Extent of Dopant Activation after Microwave and Rapid Thermal Anneals Using Similar Heating Profiles

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Abstract:

Many sustainability issues arise with the current manufacturing processes used for semiconductor-based solar cells. Microwave (MW) heating could be adopted as sustainable since its capital costs are less and it more efficient than conventional furnace systems. In addition, microwave heating is directly produced inside the material. This study compares the extent of dopant activation and damage repair for a MW anneal and a conventional rapid thermal anneal (RTA) with identical heating profiles. Sheet resistance measurements were used to assess the extent of dopant activation and ion channeling was used to monitor the extent of damage repair. The results showed that for identical heating profiles, MW annealing resulted in better dopant activation and damage repair.

Introduction:

When high concentrations of dopants are implanted into silicon, the surface layer becomes damaged. Large amounts of lattice damage results in increased sheet resistance. High temperature anneals are performed to repair the damage created during ion implantation and to also electrically activate the implanted dopants [1]. Rapid thermal annealing (RTA) has been used to reduce the diffusion of dopants during annealing. However, uneven heating sometime occurs due to differences in the emissivities of the various near-surface device materials. Additionally, the photons used in the RTA lamp and laser heating were not able to penetrate beyond the surface regions of the silicon [2]. However, MW of silicon allows for volumetric heating of the wafer due to the greater penetration depth of the microwave radiation [3]. In this study, we investigate the extent of dopant activation and damage repair for a MW anneal and a conventional RTA with identical heating profiles.

Experimental Procedure:

Silicon wafers received a 180 keV arsenic ion implant with one of three different doses: 1, 2 or 4 × 10^{15} ions cm^{-2}. A single-frequency (2.45 GHz) 2.8 × 10^4 cm^3 cavity applicator microwave system with a 1300 W magnetron source was used to MW anneal the arsenic implanted silicon. A pyrometer, mounted through the cavity wall, with a spectral response of about 3.9 μm, was used to monitor the near surface temperature. The heating curves were then plotted in order to determine ramp up temperatures, times, and rates. A Heat Pulse 610 RTA was used to anneal each sample to obtain a similar heating curve as that of the corresponding microwave annealed sample. To monitor dopant activation, the sample surfaces were contacted with an in-line four-point-probe (FPP) equipped with a 100 mA Keithley 2700 digital multimeter. In order to determine the carrier concentration after microwave processing, Hall effect analysis was also performed. Rutherford backscattering spectrometry (RBS) was used to measure the extent of recrystallization of after each anneal.

Results and Conclusions:

Figure 1 shows the close match between the heating curves for both 50 sec MW and RTA anneals of the 2 × 10^{15} cm^{-2} sample. These results are consistent for all samples in this study. In Figure 2, sheet resistance values are shown for all three doses as a function of microwave and RTA annealing times. The MW saturation point for the dopant activation is 50 seconds. Based on this result, two set times are used for the RTA: 50s and 100s. The sheet resistances for the 50s RTA anneals are out of range (for all three doses); hence, the single hollow plotted points for the 100s RTA samples. Table 1 displays the Hall measurement results, including the carrier concentration and the sheet resistance for each MW dose.

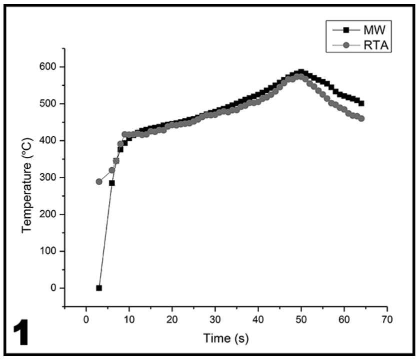

Figure 1: Illustration of the heating curve comparison between MW and RTA.

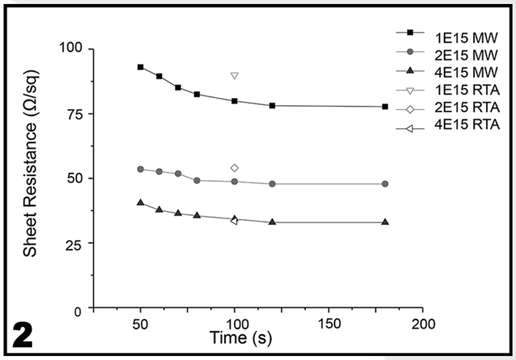

Figure 2: Comparison of the sheet resistance for MW and RTA samples.

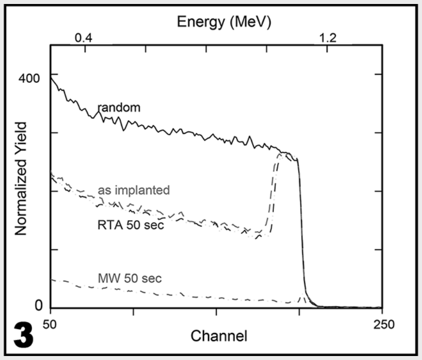

Figure 3: Represented the RBS data for four selections of samples.

Microwave annealing the samples allowed for a wider range of annealing times after the already determined saturation point. Based on the data in Table 1, it can be concluded that higher the dose and time of arsenic in the silicon, the smaller the difference in the sheet resistance between the RTA and microwave annealing. For the MW Hall measurements, the 1×10^{15} ions cm^{-2} 100s sample has a higher carrier concentration than the 2×10^{15} ions cm^{-2} 50s sample. For all three 50s doses for the RTA samples, the sheet resistance was observed to be inconclusive as a result of not reaching the saturation point.

Figure 3 illustrates the normalized yield and energy between a random, as implanted, RTA 50s, and MW 50s samples. These results showed that the MW anneals gave better dopant activation and damage repair for short times for identical heating profiles.

Future Work:

Optimize and model the microwave induced dopant activation heating process, and present findings at TMS 2015 conference.

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Dose (cm^{-2})	Time (s)	Carrier Concentration ($\#/cm^3$)	Sheet Resistance (Ω/sq)
1.00E+15	50	9.00E+19	92.6
1.00E+15	100	1.00E+20	80.3
2.00E+15	50	1.70E+20	53.5
2.00E+15	100	1.80E+20	48.7
4.00E+15	50	3.40E+20	40.4
4.00E+15	100	4.00E+20	34.2

Table 1: Depiction of the Hall measurements obtained from the MW samples.