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Achievement of Quantitatively Accurate Simulation of Ion-Irradiated Bipolar Power Devices

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Abstract

Quantitatively accurate simulation of He^{2+} irradiated power diode was achieved. The results have showed that accuracy of device parameter prediction depends essentially on accurate prediction of total defect concentrations and their projected ranges while other parameters, e.g. the defect profile shape, have been proved irrelevant. The $VO^{(0/-)}$ defect level was found to be dominant for devices febricated on low-doped FZ NTD n-Si.

1. Introduction

On SISDEP'93 we presented the original way of simulating behaviour of silicon devices that were subjected to hydrogen and helium irradiation [1]. The simulation procedure comprises primary defect generation by means of Monte-Carlo simulation code TRIM-90, re-scaling of the primary defect profiles into appropriate deep-level profiles by use of experimentally oriented database, and the device simulation with full trap dynamics involved [2]. This approach provided a good qualitative agreement when applied to hydrogen, helium, and electron irradiations and their combinations [3].

The main role of the experimentally oriented database, which is a key element of the simulation, is to predict the resulting defect electronic structure and its spatial distribution from primary damage deposition and information about both the material and irradiation procedure. It works with many parameters obtained experimentally (see e.g. [4,5,7]) with big scatter and various accuracy (e.g. deep level capture and emission rates). Moreover, many re-scaling algorithms (introduction rates and distributions of secondary defects, e.g. divacancies VV, vacancy-oxygen pairs VO, vacancy-phosphorus pairs VP, etc.) are hard to verify when we proceed to higher irradiation energies. Therefore, we focused our attention in this paper on influence of particular parameters and re-scaling procedure on simulation results. The sensitivity analysis performed and careful comparison with experiment provided us with information which parameter and re-scaling factor is crucial for the proper prediction of device operation and which is irrelevant. This information is of importance for those making tedious and expensive experiments for data extraction in order to improve their models and accuracy of input simulation parameters.

2. Experiment and simulation

The device under test was P^+PNN^+ $370\mu m$ long, 16 mm diameter power diode (2.5kV/100A) fabricated on <111> FZ NTD 110 Ωcm n-type silicon. The double-diffused p-layer ($8\mu m$, $N_A = 3x10^{19}$ cm^{-3}, $50\mu m$, $N_A = 5x10^{17}$ cm^{-3}) and diffused n-layer ($15\mu m$, $N_D = 10^{21}$ cm^{-3}) formed p^+ and n^+ emitter, respectively. The diode was irradiated from the anode side with defocused He^{2+} cyclotron beam with final energy 12 MeV at different doses ranging from $8x10^9$ to $6x10^{10}$ cm^{-2}. Helium irradiation was chosen because it results only in pure damage (vacancy-related) defect levels, the distribution of which follows that one of vacancies to be accurately simulated by available means.

The magnitudes of input parameters used for the simulation procedure [2] (defect activation energies, capture and introduction rates) we chose according to our own experimental results and carefully verified results from refs. [4 - 7].

Simulated output parameters were chosen according to standard measurements available. The forward voltage drop V_f was simulated for the dc current of 100 A from which the subsequent reverse recovery process was initiated. The reverse recovery current was decreasing with the slope of 100 A/μs by use of a resistive-inductive load. The reverse recovery time t_{rr} was determined in usual way from 90% and 25% of the maximum reverse current. The soft factor was defined as a ratio of the fall and storage time [2].

3.Results and discussion

Fig.1 shows VO pairs distributions in the irradiated diode predicted by our system (simulation II □) and measured by DLTS (■). In order to study the influence of the defect profile shape we narrowed (sim.I △) and widened (sim.III ◇) the FWHM while the integral defect density and projected range R_p, which was predicted with good accuracy, was unchanged. The simulated trade-offs of device parameters with the above mentioned profiles are compared with measured ones on Fig.2.

