Simulation Standard

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Very Low Energy Boron Implant Simulation Using New BCA Monte-Carlo Model

I. Introduction

ATHENA version 5.0 includes a new Binary Collision Algorithm (BCA) for accurate Monte-Carlo implant modeling down to sub-1keV energies. This new BCA code is a 3D model that takes account of channeling in all possible crystal directions, not just the vertical direction. Accurate modeling of all channeling directions becomes an important factor for low energy implants such as is used by the new generation of very deep submicron devices.

Typically for MOSFET applications using <100> silicon substrates and very low energy boron channel implants, in addition to channeling in the vertical direction, channeling also occurs in the <110> directions which includes a channeling direction along the surface of the crystal as shown in Figure 1.

This simulation assumed a 10A (1nm) native oxide on the surface and simulated all the implanted ions being implanted at the center point using a vertical beam with a simulated beam spread angle of $\pm$ 1 degree.

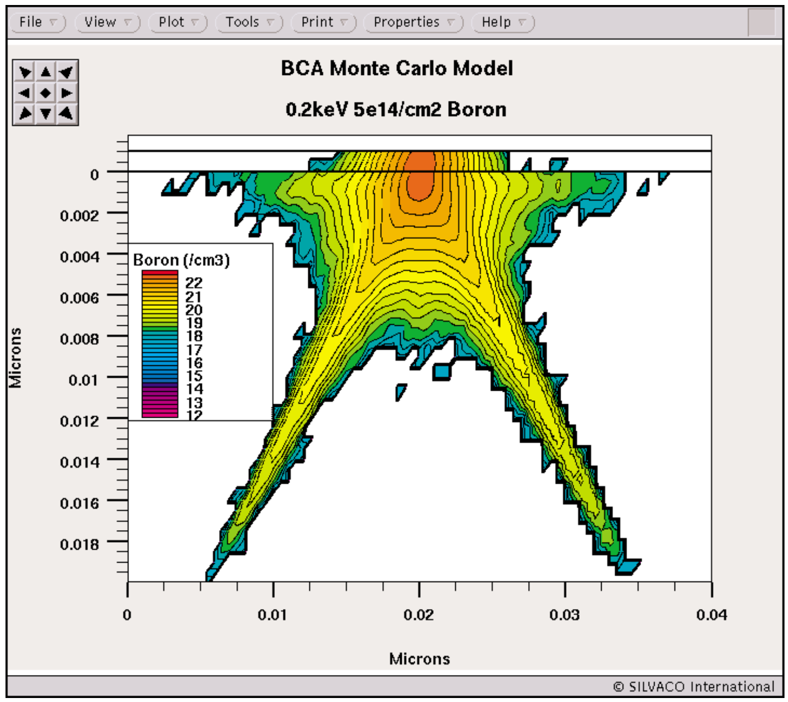

Figure 1. A point impact implant of 0.2keV boron to demonstrate channeling along the <110> planes

II. Measured Data

The output of the model was compared with published data from two separate SIMS studies using Implanters from Applied Materials and Eaton. The measured SIMS data is described in table 1.

The purpose of the germanium implants of 1keV and below was to pre-amorphise the surface layer of silicon to compare the profiles of the channeled data with non-channeled data. For energies of 1keV and above, another unspecified method was used to amorphise to a greater depth to prevent channeling.

The measured data showed several key features that were verified using the new BCA code.

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INSIDE

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Implanter	Species	Energy (keV)	Dose (/cm2)	Angle (Deg)	Substrate
Applied	B	0.2	5e14	zero	crystal
Applied	B	0.2	5e14	7	crystal
Applied	Ge / B	5 / 0.2	1e15 / 5e14	zero	crystal
Applied	B	0.5	5e14	zero	crystal
Applied	B	0.5	5e14	7	crystal
Applied	Ge / B	5 / 0.5	1e15 / 5e14	zero	crystal
Applied	B	1.0	5e14	zero	crystal
Applied	B	1.0	5e14	7	crystal
Applied	Ge / B	5 / 1.0	1e15 / 5e14	zero	crystal
Applied	B	1.0	5e14	zero	amophized
Eaton	B	2.0	3e13	zero	crystal
Eaton	B	2.0	3e13	7	crystal
Applied	B	2.5	5e14	zero	crystal
Applied	B	2.5	5e14	7	crystal
Applied	B	2.5	5e14	zero	amophized
Applied	B	5.0	5e14	zero	crystal
Applied	B	5.0	5e14	7	crystal
Applied	B	5.0	5e14	zero	amophized
Applied	B	10.0	5e14	zero	crystal
Applied	B	10.0	5e14	7	crystal
Applied	B	10.0	5e14	zero	amophized

Table 1. Measured SIMS data from Applied and Eaton used for validating the new Binary Collision Approximation Monte Carlo model.

