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High Dose Hydrogen Implant Blistering Effects As a Function of Selected Implanter And Substrate Conditions

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Abstract. Buried dielectrics using high dose Hydrogen with subsequent wafer splitting and bonding (Smart-Cut™ for example) is a well-known process [1]. The ion implantation portion of this popular process in silicon is a key step and it is not fully characterized in silicon as to dose rate, dose duty cycle or wafer platen differences. Failures or problems in wafer splitting are not uncommon due to improper or non-uniform heat sinking or other seemingly common implanter problems such as parameter holds or changes in beam spot size. This paper will focus on ion implanter variations and will use the generation of surface blisters and sub surface damage formation under various conditions. One common anneal temperature and times is proposed. Various microscopy and metrology tools will be correlated with respect to H dose, the dose variations and various wafer platen conditions. There will be a brief discussion of implanter scan types related to high dose H^+.

INTRODUCTION

The authors' workplace, an implant foundry, performs a wide range of H+ implants as well as H+ with a co-implant species for various thin film exfoliation applications. There are occasional problems with total exfoliation or total uniformity of "damage' due to a number of implanter issues – some not usually thought of as major inhibitors of good performance. Some of the root causes have included: improper heat sinking or wafer temperature. Problems in a given application are often solved in one run or after a short series of experiments. This study is an overview of some of the parameters studied but in a full test under controlled pre and post implant conditions as compared to former studies done at our lab under conditions that had a variety of different pre and post implant processing. This test was designed to determine sensitivities to various implant conditions. As such, anneal conditions were not optimized for each implant and the blister data is quoted to indicate differences between implants rather than as an indicator of overall wafer quality. In most cases, deviations in blistering or exfoliation may easily be accommodated with slight changes to post processing.

EXPERIMENTAL

A number of wafers were run on two different types of implanters. On some wafers, small implant areas were used so as to reduce implant time on a serial implanter. Wafer types Czochralski (CZ) Si <100>, p-type were used.

High dose Hydrogen implanted bare wafers that are annealed without bonding will manifest surface blisters [2]. This provides a simple method for determining the effects of implant or anneal temperature, dose and energy [3,4]. For investigating Hydrogen agglomeration or growth as a function of common/possible implanter problems we kept implant energy, dose and the anneal conditions the same since most H^+ implant papers involve various changes to the implant recipe as a function of blister density. [3]. We wanted to see what differences might be discernible on silicon with the following: Three different substrate temperatures: +250C, RT and –120C, two dose duty cycles – full/100% as well as ¼ x 4 duty cycle to observe any damage change to due to implant interruption whether planned or not and we ran wafers with two different wafer "clamping" or heat sinking problems. The test also included three different beam densities of 0.5, 1.0 and 3.8 $\mu A\ cm^{-2}$, which bracket the beam densities of most high current implanters. 3.5 $\mu A\ cm^{-2}$ is equivalent to ~30 mA on a 200 mm wafer implant disk/wheel. In addition, a H/He implant combination was also run with the He at three different energies. Table 1 shows the test set.

Table 1. Variables for H (and H/He) Test			
Parameter	Number	Values	Notes
Energy	1	40 keV	
Dose (H/cm^2)	2	3.6 & 7.2 E16 cm-2	
Beam Density	2	1 & 3.8 uA cm-2	
Substrate Temperature	3	250C, RT, -120C	
Dose Duty Cycle	2	100%/Full, 1/4 x 2	1/4 x 4 simulates Implant HOLDS and Interrupts
Heat Transfer Integrity	2	Normal & Damaged, Diminished	
He Implant Supplement	3	Shallower, Same as or Deeper than H	On one standard H implant (H, 40 keV, 1E16)

For the He implants, the energies were tailored to have one run at the same depth of the H, one profile 500Å shallower and one 500Å deeper than the H profile. One anneal (550C, 25 min) was used for most off the wafers while a few wafers with H and He were annealed at the same temperature but a slightly longer time. (33 min). The characterization involved the use of standard optical microscopes SEM, AFM – done using a NanoScope™ III, Dimension 5000. We also used an optical 3D profiler – a Zygo™ NewView in order to look at blister depth and cross sections as a supplement to the AFM. A series of optical microscope fields were used, generally 5 or 9 fields on each wafer, in order to see the uniformity of blister density across the wafer.

