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# Momentum Transfer Implantation for Sidewall Doping of FinFET's

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## 1. Introduction

The 2009 ITRS roadmap forecasts the introduction of FinFET technology by 2015.[1] One of the new fabrication challenges for FinFET's is sidewall doping, which has proven problematic based on shadowing, low implant efficiency and photo-resist strip issues. Shadowing is particularly important since it forces the implant angle to be around 10° which results in very low efficiency of retained dose. The reasons are (1) the sin$\theta$ effect, (2) reflection by scattering at the surface of the side walls and (3) sputtering.[2] Retained dose for 10-degree implant is estimated to be about 10%, which means FinFET's will require 20 times higher implant dose than planar FETs due to both the 10% efficiency and the 2-step implant for both sides of the fin.

Plasma doping was expected to solve this problem based on the presumption of conformal implant. Many experiments, however, have demonstrated that plasma doping cannot assure uniform dopant distribution. During plasma doping, the plasma sheath is formed parallel to the overall silicon wafer surface – not parallel to the much finer fin geometry. As a result, the momentum component of incident ions to the sidewall is based on only thermal motion in the plasma. Consequently, the sidewall doping occurs only by reflection.[3] Reference 4 suggests that sidewall doping occurs by electrons impacting the boron film. The momentum of electrons, however, is extremely small for this purpose. Another potential doping technique is thermal diffusion from a deposited boron film. Unfortunately, this technique cannot be expected to achieve high concentration given low thermal budgets; nor can it be used with CMOS due to low durability with photo-resist stripping.

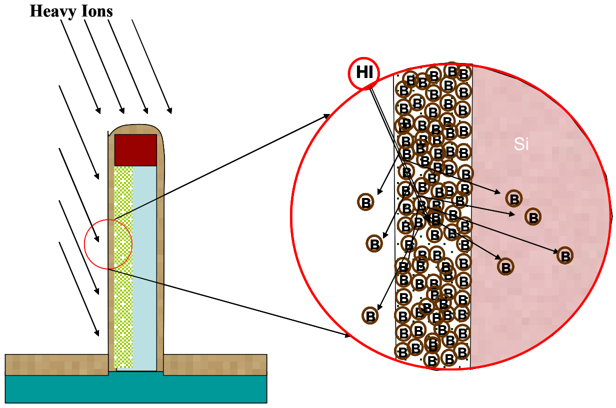


Fig. 1 MTI sidewall doping concept. Heavy ions are used to drive deposited boron atoms into the silicon crystal. The incident heavy ion stops inside the boron film or just inside the surface of the silicon.

Instead of direct ion implantation or plasma doping, a new method, Momentum Transfer Implantation (MTI) is being developed (Figure 1). MTI is accomplished by first depositing a thin boron or phosphorus film using plasma deposition. This is placed over the fin structure with a hard mask on top. The second step is to implant heavy ions, such as germanium or xenon, at a grazing angle from the side of the fin. The momentum of the heavy ions is then transferred to the boron or phosphorus atoms and drives them into the sidewall by recoil effect. The number of recoiled atoms per incident heavy ion is about 100 and more than 10% of them are implanted into the fin body. This grazing implant is then repeated on the other side of the fin to complete the doping process. Using this procedure, both sidewalls achieve precise dose control if the deposited film thickness is well controlled.

## 2. Experimental procedure

TRIM Monte Carlo simulation was performed to calculate depth profiles of boron, arsenic and displaced silicon atoms. For comparison, a boron film was deposited on a 300mm wafer using a plasma doping system originally developed by SHI. Then 60° tilt implantation of arsenic into the boron film was performed and SIMS profile of boron was taken to compare with the TRIM result.

Further TRIM simulation was done under the condition of 80° implant which is equivalent to the 10° implant as shown in Figure 3. In this case germanium and xenon atoms were selected as incident ions for boron and phosphorus films, respectively.

## 3. Results and discussion

Figure 2 shows depth profiles of boron, comparing the simulation result and SIMS result of the experiment. The concentration of boron by TRIM and experiment matches very well, especially in the region deeper than 5nm,

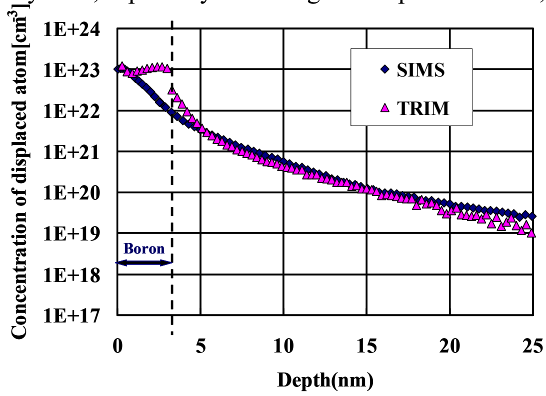


Fig. 2 Comparison of depth profiles of simulation and experiment for boron by MTI with germanium..

