SIMULATION OF ION IMPLANTATION USING THE FOUR-PARAMETER KAPPA DISTRIBUTION FUNCTION

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ABSTRACT

A two-dimensional model for the simulation of ion implantation into arbitrary geometries has been developed. The four-parameter kappa distribution function was introduced the first time in semiconductor technology to describe the vertical dopant profile of implanted ions. Owing to the low computational effort and the short simulation time the given method is an alternative to modern Monte Carlo simulations for ion implantation processes.

THE ANALYTICAL ION IMPLANTATION METHOD

To describe the ion implantation profiles, a method based on distribution functions and their spatial moments is applied. For multilayer, non-planar structures we obtain the two-dimensional dopant profile by lateral convolution of a given vertical distribution function. Therefore the given simulation geometry is cut into slices which are arranged in the direction of the incoming ions (see Fig.1). In each slice of the discretized geometry the vertical distribution function is initialized using the numerical range scaling method according to the different target materials [1]. To get the final concentration $C(x,y)$ at the spatial coordinates we add up the lateral and vertical distribution functions by

$$C(x,y) = N_d \cdot \int_{-\infty}^{+\infty} f_{vert}(x,\eta) \cdot f_{lat}(y-\eta,x)d\eta, \tag{1}$$

where η is the lateral position and N_d is the implantation dose. Due to our convolution method we would loose dopants at the given geometry boundaries, so the simulation geometry is extended to avoid this loss of dopants and to satisfy the Neumann boundary conditions at the geometry boundaries. Arbitrary tilt angles for the incoming ions can be handled with this slab method for the initialization of the vertical distribution function [2].

THE FOUR-PARAMETER KAPPA DISTRIBUTION FUNCTION

There are several distribution functions to describe the vertical dopant profile. The Gaussian distribution or distributions using higher moments, such as the family of the Pearson distributions, are used to give an accurate fit to the implantation profiles. All these distributions are based on conventional central moments. In our approach described here we introduce the so-called "L-moments" the first time in semiconductor technology to specify statistical distributions [3]. These L-moments are analogous to conventional central moments but can be estimated by linear combinations of order statistics. L-moments are able to characterize a wider range of distribution functions and are more robust to out-liners of the given data set than central moments. These L-moments can be defined in terms of probability weighted moments β_r by a linear combination.

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The probability weighted moments of a given distribution are defined by

$$\beta_r = \int_0^1 x(F) \cdot F(x)^r dF, \tag{2}$$

where $x(F)$ is the quantile function and $F(x)$ is the cumulative distribution function. We use the four-parameter kappa distribution function as vertical distribution to fit the dopant profile, because analytical formulations exist for $x(F)$ and $F(x)$ [4]. The four-parameter kappa distribution is a combination of the generalized logistic, generalized extreme-value and generalized Pareto distribution and is given by

$$f(x) = \alpha \cdot \left(1 - k \cdot (x - \xi) / \alpha\right)^{(1/k)-1} \cdot (F(x))^{1-h}, \tag{3}$$

where ξ is a location parameter, α is a scaling parameter and h, k are shape parameters. The cumulative distribution function $F(x)$ is given by

$$F(x) = \left(1 - h \cdot \left(1 - k \cdot (x - \xi) / \alpha\right)^{1/k}\right)^{1/h}. \tag{4}$$

The estimation of the parameters of the kappa distribution using L-moments requires a Newton-Raphson iteration method, because no explicit solution of the probability weighted moments for the kappa parameters is possible.

SIMULATION RESULTS

We implemented our analytical implantation model into VISTA's two-dimensional process simulation tools [5]. Fig. 2 shows the one-dimensional comparison of a Boron ion implantation profile with several distribution functions and the dopant profile computed by modern Monte Carlo simulation. Fig. 3 shows the two-dimensional result of a Phosphorus implantation at 70keV and 30 degrees tilt. Comparing our analytical results with Monte Carlo simulations (Fig. 4) we found good agreement. Due to the neglection of the reflected particles in the mask sidewall region, we obtain a lower concentration in the silicon substrate. But we get a more realistic dopant profile over the whole distribution range, where Monte Carlo simulation can only give accurate results within two or three orders of magnitude. Also the computational effort is very low compared to Monte Carlo simulations; the simulation time was reduced with the analytical method by a factor of 10 on a DEC-3000/400.

