Investigation of Implantation Damage Recovery using Microwave Annealing for High Performance Image Sensing Devices

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Abstract We propose a novel annealing technique for process damage recovery to improve the dark characteristics for CMOS image sensor without deteriorating the transistor performances. Microwave annealing (MWA) has been studied as an alternative annealing technique for diffusion-less dopant activation and recovery of process damage in advanced CMOS technology. We employed MWA technique to repair crystalline defects for the purpose of better dark characteristics in CMOS image sensor (CIS) process. We demonstrate that MWA can actualize the effect of recovering ion-implantation damage equivalent to conventional furnace annealing (FA) with lower temperature annealing. MWA can recover the process damage without transistor performance deterioration to replace the conventional annealing. MWA is promising technique for repairing crystalline defects in high performance image sensing devices with high frame rate, low power and excellent dark characteristics.

Keywords: Microwave annealing, CMOS Image Sensor, White spot, Implantation damage

1. Introduction

In recent years, the demands for the high performance and new functionality have been increased in the world marketplace of CMOS image sensing devices. Above all the performance of CMOS image sensor, it is important to improve the saturation electrons for wide dynamic range.

From another point of view, it is well known that crystalline defects introduced by the fabrication process impact dark characteristics in CMOS image sensor (CIS) 1). The implantation dosage to fabricate the buried p-n junction (photodiode) becomes large in order to increase saturation electrons. In Figure 1, higher TW (Thermal wave system) signal means more defect counts in Arsenic (As) implanted crystalline. Crystalline defects induced by ion implantation increase with increasing the dosage. This indicates that the recovering of crystalline defects is one of key technologies to improve the dark characteristics in CIS fabrication process with large saturation electrons.

Three dimensional (3D) structure is one of the candidates to overcome above issues, since CIS device and peripheral CMOS device can be separately manufactured by the suitable technique, respectively. However several issues, such as cost and productivity, still remain. Therefore we executed the approach to solve the above problem in a conventional CMOS image sensor process.

Generally, Furnace Anneal (FA) and Rapid Thermal Anneal (RTA) are utilized for annealing to recover implantation damage. However, FA and RTA might
cause degradation of characteristics for sensor devices. Because the off current of transistor increases due to dopant re-diffusion with additional annealing. This indicates that standby power consumption would be increased. The silicide resistance for diffusion / gate would be increased too. Thus the efforts of recovery damage with low thermal budget are important for an image sensor and high speed transistors.

In these backgrounds, it has been reported that MWA for shallow p-n junction\textsuperscript{2), 3), 4)}, repairing plasma damage\textsuperscript{5)} and novel silicidation annealing\textsuperscript{6)} effectively recovers the implantation damage and realize shallow junction in advanced CMOS logic technology. The effects of repairing for crystalline defects (TW signal) by various annealing are shown in Figure 2\textsuperscript{7)}. MWA can obviously repair the crystalline defects by implantation in the lowest annealing temperature.

And diffusion depth of B (Boron) atom for MWA is smaller than that of FA (Furnace annealing) in deep region for dopant profile (SIMS) as shown in Figure 3.

In this paper, we focused on reducing the crystalline defects of Photo Diode (PD) by using low temperature MWA system as alternative annealing technology for conventional method (FA or RTA) and we demonstrate the dark characteristics can be improved without deteriorations of high speed logic transistor performance by the optimization of MWA process in CIS devices.

2. Experiments

Figure 4 shows the simplified schematic of MWA apparatus. Microwave was irradiated from the source above wafer in the N2 atmosphere. An annealing temperature was monitored directly by using an infrared thermo-meter from the backside of wafer.

Figure 5 shows the schematic of process flow for logic transistor and image sensor including MWA process. In order to clarify the influence on dark characteristics of
image sensor, the logic transistor performance and the resistance of silicided diffusion/gate by CoSi2, MWA, RTA and FA were carried out after the next process.

