2-D Simulation of Ion Irradiated Silicon Power Devices

P. Hazdra, J. Vobecky, F. Spurny, J. Voves
Department of Microelectronics,
Czech Technical University in Prague
Technicka 2, Praha 6, CZ-166 27, Czech Republic

Introduction

Both the ion and electron irradiation of power devices have already become a widely used practice to locally reduce the minority carrier lifetime. Device simulation taking into account the fully characterized deep levels and solving the complete system of trap-dynamic equations is necessary for efficient and accurate design of irradiation parameters, (i.e. ion type, irradiation energy and dose, annealing temperature, etc.).

Recently, an accurate 1-D simulation of fast ion irradiated (H+, He+) power devices was presented [1, 2]. The aim of this paper is to present a 2-D simulation of ion-irradiated silicon power diodes by means of S-PISCES-2B [5, 6]. Nowadays, ion irradiation technology is widely used in practice, but there is a lack of exact theoretical (simulation) background applicable on irradiation parameter optimization. The excellent predictive capability of this simulation system in a wide range of both the static and dynamic parameters means a breakthrough in this field.

1-D Simulation Principle

The simulation principle, described in more details elsewhere [2], consists of the following steps:

1) Primary defect generation (vacancy profile) determines the ion range and damage distribution. This is simulated using the ion-implantation Monte Carlo simulation code TRIM-90 [3], .

2) Secondary defect generation (vacancy-related deep levels) is covered by a special database based on an extensive set of experiments [4]. In the case of ion irradiation it performs a re-scaling of the vacancy profile into appropriate deep levels, characterized by their charge state, energetic position and capture cross-section. It is based mainly on the following assumptions [2].

- The majority of secondary defects are vacancy related. This is much more likely for helium compared to hydrogen.
- The shapes of primary defect and deep-level profiles coincidence closely.
- The number of defects increases linearly with the dose over the close range used in device applications.

The influence of irradiation dose, dose rate, and annealing temperature for both the CZ and FZ silicon is included as well.

3) The 1-D device simulation includes improved models of thermal generation/recombination based on SRH statistics and the complete solution of equations for an arbitrary number of independent single charged traps, where the recombination rates for electrons and holes are calculated separately. Deep level concentration profiles and charge states are also incorporated into the Poisson equation [2].

The lifetime profiles calculated by the 1-D simulator for the necessary bias steps (see Figure 1) are entered into the 2-D device simulator S-PISCES-2B [6]. This version of S-PISCES-2B did not include full trap dynamics. The lifetime profiles are used to account for non-homogeneities in irradiation dose that are attributed to irradiation facilities with very high irradiation energies, (e.g. the cyclotron that was used for these experiments).
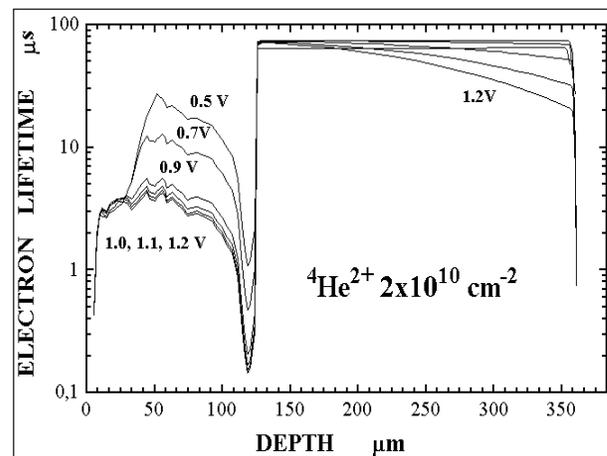

Figure 1. Spatial distribution of electron lifetime $\tau_n = \frac{\delta_n}{R_n}$ in the diode for the forward dc bias of 0.5, 0.7, 0.9, 1.0, 1.1, and 1.2V resulting from the 1-D device simulator.

2-D Simulation Principle

In order to include the influence of non-homogenous irradiation dose into a simulation, 2-D monitoring of the dose homogeneity was done using a special 3" matrix detector consisting of approx. 350 ultra-shallow P+N diodes [4]. Reverse currents generated by radiation defects within the diode space charge region were used to monitor a local irradiation dose. Final homogeneity of a defocused (cyclotron) He++ beam was estimated by comparison of the relative dose distribution and an average dose measured by the beam current integration (see Figure 2). The principle was tested on many different targets and ion species (e.g., H, He, B, Si) and shows excellent sensitivity and reproducibility. Figure 2 corresponds to 14MeV helium irradiation with the average dose of $2 \cdot 10^{10} \text{cm}^{-2}$.

A 2-D lifetime distribution necessary for 2-D device simulation is derived from the 1-D device simulator, including the full trap dynamics and multilevel recombination-generation model [1, 2] (see Figure 1) and the characterization of irradia-