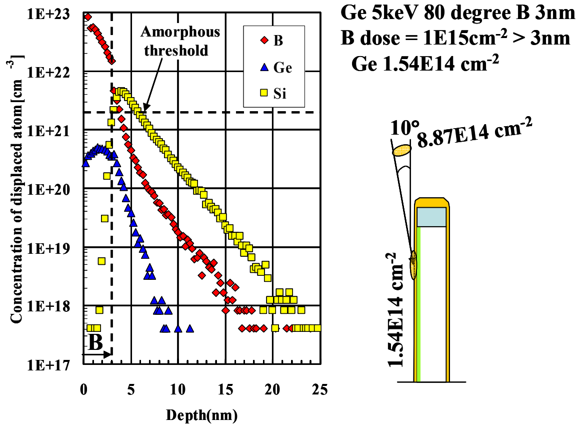

Fig. 3 Depth profiles of displaced B, Si and Ge implanted through a boron film of 3nm thickness.

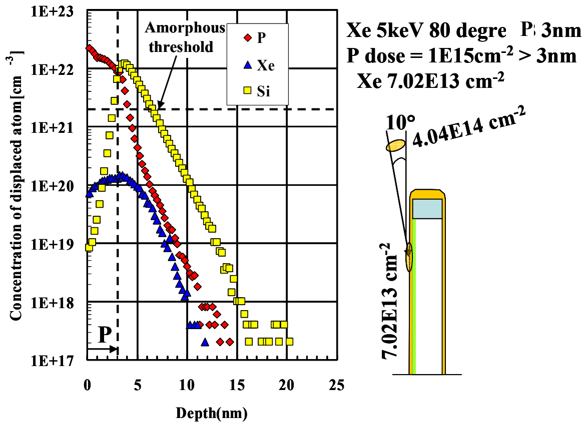

Fig. 4 Depth profiles of displaced P, Si and Ge implanted through a phosphorus film of 3nm thickness

which is 2nm in the silicon layer. This result indicates that the MTI approach does work for the sidewall doping and that TRIM simulation is reliable for analyses of MTI.

Results of further simulations are shown in figures 3 and 4. In both simulations, doses of incident ions were set so that residual dopant atoms inside the silicon layers become 1E15 $cm^{-2}$. The required implant dose for the boron and phosphorus films were 8.87E14 and 4.04E14/$cm^{-2}$ respectively for each sidewall, with the same implications as a normal implant at 10°. An actual dose of 8E15 $cm^{-2}$ is required for the direct implant of boron because of 30% loss due to reflection.[5] Xenon implant on phosphorus, however, is 2 times more efficient than germanium implant on boron. Based on these results, it's clear that the MTI technique reduces dose requirements by almost one order of magnitude, down to a level currently used in manufacturing. In Figures 3 and 4, amorphous thicknesses are less than 5nm if the concentration of displaced silicon is higher than 2E21 $cm^{-3}$.

Additional simulations were done to check dose dependences on various MTI process parameters, such as film thickness, implant energy and implant angle. The results are shown in Figures 5, 6 and 7. As expected, implant energy influence the final dose strongly. On the other hand, the dose is very insensitive to film thickness and implant

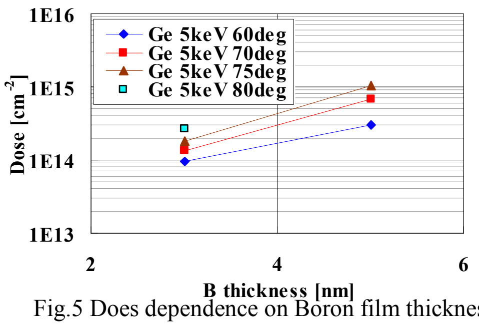

Fig.5 Does dependence on Boron film thickness

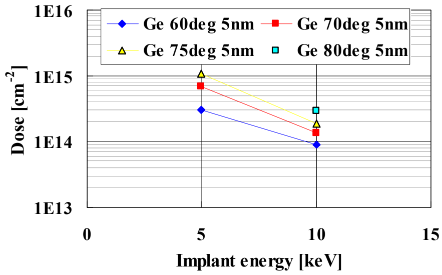

Fig. 6 Dose dependence on Implant energy

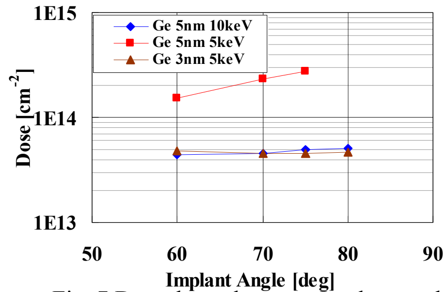

Fig. 7 Dose dependence on Implant angle

angle. This is advantageous since ion implanters generally provide very repeatable energy but are less precise in terms of angle control.

This technique of MTI is capable to apply the conformal doping for FinFETs, if the top side thickness of dopant films without a top cap is optimized.

## 4. Conclusions

It is clear that the MTI offers a promising alternative for sidewall doping of FinFET structures. MTI displays:

1. Much higher efficiency than conventional implant
2. Low sensitivity to implant angle and film thickness
3. High sensitivity to implant energy.

These observations suggest that good sidewall dose uniformity can be expected.


## Acknowledgements

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