(a) Buried P-N junction formation (PD:Photo Diode)
(b) Contact hole etching

MWA treatment were carried out in the temperature range from 650 °C to 800 °C and the temperature for FA and RTA were adjusted 800 °C to compare the dark characteristics. In order to clarify the effectiveness in image sensor dark characteristics, the amount of white spot was evaluated for MWA and conventional annealing. The white spot is the pixel whose output exceeds a certain threshold in all pixels and the threshold value couldn’t be clarified in this paper. In addition to that, logic transistor characteristics, sheet resistance for dopant diffusion, etc. were also evaluated.

3. Results and Discussion

Figure 6 shows a comparison of the normalized white spot amount for each annealing condition after the implantation of PD (photo diode) formation. The white spot count was defined to the number of cumulative pixels which exceeds a certain standard output level. The soaking time for both annealing are almost the same. The monitored temperature of MWA was 793 °C which is not setup value.

Though the temperature of MWA is slightly lower than FA, the white spot of MWA is reduced about 26% compared with FA at 800 °C. This result indicates that MWA has the ability to repair crystalline defects induced by implantation for PD more than conventional FA. Figure 7 shows the comparison of cumulative pixel counts with each annealing. The pixel counts at the rightmost of Figure 7 means all pixel counts of test image sensor. The pixel counts for MWA is smaller than FA and "Without annealing" in all dark pixel output and that of MWA is smaller than FA in a portion of dark output. This means that the improvement mechanism for white spot of MWA is different from FA.

Figure 8 shows a comparison of white spot for each annealing after contact hole etching process. Generally, FA is difficult to be employed due to logic transistor performance deterioration by excessive dopant diffusion as thermal treatment after contact hole etching. Therefore, the dark characteristic of MWA is compared with RTA not FA for the contact process. The white spot
of MWA at 652 °C is reduced about 14 % compared with that of RTA at 800 °C as shown in Figure 8.

Figure 9 shows Ion-Ioff characteristics for drain current of logic transistor on each annealing after contact hole etching. In case of RTA, the deterioration of Ion-Ioff characteristic for logic transistor is observed due to high temperature treatment. On the other hand, that of MWA are same as the case without additional annealing and its variation is also same.

In addition, the CoSi2 resistance on P+ Poly-Si gates of the sample applied with RTA shows higher resistivity compared with MWA or reference as shown in Figure 10. It is concluded that low temperature MWA can be repaired the crystalline defects without device deterioration even after silicide formation.

Figure 11-14 are cross-sectional TEM microphotograph for Boron implanted and annealed samples.

The annealing conditions for Figure 11-14 are RTA only, two conditions of MWA+RTA and RTA+MWA treatment for high energy Boron implanted samples respectively. The dislocation loops can be observed at the sample with RTA only. However these dislocations can be eliminated by additional low temperature MWA(650 °C 10min.) as shown in Figure 12. But there are some dislocations by high temperature MWA(800 °C 10min.) in Figure13 and in spite of additional high temperature MWA(800 °C 10min.) in the inverse order, no dislocations are observed as shown in Figure14.

Thus repairing for defects and dislocation is strongly concerned with the thermal budget and process sequence including MWA. In other words, it's necessary to control the condition for MWA for the generation and growth of defects or dislocations.
The behavior of implanted dopant after MWA treatment was presumed as Figure 15. In case of (a) as-implantation, a lot of vacancy and interstitial-site Si are existed. The disarray of lattice absorbs the energy of MWA (b) and there is the possibility of the acceleration for the replacement from vacancy to implanted ions.

4. Conclusion

The improvement in dark characteristics due to crystalline defects by MWA is demonstrated for CMOS image sensing devices. MWA has the ability to repair the crystalline defects induced by ion-implantation more than FA without performance deterioration. MWA is promising technique for repairing crystal defects in high performance image sensing devices with high frame rate, low power and excellent dark characteristics.

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References


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