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# On artefacts in the secondary ion mass spectrometry profiling of high fluence $H^+$ implants in GaAs

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ABSTRACT

High fluence (>$10^{17}$ H/cm$^2$) ion implantation of H in GaAs is suitable for the ion cut process, and produces H bubbles under the surface which may cause blistering. By comparing the destructive depth profiling of these implants by secondary ion mass spectrometry (SIMS) with non-destructive profiling by elastic recoil detection analysis (ERD), we demonstrate that SIMS underestimates total H content by up to a factor of 2 due to undetected H escaping from bubbles during analysis. We also show that the depth of the maximum H concentration from SIMS can be in error by 20% due to large variations in the sputter rate through the profile.



## 1. Introduction

It is well known that implantation of hydrogen into metals and semiconductors can lead to blistering and exfoliation of the surface [1]. Depending on the implantation conditions, the blisters are formed either during implantation or after subsequent annealing. Transmission electron microscopy (TEM) analysis has shown that the implanted hydrogen agglomerates into planar defects called platelets [2]. As the material is annealed, the platelet defects grow and evolve into hydrogen-filled microcavities. Eventually, the pressure in the microcavities becomes sufficient to cause permanent deformation of the material, and blisters appear on the surface. If a material is implanted with hydrogen, bonded to another substrate and annealed, the microcavities coalesce to form microcracks, which propagate through the material and eventually lead to delamination of the wafer around the projected range of the ions [3]. This layer transfer technique, trademarked "Smart Cut", has been developed for the industrial manufacture of silicon-on-insulator wafers and was shown to be transferable to a host of other materials – including GaAs [4] and SiC [5]. GaAs in particular, is of interest to the semiconductor industry due to the potential for integration of optical and electronic devices on a single chip [6].

In contrast, the suppression of this process is sought-after by the nuclear industry to ensure the longevity of reactor materials [7,8]. In either case, reliable hydrogen depth profiles are highly desirable for understanding the underlying mechanisms so that the process can be either optimised or suppressed. Of the techniques available for depth profiling hydrogen, two of the most widely used are elastic recoil detection analysis (ERD) and secondary ion mass spectrometry (SIMS). Both SIMS [9–12] and ERD [13–16] have been used for depth profiling of hydrogen in studies of blistered material. Several nuclear reaction analysis (NRA) methods are also available for depth profiling H and these have been shown to give equivalent results to ERD [17].

We compare depth profiles of hydrogen obtained by SIMS and ERD in blistered and unblistered samples of GaAs. We will show that SIMS underestimates the H content, particularly in blistered samples, and that the depth scale is seriously distorted because of topography effects in the implanted region.

## 2. Experimental

In this work, semi-insulating GaAs wafers were implanted with 190 keV $H_2^+$ to a dose of $1 \times 10^{17}$ H/cm$^2$ at a target temperature of 180 ± 15 °C and at fluxes of $3.3 \times 10^{12}$, $9.8 \times 10^{12}$, $1.4 \times 10^{13}$ and $2.5 \times 10^{13}$ H/cm$^2$/s, using a Danfysik 1090 ion implanter. Samples from each wafer were studied by Nomarksi microscopy and scanning electron microscopy (SEM) using a Hitachi 54000 SEM at 20 keV to investigate surface blistering and exfoliation after implantation.

The hydrogen content of samples from each of the wafers was measured using a PHI Quadrupole SIMS instrument at Cascade Scientific Limited, UK. The primary ion beam was 350 nA of 4 keV $Cs^+$ at an incident angle of 60°, with the sample being static during the

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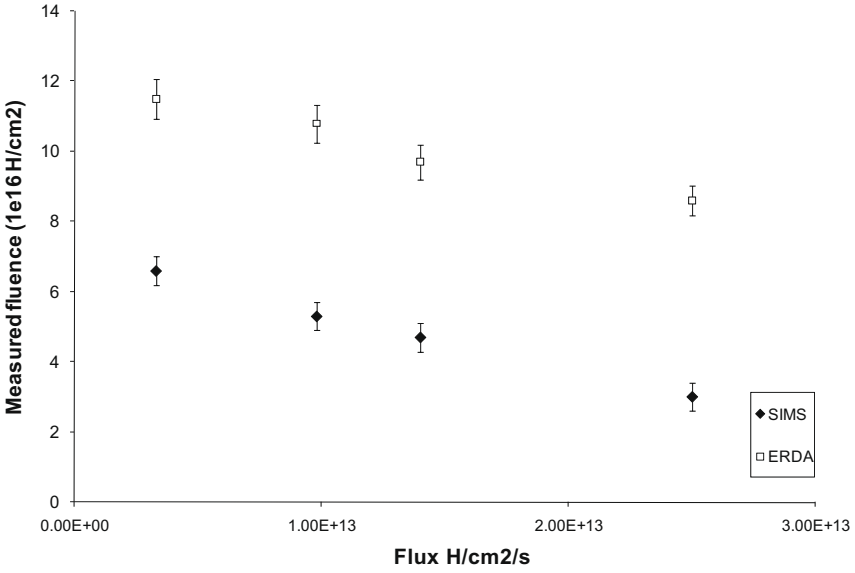