- the SIMS profiles of boron implanted at energies of 1keV and below showed no discernable difference between implantation at zero degrees from the vertical and at 7 degrees from the vertical.
- implantation at energies of 2keV or greater showed a progressively increasing difference between implantation at zero degrees from the vertical and at 7 degrees from the vertical.
- implantation of boron into deeply amophized substrates showed no channeling tail, even down to concentrations of 1e16/cm^3 which was approximately the detection limit of the SIMS for the experiments.
- implantation into a surface layer amorphized using 5keV Ge with a dose of 1e15/cm^2 showed tails in the profiles below concentrations of approximately 1e19/cm^3.
- implantation at 0.2keV showed no difference between implantation in crystalline material and implanting into an amorphized substrate.

III. Simulations

All the simulations represented in the SIMS data above were simulated using the Binary Collision Approximation (BCA) model in ***ATHENA***. The model accurately represents the damage caused by previous BCA implantations. No special damage models are required to be specified in the input file when amorphizing with the germanium implants. The user simply implants germanium first which will amorphize the surface layer, then implants boron. The model automatically calculates the depth of the surface amorphous film is from the simulated damage profile.

In order to simulate implantation into completely amorphized silicon, a polysilicon substrate was specified rather than using self implantation of high doses and energies of silicon. Both methods would have given the same result, as the BCA model treats polysilicon material as amorphous. However using polysilicon results in a faster simulation since only one implant has to be simulated instead of two.

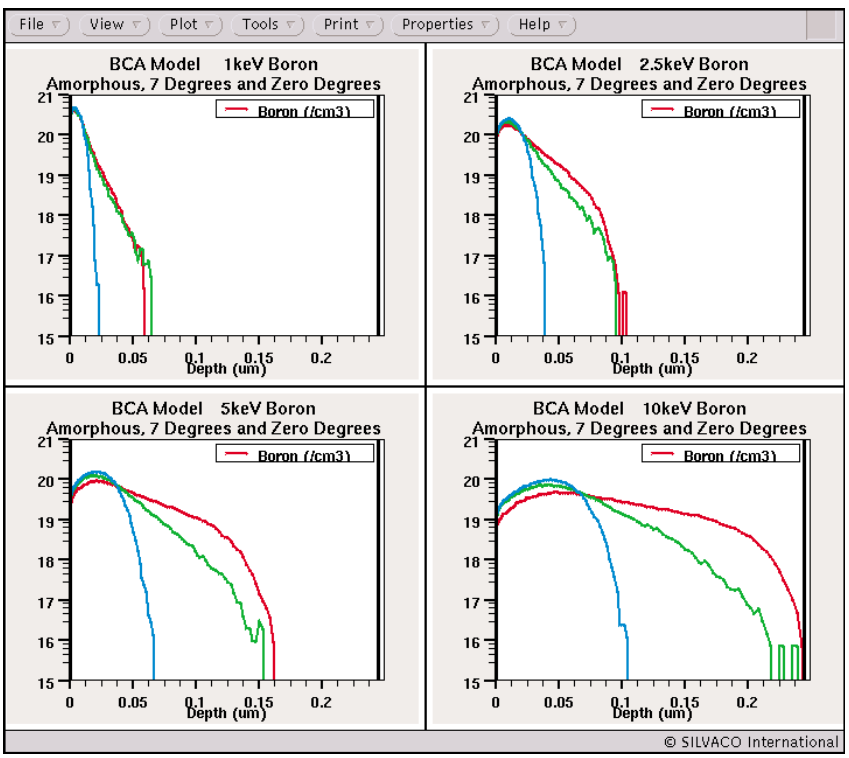

Figure 2 Simulated implants from 1keV to 10keV. The implant with the shortest range in each plot is using an amorphous silicon substrate. The implants with the medium range and longest range are into crystalline silicon at 7degrees and zero degrees repectively.