RESULTS

The data collection began with optical microscopy using at ~1000X with views ranging from ~16,000 - 64,000 μm^2 . SEM pictures were taken on selected wafers. On the optical microscope, the wafer was scanned in several axes to see the general uniformity of blisters and a minimum of five views per wafer was noted to determine relative blister uniformity SD% using a counting template on the views. The blister density and blister evolution (onsets and full blistering and % broken blisters) were generally consistent within our data and in one significant case, the low temperature implants, were different from results seen on other papers [5]. Some of these differences were related to % broken blister density and may be a result of the high beam current density used here in these cases. Fig 1 shows a very general comparison of blister density. We have included the lower dose H & He for reference purposes. The density and the % of broken blisters on H^+, high dose only, was highest on the wafers implanted at full dose, full duty cycle with low temperature substrate (-120C). See Fig. 2. This is inconsistent with other reports but two different tests were done with similar results.

Substrates with full dose but with lower duty cycle compared to full dose and full duty cycle show a substantial reduction in blister evolution. When comparing all implant cases or substrate conditions but where the doses were different, we see where the dose is high, the blister density is high and the % of exploded blisters is higher than with lower doses.

In all cases where the dose was interrupted three times (25,50,75% complete) during the implant for high dose and regardless of platen temperature, the number of blisters per unit area was lower by 1/3 to 1/2 than with a full, dose duty cycle. This is consistent with dose measurements on “crystal damage measurement” tools. This needs further study since the H^+ implants are a relatively high dose and there is a chance of beam interruptions or even a quad mode implant in the case of some serial high current implanters might manifest sensitivity.

Some 10-15% of our implants were done on a batch implanter using a beam density of 0.5 – 1 mA H^+. Wafers in this group that used typical clampless holders were evaluated at the top, bottom and center along the axis of slow scan. Although the top, center and bottom have similar blister density and sizes, there is a noticeable difference the top or bottom versus the center with regards to “blister lids” – the tops of broken blisters that are of similar topography and size as surrounding broken blisters (or open craters). These lids or flakes are large 3 – 5 μm flakes which when in the AFM for assessment of crater information, tend to be dragged along by the probe. The top/bottom versus center “unbroken flake-lid” difference is likely due to difference in damage and/or slight temperature differences from the turn-around on the wafer annulus.