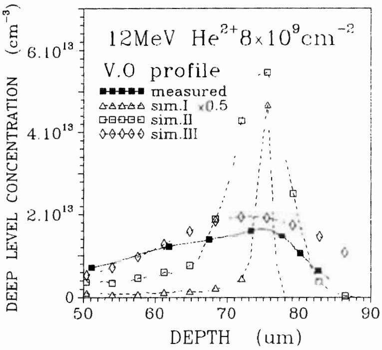

Figure 1: Predicted (□) and measured (■) profiles of $VO^{(0/-)}$. Simulation profiles (△, ◇) have the same R_p but different FWHM.

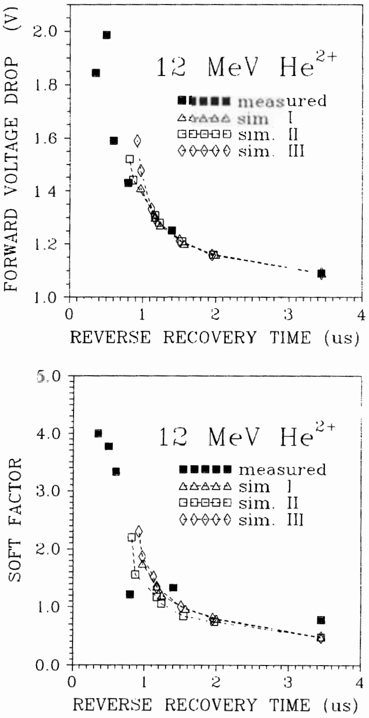

Figure 2: Measured (■) and predicted (□) V_f-t_{rr} (upper) and S-t_{rr} (lower) trade-off of 12 MeV He^{2+} irradiated P^+NN^+ diode. Data (△, ◇) correspond to level profiles with various FWHM (see Fig.1).

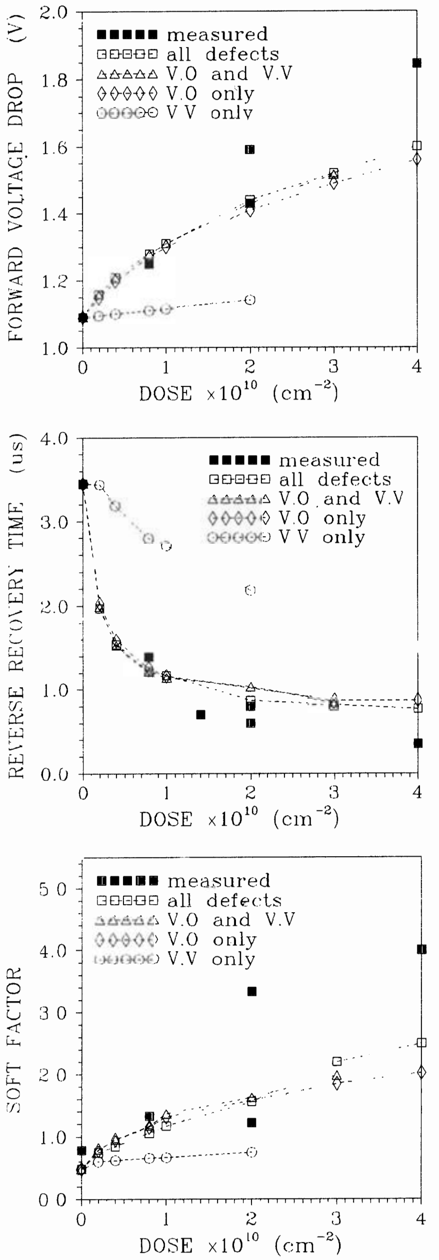

Figure 3: V_f (top), t_{rr} (middle) and soft factor (bottom) versus irradiation dose. Measured (■) and simulated data (sim. II) for all levels (□), $VO^{(0/-)}$ and $VV^{(0/-)}$ (△), $VO^{(0/-)}$ only (◇) and $VV^{(0/-)}$ only (○).