tion dose homogeneity. As an example, Figure 3 shows the distribution of extracted 2-D electron lifetime for one half of a irradiated diode (total length 370μm, diameter of 40mm). The defect peak is clearly visible for distance of 140μm from the anode. The lifetime distribution from Figure 3 is converted into parameters governing the Shockley-Read-Hall recombination mechanism in S-PISCES-2B [6] with 2-D features conserved. Hence, the lifetime profile is resolved into 6 regions. Figure 4 shows the comparison of measured and simulated I-V curves for helium irradiated (16MeV, average dose of $5 \cdot 10^{10} cm^{-2}$) and non-irradiated diodes. The curve denoted as "1-D *simulation*" corresponds to the 1-D simulation when non-homogeneity of irradiation dose is not taken into account. Cubes and circles correspond to the measurements while the remaining line is from S-PISCES-2D. This way the quantitative differences between 1-D simulations and experiment may be eliminated. This principle may efficiently provide the "lifetime" input data for any 2-D device simulator without full trap dynamics capability. However, the calculations may be markedly improved if the latest version of the ATLAS device simulator is used.
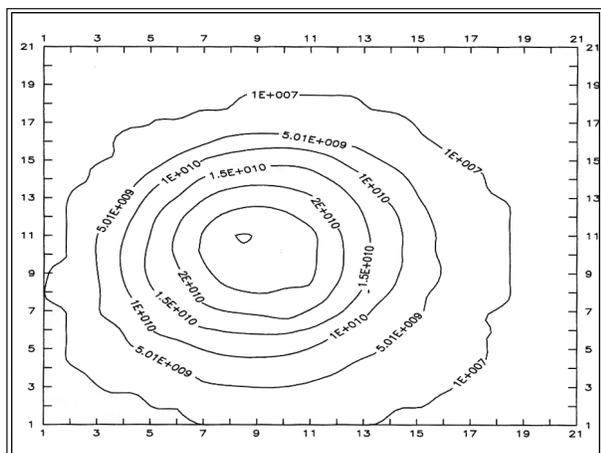

Figure 2. 2-D distribution of irradiation dose for helium irradiation (14MeV/2.10^{10} cm^{-2}). The numbers at coordinates belong to the individual detecting diodes on the wafer (the distance is 3.8mm). Isodoses are given at cm^{-2}.
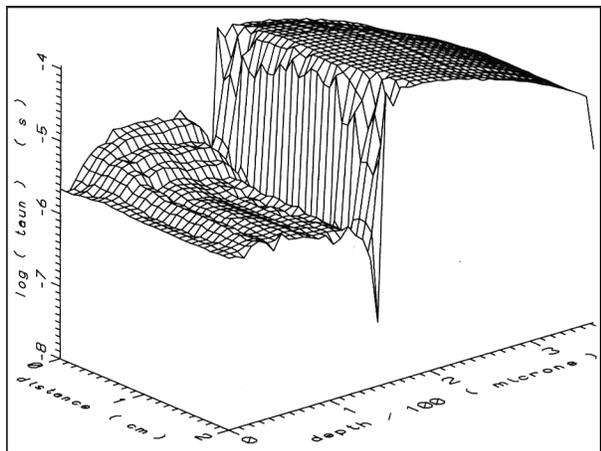

Figure 3. 2-D lifetime spatial distribution for helium irradiated diode to be extracted from 1-D simulations for doses corresponding to the Figure 2.
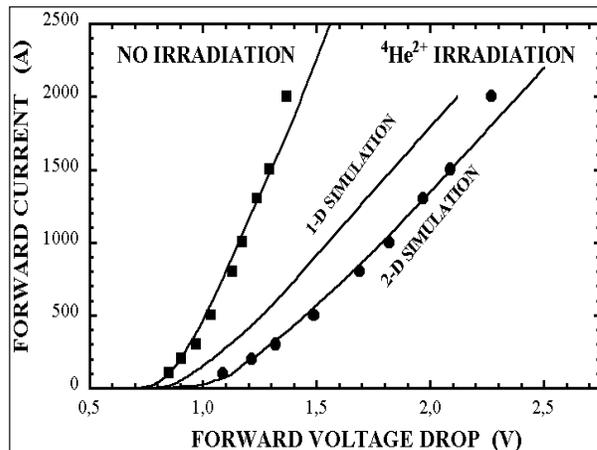

Figure 4. Comparison of the simulated (lines) and measured (points) I-V curves for helium and non-irradiated diodes.

Conclusions

Accurate simulation of devices subjected to ion irradiation has been described. The simulation system enables DC as well as transient analysis starting from the true technological parameters . No fitting procedures were required, except for adjustment of recombination centers of the starting material. This approach has shown very good agreement with experiment. In order to reach such satisfying agreement for other simulation conditions, (e.g. for devices with different starting material), the magnitudes of some parameters entering the device simulator should be changed [7]. These parameters are concerned with the relevant deep levels involved such as the emission and capture rates of individual defects, charge states, and magnitudes of the defect introduction rates. The irradiation dose range for which the simulations converge satisfactorily has a limit at $1 \cdot 10^{11} cm^{-2}$ for hydrogen and $5 \cdot 10^{10} cm^{-2}$ for helium irradiations. This completely covers that range important for power device applications.

References

[1] P. Hazdra and J. Vobecky, "Modeling of Localized Lifetime Tailoring in Silicon Devices", in: Simulation of Semiconductor Devices and Processes Vol.5, pp.437-440, Springer-Verlag Wien, 1993

[2] P. Hazdra and J. Vobecky, "Accurate Simulation of Fast Ion Irradiated Power Devices", Solid-State Electronics, Vol. 37, pp. 127 - 134, 1994

[3] J. F. Ziegler, J. P. Biersack and U. Littmark, The Stopping and Range of Ions in Matter, 2nd Edn. Pergamon Press, New York, 1985

[4] P. Hazdra, V. Haslar and M. Bartos, Nucl. Instr. Meth. Phys. Res. B55, p.637, 1991

[5] J. Vobecky, P. Hazdra, J. Voves, F. Spurny, J. Homola, "Accurate Simulation of Combined Electron and Ion Irradiated Silicon Power devices for Local Lifetime Tailoring", Proc. of the 6th ISPSD'94, pp. 265 - 270, Davos, 1994

[6] S-PISCES-2B, User's Manual, SILVACO Int., Santa Clara, 1992

[7] P. Hazdra, J. Vobecky, "Achievement of Quantitatively Accurate Simulation of Ion-Irradiated Bipolar Power Devices, Proc. of the SISDEP/SISPAD'95, Erlangen ,1995, accepted for publication.