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Invited

Implantation and Annealing Strategies for Ultra-Shallow Junction Formation

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1. Introduction

The 1998 update of the International Technology Roadmap [1] predicts drain extension depths in the 20-40nm range for the 100-nm technology node planned for production in the year 2005. Formation of such shallow junctions has already been demonstrated by optimizing conventional ion implantation and rapid thermal annealing [2-3]. The optimization consists of reducing the dopant ion-implantation energies to the sub-keV range (ultra-low energy, *ULE* implantation) [4] and of reducing the thermal budget by *spike*-annealing (minimizing the dwell time at temperature) [3]. Such strategies are not straightforward, however, and the implantation and annealing processes must be optimized both separately and together with respect to other process parameters as well, including manufacturing productivity. Examples of such considerations are presented.

2. Ultra-low energy ion implantation

Based on the dependence of transient-enhanced dopant diffusion on implantation energy [5] it might be concluded that the lower the implant energy the shallower the resulting junction. However, at too low an energy, such as 0.2-keV, a significant fraction of B is self-sputtered back out of the wafer during the implantation process [6] (Fig.1). Such a physical limitation, combined with the fact that both ion beam extraction and transport become increasingly more difficult with decreasing energy, imply that a slightly higher energy of 0.5-keV might be optimal for increasing productivity.

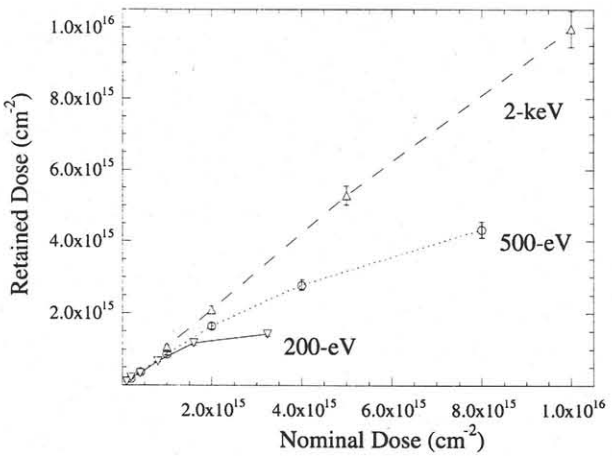

Fig.1 Retained B concentration measured using the *B(p, α)Be* nuclear reaction vs. nominal (target) dose. For a nominal dose of 1x10^{15} cm^{-2}, the retained dose is 20% less at 200eV, and 10% less at 500eV.

3. *Spike* rapid thermal anneals

Reducing the thermal budget by spike annealing ULE implants is advantageous since it promotes dopant activation while minimizing dopant diffusion [7]. In addition to minimizing the dwell time via a spike anneal, the thermal budget can be further reduced by aggressively increasing the ramp-up rate [2,3]. The benefit of increasing the ramp-up rate quickly saturates, however, since the ramp-down rate is usually limited to a much lower ramp-down rate (Fig.2), and because the dwell time, while minimized, remains finite [8]. Higher ramp-up rates also, necessarily, make the annealing process less repeatable and controllable in terms of achieving acceptable thermal uniformity.

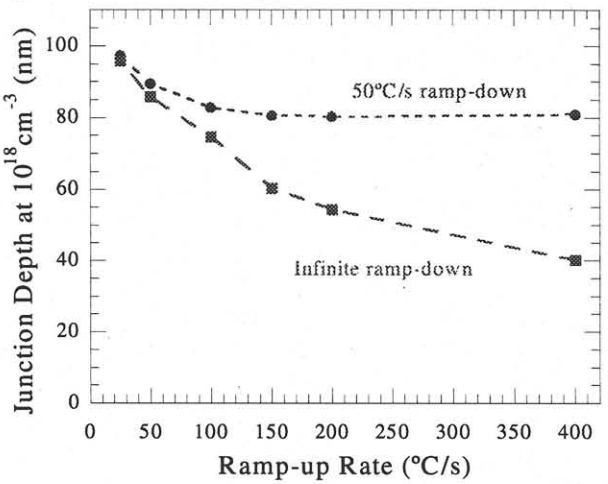

Fig.2 Simulated junction depth from spike-annealing a 1-keV, 1x10^{15} cm^{-2} B implant, as a function of the ramp-up rate, with a finite (50°C/s), or an infinite ramp-down rate [8]. TED physics was included in the simulation with the plus number set equal to 0.4 [8].

4. Optimizing implantation and annealing together

Some of the manufacturing concerns such as process repeatability and control can be addressed by optimizing the implantation and annealing processes together. For example, the advantages of increased ramp-up rates can in part be duplicated by modifying implantation parameters (Fig.3). A shallower junction can be achieved by spike annealing a slightly lower-dose implant instead of aggressively increasing the ramp-up rate. Of course, this results in higher junction resistivity but avoids the risk of poor process repeatability which necessarily accompanies the use of higher ramp-up rates. A survey of published spike-anneal data [8] from several sources [3,8-12] further illustrates the tradeoff between annealing parameters such as ramp-rates and implantation parameters such as dose and energy (Fig.4).