**Fig. 1.** Hydrogen fluence measured by SIMS and ERD as a function of flux of implanted H, for GaAs wafers implanted $H_2^+$ with 190 keV at a nominal dose of $1 \times 10^{17}$ H/cm$^2$ and at 180 °C.

measurement. The conversion of the measured secondary ion counts to concentration was achieved using relative sensitivity factors (RSFs). The elemental concentrations were derived from ion implanted GaAs reference material from Evans Analytical containing $2.5 \times 10^{15}$ H/cm$^2$, which is a fluence sufficiently small to preclude blistering [5]. The depth scales were constructed by assuming a constant sputter rate calculated from the depths of the analytical crater. The crater depths were determined from stylus profilometry using a Tencor Instrument, Alpha Step 200. The accuracy of the depth calibration is estimated at ±5% (one sigma). The craters were $370 \times 370$ μm.

Hydrogen profiles for each sample were also measured using ERD with a 5555 keV $^4He^{++}$ beam generated by the 2 MV HVEE tandem accelerator at the University of Surrey Ion Beam Centre, UK [18]. The beam current during the analysis was ~40 nA. The sample was oriented at glancing incidence (15 ± 0.08°), verified by channelling on each sample. Rutherford backscattering (RBS) spectra were recorded for RBS detectors at 148° (so-called "IBM" geometry) and at 166° ("Cornell" geometry), with solid angles of 3.32 and 1 msr, respectively. The ERD detector was at 30° with a solid angle of 1.12 msr. The ERD range foil (25 μm of kapton ($C_{22}H_{10}O_5N_2$) and 10 layers of 0.9 μm mylar ($C_{10}H_8O_4$) was used to absorb forward scattered He.

Electronics calibration of the RBS detectors was achieved using a Au/Ni/$SiO_2$/Si sample [19]. Electronics calibration of the ERD detector was achieved using the surface H signal from a glass sam-

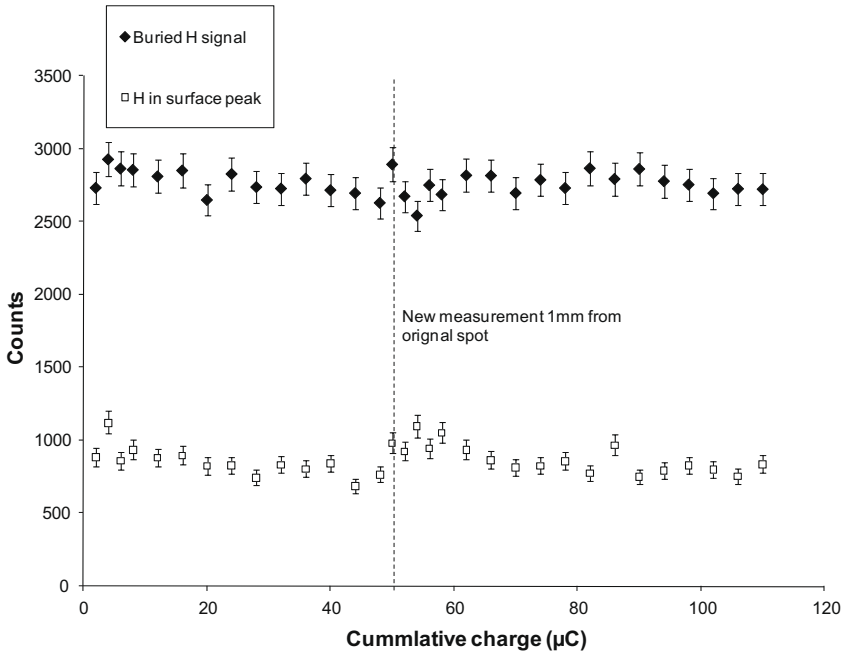


**Fig. 2.** Hydrogen counts in ERDA profile as a function of charge (measurement time). After 50 μC of measurement, the analysing beam was moved to a new spot on the sample.