DLTS CHARACTERIZATION OF N-TYPE SILICON AFTER RAPID THERMAL ANNEALING OF BORON IMPLANTATION

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ABSTRACT

DLTS measurements show that majority-carrier traps exist after quartz-lamp, rapid-thermal annealing (RTA) activation of B^+ and BF_2^+ ion implants in n-type silicon. Levels at E_c-0.17, 0.27, 0.44 and 0.57 eV annealed out with an additional 20 minute isochronal anneal at 550°C in argon. A stable defect at 0.37 eV existed at temperatures above 750°C. DLTS measurements of a Schottky diode on n-type silicon after only RTA indicated that electron traps could be introduced into n-type silicon by the RTA alone.

INTRODUCTION

The annealing of boron implantations with short-time annealing techniques is of interest because there can be activation with minimum dopant movement.[1] Residual damage related to boron implantation has been reported (see for example the review by Mader[2]). Studies of the application of RTA to boron implantation by Sadana have shown that above 1100°C annealed implants were free of precipitation.[3] BF_2^+ implantation offers the advantage of a lower energy implant and results in a shallower junction for VLSI applications.[4] Residual damage related to BF_2^+ which had been given conventional furnace anneals has been observed by Chen and Wu.[5] Seidel et al. have reported TEM results for RTA of boron implants.[6] More recently, Lunnon et al. reported on RTA of BF_2^+ giving evidence of residual damage and fluorine using TEM and SIMS.[7]

In addition to the ion implantation process itself, certain rapid annealing processes can contribute damage. For example, Kimerling and Benton have shown that with laser annealing of n-type wafers without ion implantation, levels at 0.19, 0.23, 0.33, 0.43 and 0.48 eV from the conduction band were observed.[8] Laser annealing of silicon implantation into silicon has been shown by Johnson et al. to result in deep levels.[9] Laser annealing is an extreme of a non-equilibrium reaction that usually involves melting. With a quartz-lamp RTA tool, cool-down rates of RTA with quartz lamp systems can be of the order of a 100°C/sec and there, also, can be non-uniformities in power application and cooling. Such annealing might well be non-equilibrium, though always solid state. Recent work by Pencl et al. reported a trap created by RTA in p-type silicon.[10]. They did not observe any levels in n-type silicon.

In this work, DLTS was used to detect traps after quartz-lamp rapid annealing of B^+ and BF_2^+ implantations. A comparison is made to a n-type wafer after only RTA at 1100°C for 10 seconds.

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EXPERIMENTAL

Samples were n-type (100) silicon wafers with resistivity of 10 Ωcm. After standard cleaning a 30 or 50 KeV boron implantation of $5x10^{13}$ or BF_2^+ at 50 KeV at $1x10^{14}$ were made. All boron implants are below threshold for extended defects and this was consistent with TEM observations of no extended defects. The BF_2^+ samples were on the threshold of causing extended defects and this was confirmed with TEM.

Samples were annealed in a HEATPULSE annealing apparatus (models 210 and 410, A.G. Associates, Palo Alto, Cal.) or NOVA tool (NOVA Corporation, Beverley, Mass.). The HEATPULSE tool consists of two vertical stacked horizontal arrays of tungsten-halogen lamps within a reflector. The wafer is supported between two quartz diffuser plates which in turn are placed between lamp arrays. The temperature was controlled by feedback from a thermocouple specially imbedded in a small Si chip placed near the sample wafer or by pyrometer. The temperature of the sample was known within about 15°C. The anneals were done in an nitrogen ambient. The NOVA tool consists of a hi-powered vortex-cooled argon discharge lamp. Control samples were made with conventional furnace anneal of 950°C for 30 min. in argon.

Metal for junction contact was deposited by resistive evaporation using a shadow mask. Diodes were fabricated by wet chemical mesa etching.

The DLTS measurements were made with full-waveform capture of the capacitance transient. The analog signal of a modified Boonton 72BD capacitance meter was digitized using an IBM Personal Computer with a Tecmar Labmaster 14 bit A/D converter. A conversion was made every 200 μs for a total measurement time for each transient of 200 ms. The temperature dependence of the DC capacitance was detected and the measurement voltage applied to the sample was corrected so that a constant depletion volume was maintained during the entire temperature scan. The capacitance transient which occurred following the injection pulse was multichannel averaged and the resulting digitized transient for each temperature interval was then stored for analysis at a later time. This data set of transients was analyzed with a curve-fitting algorithm to obtain an Arrhenius plot for the activation energies of the various levels.