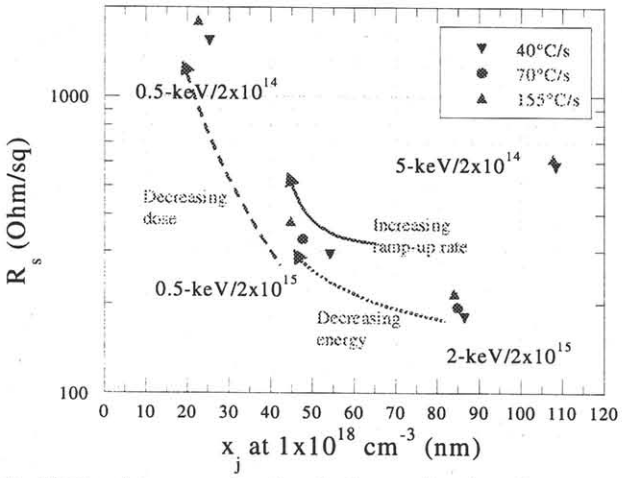

Fig.3 Sheet resistance vs. junction depth as a function of ramp rate, implantation dose and implantation energy [3,8].

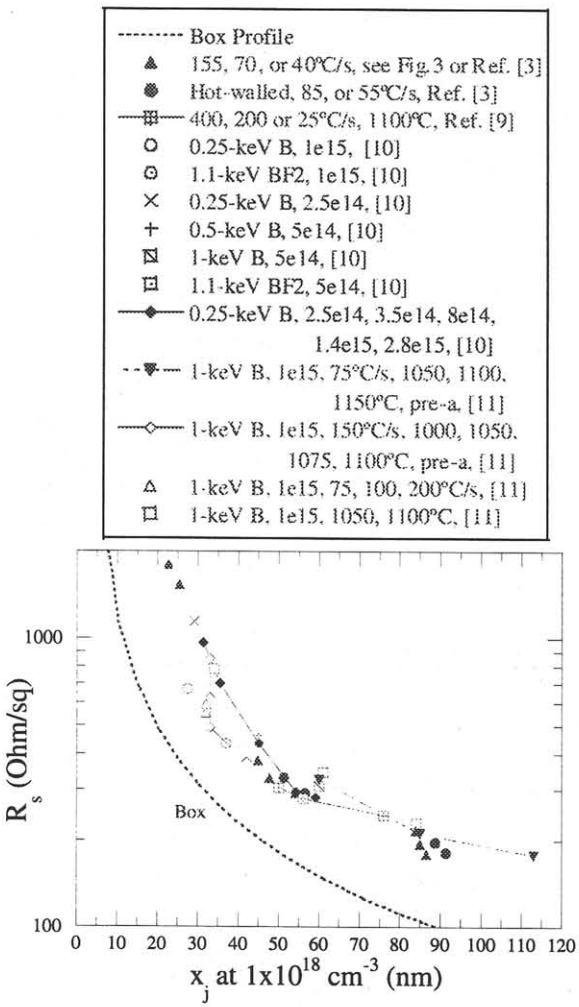

Fig.6 Comparison of sheet resistance vs. junction depth data from various sources [3, 8-12] illustrating similar general behavior and the non-uniqueness of any single process. The curve marked Box is a theoretical limit for a box-shaped B profile where the B concentration is equal to its solubility at 1050°C. Given the phenomenon of self-sputtering, it may be necessary to recalculate the quoted doses at the lowest energy of 0.25-keV.

5. N-type dopant deactivation

While it appears that the combination of ULE-implants and spike-anneals can achieve the desired junction depth targets, there remain some process issues to be addressed such as whether electrically active defects resulting from the implantation damage are adequately annihilated, or whether the spike-annealed junctions are stable enough during subsequent thermal processing [10] (Fig.5).

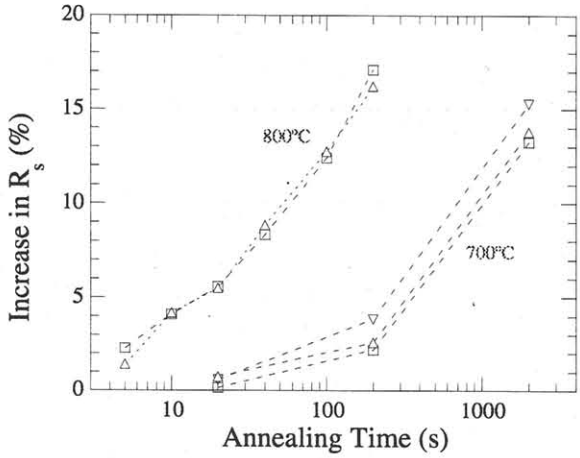

Fig.5 Increase in R_s, of an ultra-shallow junction formed by a 4-keV As implant and 1050°C spike annealing, during subsequent annealing at lower temperatures due to dopant deactivation and outdiffusion [13]. Multiple curves correspond to different ramp-up rates during the initial spike anneal.

6. References

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