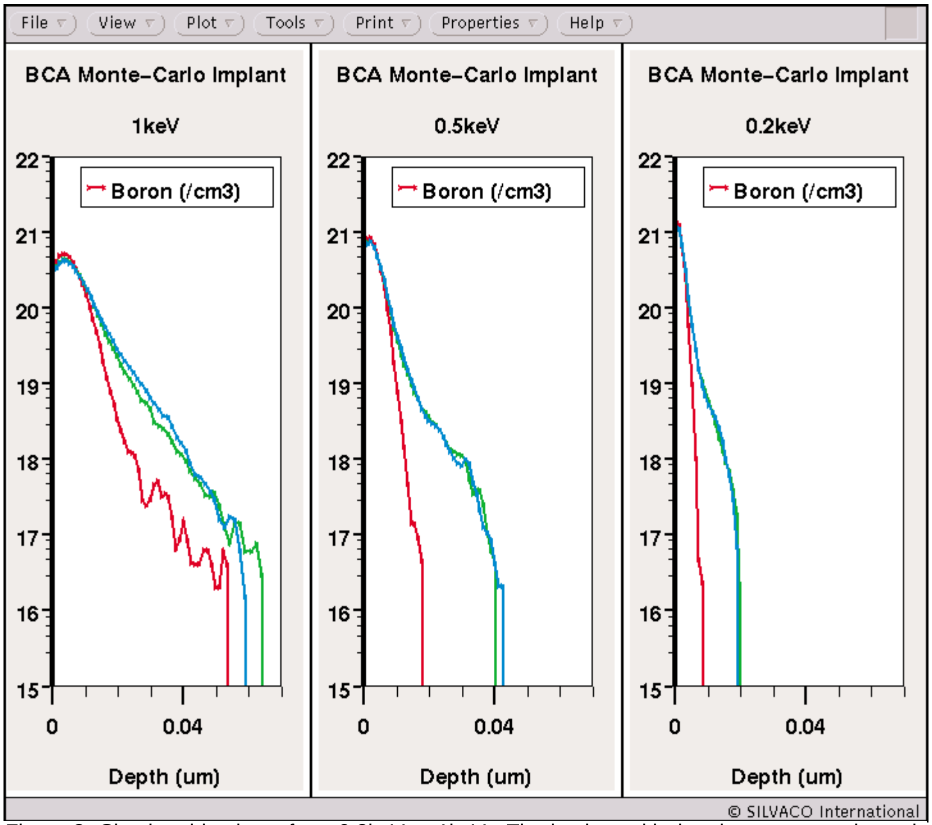

Figure 3 Simulated implants from 0.2keV to 1keV. The implant with the shortest range in each plot uses a 5keV germanium implant to pre-amorphise the surface film prior to implantation of boron. The longer range, overlapping implants are into crystal silicon at 7degrees and zero degrees repectively.

In the simulations a native oxide of 10 Angstroms (1nm) was assumed and a beam angle spread of $\pm$ 0.1 degrees.

(a) Simulations from 1keV to 10keV

Figure 2 shows simulations from 1keV to 10keV where the channeled profiles at implant angles of zero and 7 degrees are compared with simulations of a deeply amorphized substrate.

All the simulations in figure 2 show excellent agreement with the measured results both in form and absolute values. The implants at 1keV show little difference between implant angles of zero degrees and 7 degrees as shown by the measured data. At 2.5keV, differences between the two implant angles emerge, with an increasing difference at higher energies in the same manner as the SIMS data.

It is interesting to note the form of the implants into truly amorphous material. These amorphous implants all show a similar sharp cut off at the end of range of the implant both in the simulations and in the measured data. This point is highlighted as it is relevant to the discussion of the lower energy implants that follows.

(b Simulations from 0.2keV to 1keV

Figure 3 shows low energy implants from 0.2keV to 1keV. In these simulations, the "non channeled" implants were not implanted into a deep amorphous surface film as before but in this case only the top surface film was amorphized by implanting 1e15/cm^2 germanium at 5keV. If the 1keV "non channeled" data from this method is compared to the 1keV "non channeled" data obtained by implanting into a deep amorphous film, there is a difference in the tail of the implant profile, exactly as there is in the measured SIMS data.

Examination of the tail of the implant in the case where surface amorphization was created by implanting 5keV germanium shows a second point of inflection which is characteristic of channeling in this region. Implantation into a truly amorphous film results in a sharp cut off in the tail of the implant without a secondary point of inflection in the curve at the tail.

The reason the two 1keV "non channeled" data are different is because the 5keV germanium implant creates an amorphous surface film that is less than 100A (10nm) thick. Figure 4 shows the geranium implant profile. This is significantly less than the total depth of the amorphous profile of 1keV and so some channeling occurs in the tail of the implant.

Once again, the channeled data implanted at angles of zero and 7 degrees from the vertical (these overlay at energies below 1keV) showed good correlation with the measured SIMS data.

