Transposed Splitting of Silicon Implanted with Spatially Offset Distributions of Hydrogen and Boron

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Abstract

We have observed surface blistering and splitting of silicon implanted with moderate dose boron and higher dose hydrogen with concentration peaks that are offset. The splitting has been observed to occur near the location of the boron peak after a 10 minute anneal at 300 °C.

Introduction

In recent years there has been considerable interest in high dose hydrogen ion implantation into silicon. A recent review article describes a wealth basic physical theory and experiments related to hydrogen implanted silicon [1]. Bruel first described the Smart Cut ® technique that leads to silicon-on-insulator, SOI, material for use in silicon microcircuits [2,3]. Since that time a number of authors have described and have proposed theories to quantify the hydrogen bubble generation and crack phenomena that in combination with direct bonding leads to SOI formation [4,5,6]. Recent publications have described variations on Bruel's work. Tong et al has described layer splitting with ion implanted hydrogen in Ge, SiC and diamond [7]. Bower et al has demonstrated low temperature bonding may be used with hydrogen ion implantation to produce SOI with a bonding temperature of 200 °C and a split temperature of 400 °C [8,9]. Tong et al has shown that boron and hydrogen when implanted to the same projected range allow optically observable surface blisters to be produced with heat treatments of 200 °C for approximately 100 minutes [10]. Agarwal et al have demonstrated that the hydrogen ion dose may be reduced from 5 10^{16} /cm^2 to 1 10^{16} /cm^2 when silicon is also implanted with Helium also at a dose of 1 10^{16} /cm^2 [11].

Experimental Results and Discussion

Boron was implanted into (100) single crystal silicon at an energy of 100 KeV with a dose of 1 10^{15} /cm^2. Trim 95 predicts a mean penetration Rp ≈306 nm and vertical straggling ΔRp ≈66.7 nm for this implanted boron[12]. The sample was then rapid thermal annealed at 950 ° C for 15 seconds. The sample was then implanted with H^+ at 40 KeV with a dose of 5 10^{16} /cm^2. In this case, Trim 95 predicts a mean penetration Rp ≈457 nm and vertical straggling ΔRp ≈87.3 nm for this implanted hydrogen[12]. The samples were then subjected to isochronal anneals for ten minutes at 100, 200, 300 and 350 °C. Blistering occurred in the samples heated to 300 and 350 °C. A small sliver split off the surface of the sample heated to 300 °C that allowed a measurement of the thickness of the expunged surface layer. Figure 1 shows the Sloan DEKTAK trace of the step across the split portion of the surface. The thickness of this expunged surface layer is found by this measurement to be 330 ± 15 nm. This clearly indicates that the crack occurs within experimental error near the projected range, Rp, of the implanted boron, and far from the Rp of the considerably deeper hydrogen implantation.

The experimental evidence in this paper strongly suggests that the high dose implanted hydrogen into silicon migrates and accumulates in the region of the lower dose boron distribution where it blisters and cracks the silicon near the peak of the boron profile. The blister and crack time and temperature is consistent the results found by Tong et al in their experiments with boron and hydrogen implanted to the same peak depth [10]. While the migration of the hydrogen to the boron peak is reminiscent of the work of Marwick where Ga in silicon is found to attract hydrogen implanted into silicon [13]. The Marwick paper suggests that ionized Ga^- in silicon attracts H^+ ions and at temperatures of ~200 °C may attract quantities of H much in excess of the density of Ga present by the reaction:

$(HGa)^0 + e^- + n H^0 \rightarrow Ga^- + (n+1) H^0$ (1)

We suggest that ionized boron may attract and accumulate hydrogen in much the same manner in our work. The equation (1) does not explain where the accumulated hydrogen would reside, but other literature suggests that it might cluster near the Ga or B or perhaps in silicon defect structures that would be present after an implantation near these acceptor sites [1, 13]. The importance of the RTA of the boron in our experiments is not known, but may be important in the light of the ionized donor argument just described, since without the RTA the boron would not be expected to be electrically active and act as an ionized acceptor.

Conclusions

This paper demonstrates that hydrogen implanted into silicon may be accumulated and produces blistering and cracks remote from its point of implantation. A low dose implantation of boron has been shown to act as the getter that allows hydrogen to collect and cause a crack near the boron peak. We believe this result may have interesting implications and applications in the formation of SOI and other structures. Allowing the hydrogen to be implanted in a location remote from the crack plane may allow the damage associated with the moderately high dose hydrogen implant from being present in the thin cut film, for example. The dose of hydrogen required, and its separation distance from the boron or other getter ions are issues of great interest and currently under investigation at this time.

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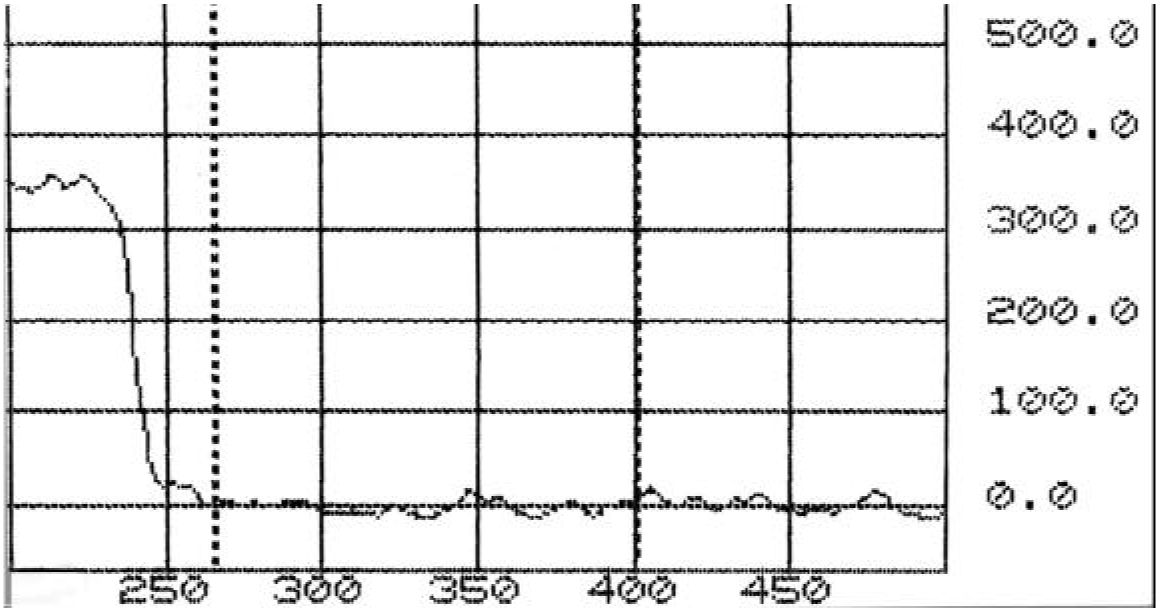

Figure 1. Sloan DEKTAK 3030 line scan of surface split in hydrogen and boron implanted silicon after a 300 °C 10 minute anneal. Vertical axis is in nm and horizontal axis in µm.