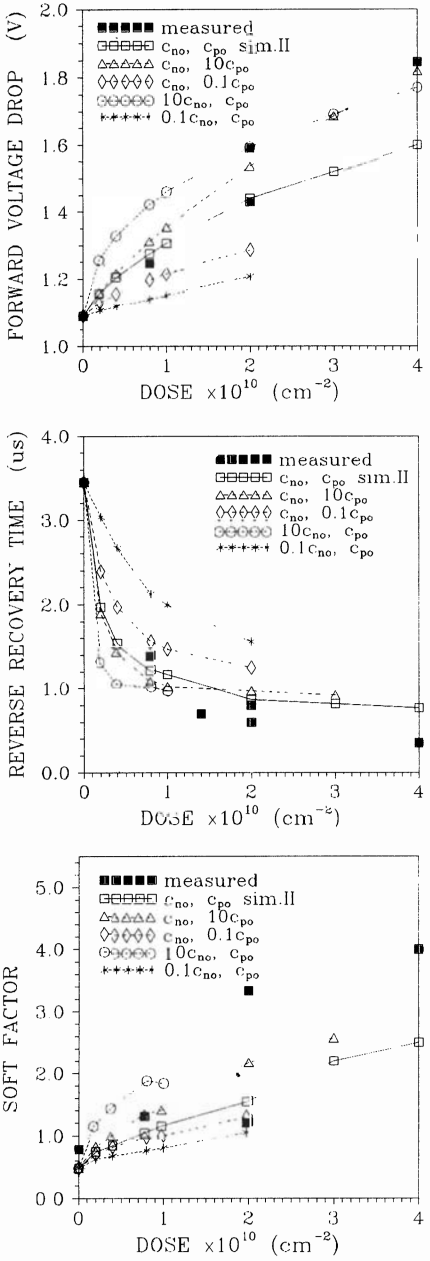

Figure 4: V_f (top), t_{rr} (middle) and soft factor (bottom) versus irradiation dose. Measured (■) and simulation (sim. II) data - capture rates c_{no}, c_{po} of level $VO^{(0/-)}$ were changed up/down by one order.

It implies that the defect profile shape is of less importance for achievement of accurate results. On the other hand, it is important to accurately predict both the projected range R_p [2], which affects the shape of the trade-off curve, and the total defect density that controls the position within a trade-off curve given by R_p. This means to know precisely an actual irradiation dose and defect introduction rate of particular defects.

The significance of individual radiation defect levels on simulation accuracy is clearly demonstrated on Fig.3. The simulations were performed for the following cases: all generally accepted defect levels resulting from helium irradiation (E1, E2, E3, H5) [2] are involved (□), two levels that are believed to be the most important ones, i.e. E1 ($VO^{(0/-)}$) and E3 ($VV^{(0/-)}$), are involved (△), and these levels are involved individually in (◇, resp. ○). These results clearly show that the VO pair is of the major importance for given starting material. It puts a clear insight into a widely discussed question concerning the defect take over from the angle of both the ON-state and reverse recovery parameters. Last but not least parameters to discuss are the capture rates the magnitudes of which are presented in publications with a rather big scatter. Fig.4 shows the agreement of measured parameters with simulated ones (sim.II) together with scatter of simulation outputs when the capture rates c_n and c_p of the VO pairs are 10 times decreased or increased. It corresponds to the range in which these rates are known from literature. It is clearly shown that c_n is important to know accurately in the first place. Further on, it is evident that capture rates are sufficient to be known with one digit accuracy.

4. Conclusions

Irradiation dose, defect introduction rate, projected range, and VO pair parameters were found relevant when quantitative agreement between measured and simulated parameters, describing both the ON-state and reverse recovery process, has to be achieved. The defect profile shape is irrelevant if both the projected range and integral defect density along the whole ion track are kept constant.

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