ACKNOWLEDGEMENTS

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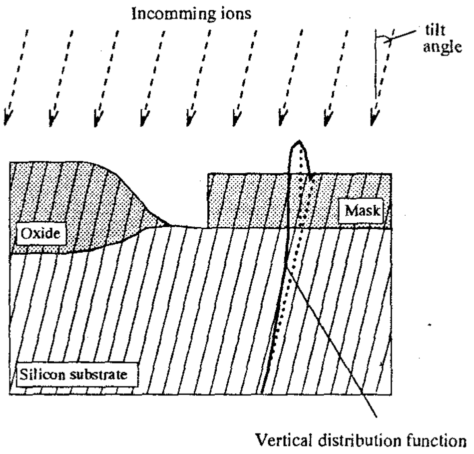

Figure 1: Discretization of the geometry using the slab method and the initialization of the vertical distribution function

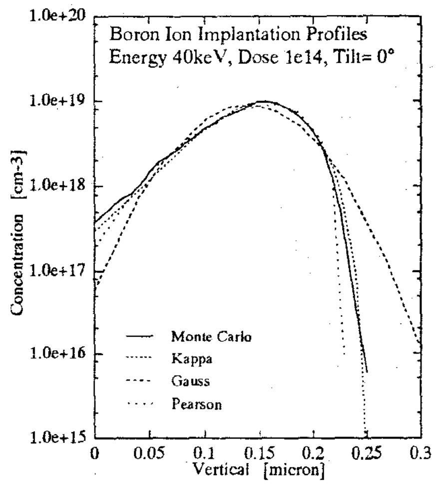

Figure 2: Comparison between analytical implantation profiles and Monte Carlo simulation

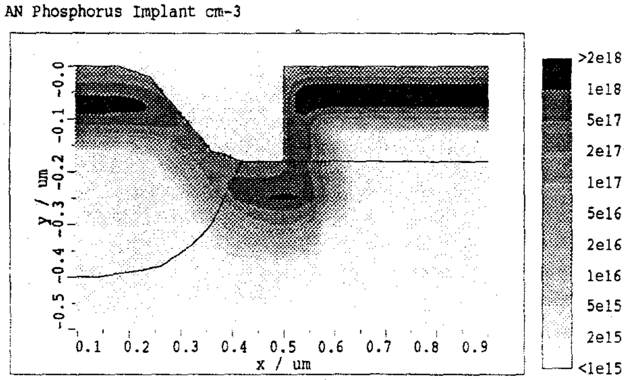

Figure 3: Two dimensional Phosphorus implantation profile with the analytical method (70keV,$10^{13} cm^{-2}$, +30° tilt)

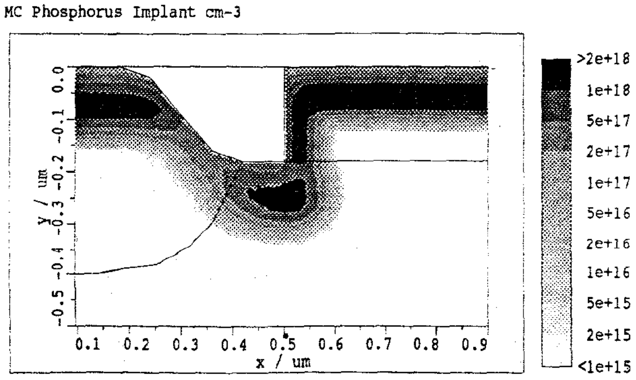

Figure 4: Two dimensional Phosphorus implantation profile with the Monte Carlo method (70keV,$10^{13} cm^{-2}$, +30° tilt)