The only point of contention between the measured data and the simulated data is in the very low energy implant of 0.2keV. The measured data shows little difference between implantation into the germanium amorphized film and the channeled data. It might be suggested that because at very low energies the boron implant itself amorphises the film. The Monte-Carlo physics suggests that this might not to be the case. A possible explanation of the measured data is that the resolution limit of the SIMS profiling technique was reached. Further evidence that this is the case is suggested by the facts that:

(i) all the measured SIMS data for 0.2keV correspond to the channeled data in the simulations.

(ii) the measured data shows a clear secondary point of inflection in the tail which suggests that the vertical resolution limit approximated to the channeled data at 0.2keV as opposed to the non channeled data.

(iii) there is little difference in the measured data versus depth between the tail of the profiles at 0.2keV and the corresponding profile of the tails of the profile of the 0.5keV implant into the surface amorphized implant.

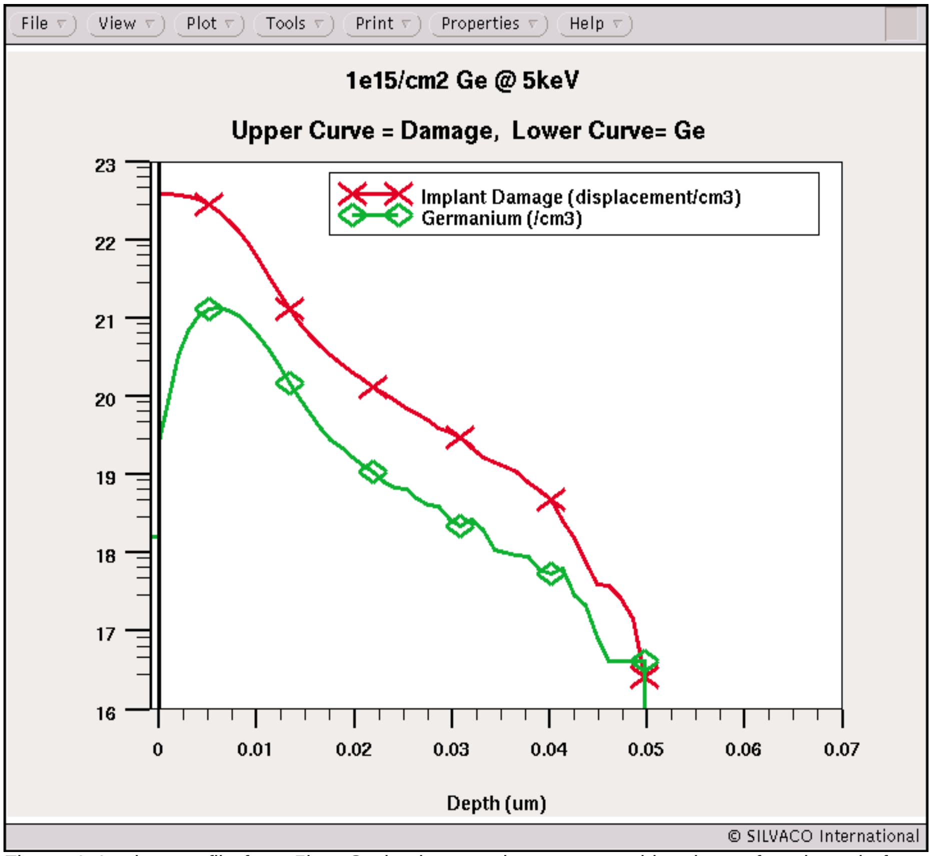

Figure 4. Implant profile from 5kev Ge implant used to pre-amorphize the surface layer before the low energy boron implants. The implant damage (which is distinct from point defect concentration) is also shown. Amorphization takes place when the damage reaches 50-60% of the substrate atomic concentration

IV. Conclusion

In conclusion the new Binary Collision Approximation implant model in ***ATHENA*** gives highly accurate results for low energy implants. A discrepancy between measured and simulated data at 0.2keV for implantation into a pre-amorphized surface film can only be resolved with repeated measurements with a better resolution limit.

To summarize, both measured and simulated data show that:

- boron implanted at energies of 1keV and below show no discernable difference between implantation at zero degrees from the vertical and at 7 degrees from the vertical.
- implantation at energies of 2keV and greater showed a progressively increasing difference between implantation at zero degrees from the vertical and at 7 degrees from the vertical as the implant energy increases.
- implantation of boron into deeply amorphied substrates invariably showed a sharp cut off of dose with distance near the end of range of the implant, regardless of implant energy. Any tail in this region is therefore strong evidence of channeling.
- implantation into a surface layer amorphized using 5keV Ge with a dose of 1e15/cm2 showed tails in the profiles which is strong evidence of channeling. 5keV germanium is therefore not sufficient to prevent channeling of implants above energies of 0.2keV.