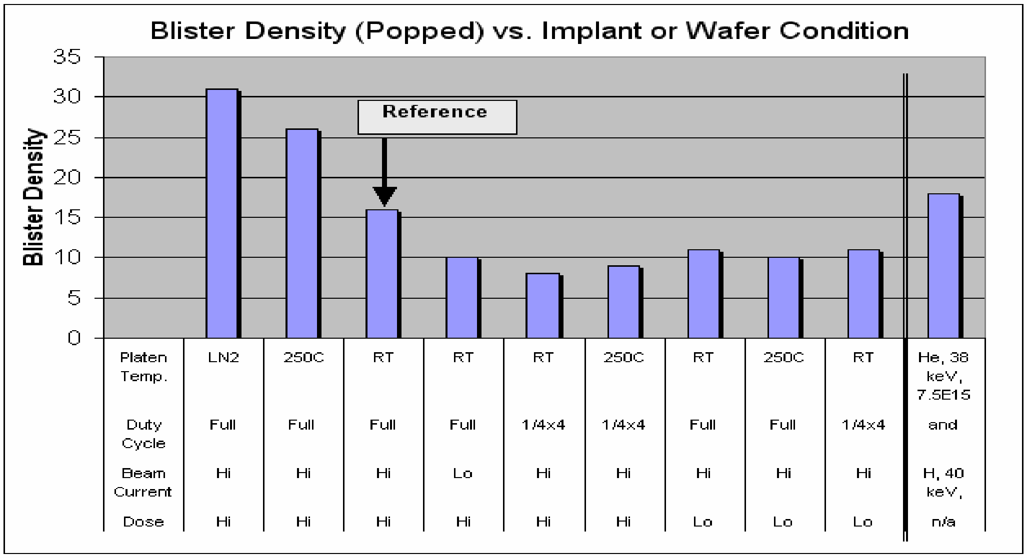

FIGURE 1. Blister Density (counting template area ~ 900 μm^2) comparison. Note the Reference Implant of full dose, high beam current, full DC and RT.

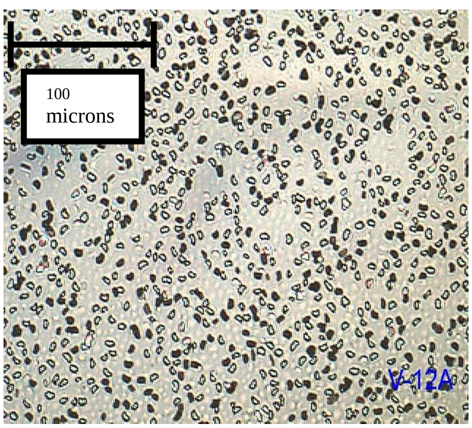

FIGURE 2. Optical micrograph picture of a high density of broken blisters and flakes (blister lids?). High dose, high beam current density, low substrate temperature.

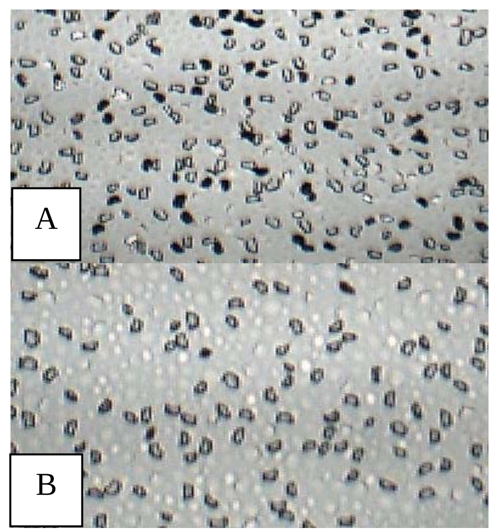

FIGURE 3. Sample S-13 done on a batch implanter shows the difference between A - Center of the Wafer and B - Bottom of the Wafer. (Bottom of wafer is at the slow scan turnaround). Implant was high dose, high beam density, RT.

See Figure 3 for a comparison on wafer center vs. wafer top, for example, on a full dose, full beam current implant on a batch implanter. Note that "top of wafer" denotes top of slow scan. This might also occur on serial high current tools running high dose H^+ although the beam density is much lower. In cases where broken blister density was high, they also manifested, as one might expect, the highest % of larger unbroken blisters – blisters that had coalesced almost to the point of breaking. Test samples run with lower duty cycle, i.e., planned, interrupted implant, showed lower blister density than tests run with the same implant conditions except for full duty cycle. This might infer that interruptions in some implants especially for long, high dose implants, may need remedial post implant processing for proper exfoliation. Wafers that had the normal heat sinking compromised with 2 layers of Kapton™ tape or with a dummy wafer beneath the test wafer showed very close approximation of blister density (broken as well as larger unbroken blisters). So called "blister lids" were more abundant on wafers with compromised heat sinking. It is interesting to note in Fig. 4 the AFM broken blister depth data was consistently in agreement with range data from Profile Code™ while the Zygo depth data (Fig. 5) was consistently in agreement with SRIM 2003. Both are within ~10% of each other for this H^+ implant recipe. In our study, and our conditions, with the H^+ and He^+ implant we observed that the implants with H^+ at 40 keV with the accompanying deeper and shallower (500 Å each) He^+ implant, the shallower implant had a 4X higher blister density. Although all three He^+ implants had scattered clusters of blisters, the deeper energy He^+ (55 keV) substantially less clusters and the average density within a cluster was very low whereas the shallower He^+ with its H^+ was about equal to the baseline H^+ athat had > 4X the H^+ dose.

