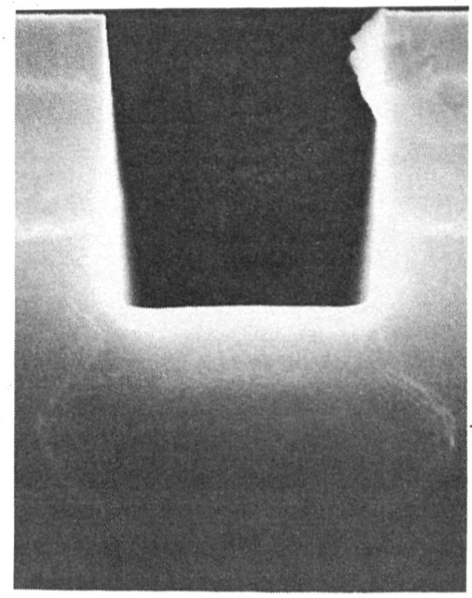

Fig.3. Impurity concentration profile by Etching-TEM

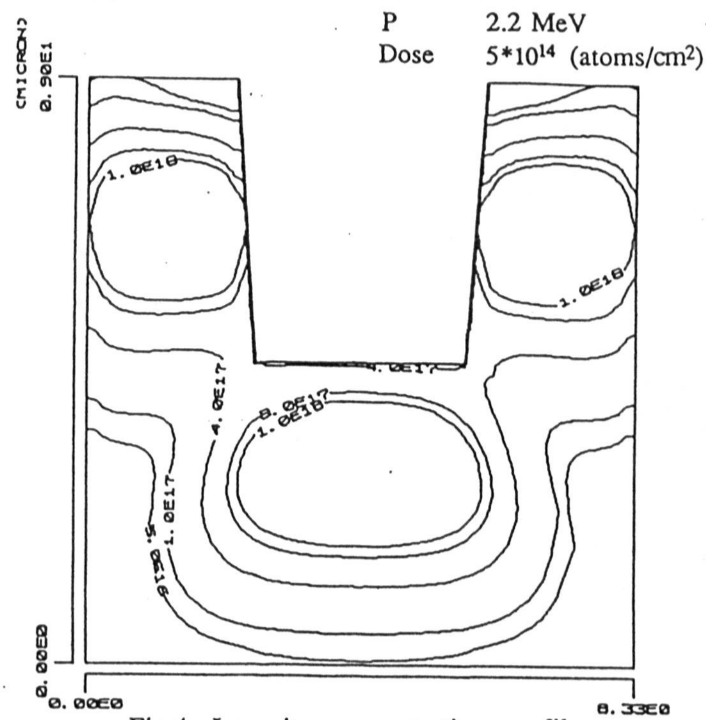

Fig.4. Impurity concentration profile by F-P method