Accurate and Direct SIMS Quantification in the First Few nm of Ultra Shallow Implants with Capping

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Abstract

Depth profiling of ultra shallow junctions has become an important application for SIMS in the recent years. Undoubtedly it is necessary to use low energy primary ions for this task and protocols with 500eV and below are well established. On the other hand, it is also well known, that there are several artifacts of SIMS-transient, influencing the depth profile in the very first nano-meters of depth [1].

In this contribution we propose capping as a way to accurate and direct measurement of implant shape, dose and junction depth with conventional quantification, even in the first nm. We will evaluate the stability of results with capping under different analytical conditions (with and w/o flooding, various sputter angles and energies).

SIMS protocols, sample preparation and corrections

As demonstrated in fig.1, the transient at the very beginning of a SIMS depth profile does not show the true distribution of the elements of interest. The transition width and the height of the initial spike vary with the analytical conditions like energy, angle or vac/flooding.

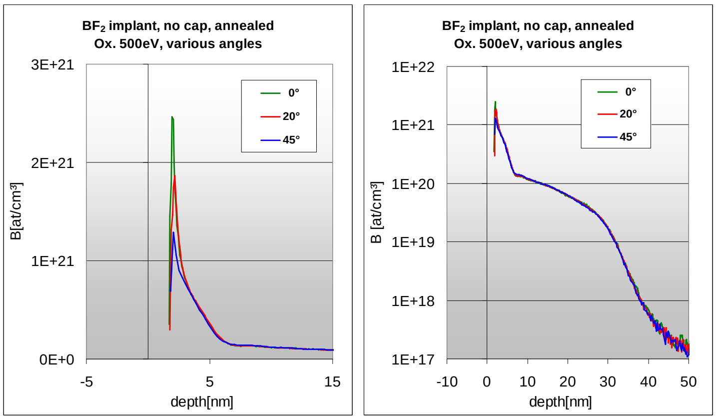

Fig. 1: One sample, three PI-beam impact angles: Without capping the transient is an important factor for USJ-measurement because most of the dose is located in the first few nm.

One easy way to avoid such artifacts is obviously to add some silicon onto the surface, e.g. with a sputter coater. The surface transient, until a steady state of dynamic SIMS conditions is achieved, will take place at the new surface. When reaching the point of interest, the original sample, there is no pile-up or shift anymore.

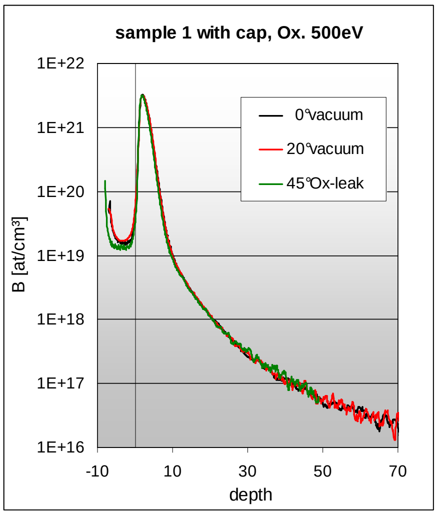

Fig. 2: One sample, three measurement conditions (all „fully“ oxydized): With capping the profile shape is independent of the analytical settings -as long as a sufficient depth resolution is maintained.

When measuring under conditions of “full” oxidation, e.g. 500eV oxygen beam at <20° from normal incidence or with oxygen flooding, the method is very robust: very similar profiles for all three conditions (fig. 2). Measurement at 0° and 20° were carried out with a CAMECA 4550 quadrupole SIMS instrument, the measurement at 45°with flooding on an IMS6f (magnetic type instrument) with low energy attachment.

The direct comparison of capped and non-capped sample (fig. 3) unveils the advantage: there are significant differences in the first nm of ultra shallow implants deriving from different process parameters - valuable information for profile and diffusion modeling.

Another advantage of capping is the ability to detect the position of the original surface while monitoring a contamination, e.g. carbon or hydrogen, which is always present. One can obviously measure the real (junction) depth relative to the surface.
The main disadvantage of sample capping is adding sample preparation which is typically not necessary for SIMS measurements.