RESULTS AND DISCUSSION

A DLTS spectrum for a 50 KeV, $5x10^{13}$ boron implantation after 1280°C for 8.3 seconds in a NOVA quartz-lamp system is shown in Figure 1. Electron traps with activations of 0.17, 0.27, 0.43 and 0.57 eV from the conduction band were detected. A DLTS spectrum for a 50 KeV, $1x10^{14}$ BF_2^+ annealed at 1187°C for 2.9 seconds in a NOVA system is shown in Figure 2. Here four trapping levels at 0.17, 0.26, 0.43 and 0.57 eV from the conduction band were observed. Capture cross-sections were calculated for these to be 10^{-17},10^{-18}, 10^{-14} and 10^{-14}, respectively. There was no evidence of an additional level which might be related to fluorine. When this sample was given 20 minute isochronal anneals in argon, the levels showed different annealing behaviors. Concentrations of both the 0.17 and the 0.26 eV levels monotonically decreased with increasing temperature. The 0.43 eV level concentration reached a maximum after a 250°C additional anneal and then decreased with increasing temperature. The 0.57 eV level tended to increase in concentration up to 400°C. When a sample with a $3x10^{15}$, 50 KeV boron implantation was given a 550°C anneal after RTA of 1100°C for 10 seconds, only a level at 0.37 eV from the conduction band was detected. This level was observed after 750°C also.

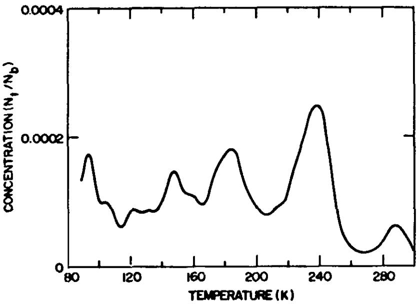

Figure 1. DLTS of 5x10[13] boron implant at 50 KeV activated at 1280°C for 8.3 seconds.

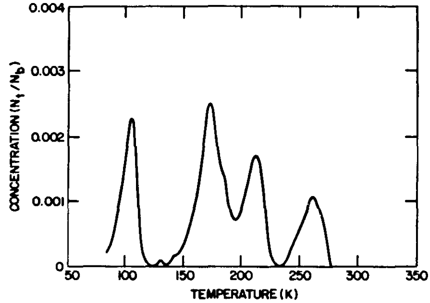

Figure 2. DLTS of BF_2^+ at $1x10^{14}$ at 50 KeV activated at 1187°C for 2.9 seconds.

Light ion implantation with low fluences ($\leq 10^{15}/cm^2$) produces a partially damaged layer in the silicon. Certain damage has shown itself to be stable against high temperature anneals (for example, plastic deformation results of Kimerling and Patel[11]). Also, direct measurement of capture cross-sections for these levels show a logarithmic dependence of concentration with injection pulse width. It has been argued by Figielski that such behavior is caused by multi-site trapping centers.[12]

RTA of an implantation involves two severe processes. It is of interest to answer the question of whether the levels observed are due only to ion implantation or whether the RTA contributes to the damage. DLTS measurements were made of a sample annealed at 950°C for 20 minutes in argon in a conventional furnace was done on a $3x10^{15}$ boron implant and compared to a n-type sample without an implant which had been given only a RTA at 1100°C for 10 seconds in nitrogen. Figure 3 shows a DLTS spectrum for the conventional furnace anneal. Two levels are observed at 0.37 and 0.57 eV. The DLTS spectrum for a Schottky diode on the non-implanted sample is shown in Figure 4. Levels at 0.17, 0.27 and 0.58 eV were detected. Slip was visible near the edges of this 4 inch non-implanted wafer after RTA at 1100°C for 10 seconds in a Heatpulse system. The RTA was done with a power-off cool-down. Quenching experiments by Nakashima in p-type silicon have suggested that cool-down rates could be important. There was no observation of the 0.43 eV level seen in the I/I samples. Since levels are introduced by RTA in a sample without an implant, RTA processing, itself, can contribute to residual damage through quenching and thermal non-uniformities.

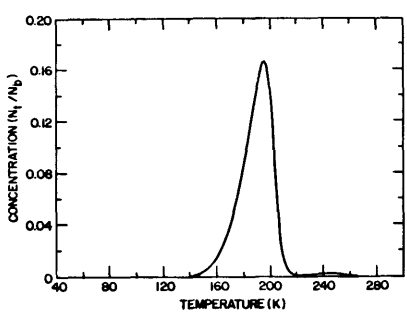

Figure 3. DLTS spectrum of a $3x10^{15}$ boron implant after anneal at 950°C for 30 minutes in argon in a conventional furnace.

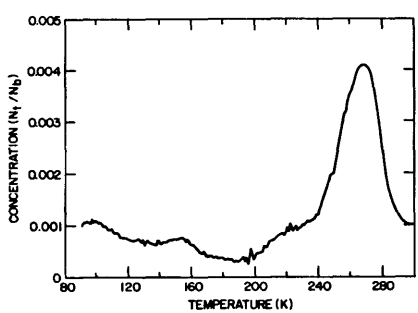

Figure 4. DLTS of a Schottky diode on non-implanted n-type silicon after RTA at 1100°C for 10 seconds.

CONCLUSIONS

DLTS measurements showed majority-carrier traps after boron implantations were activated by short-time annealing. A comparison between B^+ and BF_2^+ implantations indicated that there were no new levels which might be related to fluorine. The electron traps were still observable after additional isochronal anneals at 400°C in argon. After RTA and an additional 550°C anneal in nitrogen, there was a new stable trap detected at 0.37 eV. DLTS measurements of non-implanted samples showed traps can be introduced by the RTA processing alone. We conclude that both boron implantation and thermal stresses related to quartz-lamp RTA processing can contribute to introduction of traps in n-type silicon.

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