Several microscope view pictures show long strings of blisters in a very straight line. The number of blisters seen have between 5 to 10 and up to at least 15 blisters sometimes extending for 60 microns or longer. See Fig 6 for an example. The strings are similar to a paper [7] that refers to "string of pearls" but in this paper, the H^+ is implanted into a 5μm masked trench and the blisters are constrained. These are most likely due to blisters nucleating at crystal defect sites.

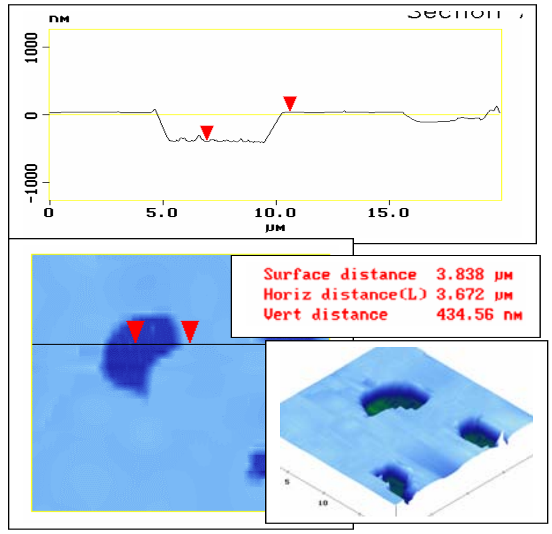

FIGURE 4. AFM pictures of typical blister showing the depth as 434.56 nm.

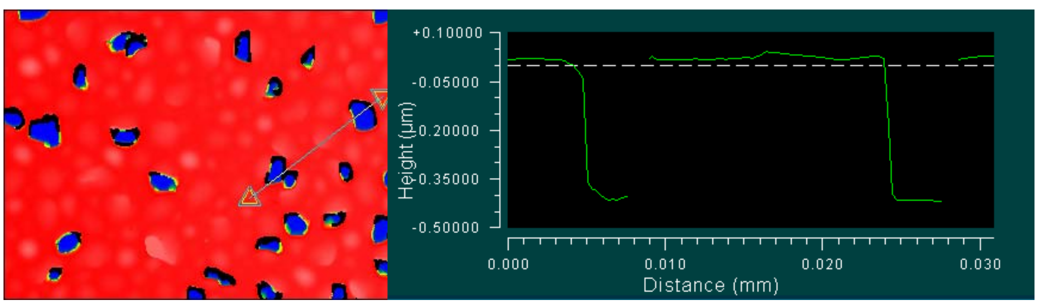

FIGURE 5. Zygo 3D Profiler showing blister depth = 0.400 μm. The depth of >25 measured blisters over 3 different wafers is the same within the precision of the measurement

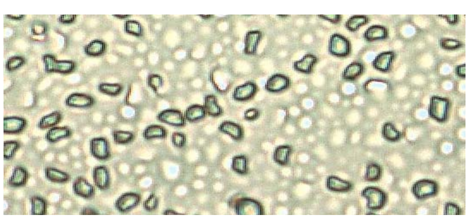

FIGURE 6. One of many "blister rows" of blisters extending from 5 – 10 or more in a straight line. The blister rows are seen on a variety of implant conditions.

SUMMARY

We have observed a number of various implanter and substrate heat sink differences. Improper clamping shows some blister density differences but the blister uniformity is still consistent across the wafer and any exfoliation issues may be overcome with post implant process adjustments. Some H/He combinations show blister densities equal to that of full dose full DC high dose H^+ only. Since the H/He combination has a much lower total dose than H^+, this could alleviate any subtle problems due to dose rate or wafer condition.

Dose interruptions during a high dose H^+ also show a blister density and size difference. This needs further investigation for various scan techniques.

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