Based on experience it should be possible to get the desired information (dose, junction depth AND profile shape) from the measurement of a non-capped sample. There are several ways to reconstruct the “true” depth profile when capping is not applied.
The simplest step is to add the so called “surface shift” [2], app. 2nm under typical conditions. It is derived from a direct comparison of capped and non-capped samples. The simple approach of surface shift corrects the depth scale and therefore allows the measurement of X_j.

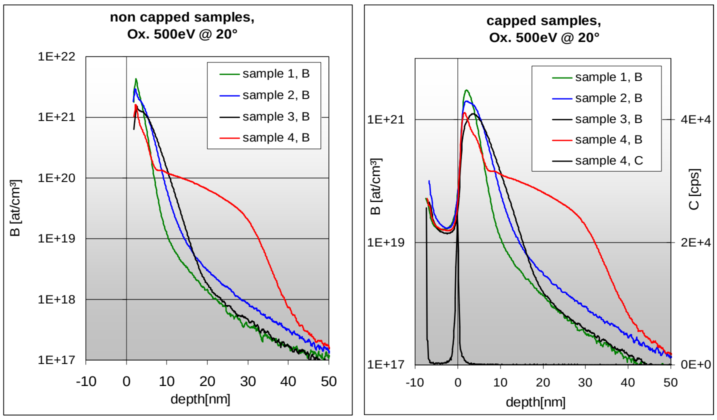

Fig. 3: Four ultra shallow boron implants, three as implanted, one annealed, measured with and without capping. Capping provides the full boron profile. The carbon signal monitors the interface between cap and the original surface.

Other models introduce a non-linear correction of the depth scale in the first few nm and compensate the artificial spike at the same time. This transient correction can lead to a profile shape close to reality (fig. 4). On the other hand, to the knowledge of the authors, there is no published and generally accepted algorithm for this kind of conversion. It can be useful in routine process control where the kind of sample is well known, in a scientific sense it remains a bit dubious.

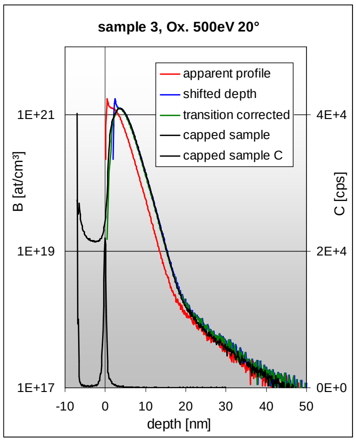

Fig. 4: The apparent profile must be shifted to achieve the correct junction depth. Further mathematics reconstruct the shape (green line). Monitoring contamination at the interface, e.g. carbon, the capped sample can clearly show the absolute depth scale.

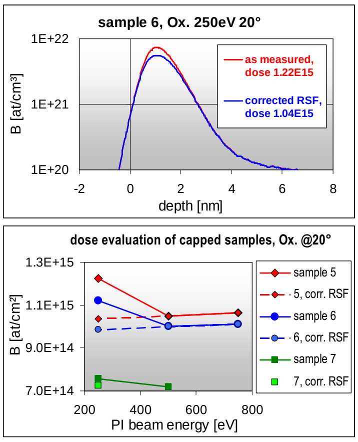

Fig. 5: At 20° and PI-beam energies above 500eV the RSF of B/Si is constant. For lower beam energies a correction, depending on the B concentration, is applied. At 500eV oxygen beam some broadening of the peak is already observed (not shown here).

At very high boron concentrations (app. 1E21at/cm³ and above) matrix effects on the RSF of B/Si occur, also for analytical conditions with full oxidation. Without RSF-correction the concentration of B is overestimated [3]. For PI-beam energies below 500eV (at 20°impact angle) a correction is necessa ry. The RFS correction recovers the profile (fig. 5 top) and the true dose is measured. By the expense of depth resolution, it is also possible to measure the dose directly using a high energy beam to ‘dilute’ the high concentration layer (fig.5 bottom).

Summary

SIMS depth profiling can determine both: accurate dose and junction depth of ultra shallow implants. Under fully oxidized conditions it is possible to compensate the transient and the matrix effect of high boron concentration on RSF.
Sample capping provides a very robust protocol. It takes advantage of an interface marker and can therefore directly measure the junction depth. It does not suffer from transient effects and measures therefore the undisturbed profile at the original sample surface.

Acknowledgenments

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