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

Masatoshi Kimura[1], Tadashi Yamaguchi[2] and Takashi Kuroi[1]

[1]Technology Division, Renesas Semiconductor Manufacturing Corp.
[2]Production Technology Development Unit, Renesas Electronics Corp.
751 Horiguchi, Hitachinaka, Ibaraki, 312-8504, Japan
Phone: +81-29-270-1643 E-mail: masatoshi.kimura.xn@renesas.com

Abstract

We propose a novel annealing technique in order to improve the dark characteristics for CMOS image sensor without deteriorating the transistor characteristics. Microwave annealing (MWA) has been studied as an alternative annealing technique for diffusion-less dopant activation and implantation damage recovery in advanced CMOS technology. We employed MWA technique in order to recover crystalline defects in CMOS image sensor (CIS) process. We demonstrate that MWA can be implemented a low thermal budget to obtain the effect of repairing the ion-implantation damage equivalent to conventional furnace annealing (FA). MWA can repair the process damage without transistor performance degradation by additional thermal treatment. MWA is promising technique for repairing crystalline defects in high performance image sensing devices with high frame rate, low power and excellent dark characteristics..

1. Introduction

Recently, the higher value systems with CMOS and non-CMOS devices on one chip have been realized such as Figure.1. The demands for the integration of high performance and functionality have been also increased in the world marketplace of CMOS image sensor.

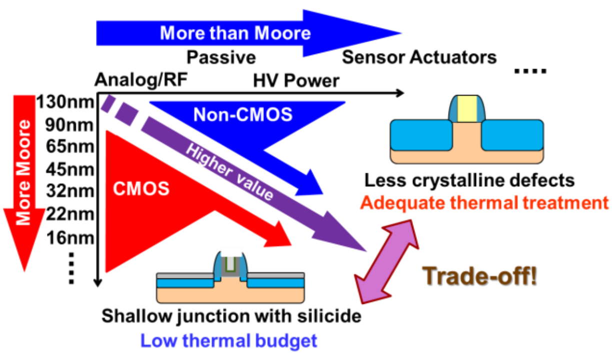

Figure 1. Higher value systems are realized by CMOS and non-CMOS components on one chip

From another point of view, it is well known that crystalline defects introduced by the fabrication process impact dark characteristics in CIS [1]. The implantation dosage to fabricate the buried p-n junction (photo diode) becomes large in order to increase saturation electrons. Crystalline defects induced by that ion implantation increase with increasing the dosage as shown in Fig.2 [2]. This indicates that the recovering of crystalline defects is one of key technologies to improve the dark characteristic 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 problem in a conventional CMOS process.

Thus the efforts of recovery from crystalline defects with low thermal budget are important for integration of CMOS image sensor and high speed transistor of CMOS logic process. Generally, Rapid Thermal Anneal (RTA) and Furnace Anneal (FA) are utilized for the annealing method in order to recover implantation damages. However, an additional FA and RTA can cause the degradation of high speed transistor characteristic, because the drain current on constant off current decreases due to excessive LDD dopant diffusion and increases silicided-diffusion/gate resistance for $CoSi_2$.

In these backgrounds, it has been reported that low temperature MWA [3] effectively repairs the ion-implantation damage in advanced CMOS logic technology. In this paper , we focused to reduce the crystalline defects of Photo Diode (PD) using low temperature MWA system as an alternative annealing technology of conventional annealing method (FA or RTA) , and we demonstrate the dark characteristics can be improved without degradations of high speed logic transistor performance by the optimization of MWA process in CIS devices.

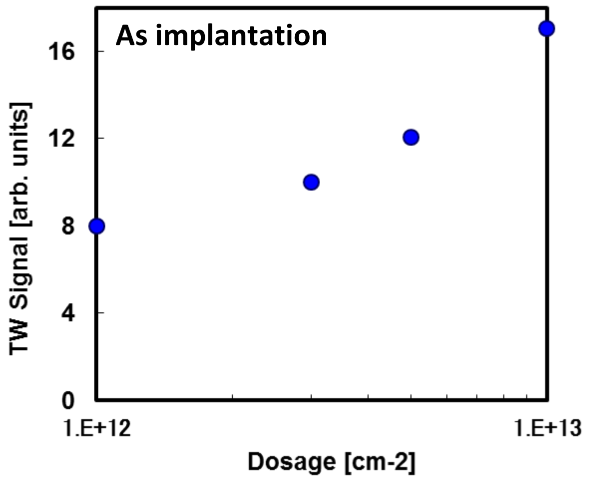

Figure 2. Crystalline defects due to ion implantation measured by Thermal Wave (TW) technology

2. Experimental

Fig. 3 shows the schematic of logic transistor and image sensor process flow, and describes the process steps for adopted MWA treatment. And the evaluation contents of MWA/other annealing method are also shown.

Fig. 4 shows the diagram of CMOS image sensor structure in this experimental image sensor formation.

In order to clarify the influence on dark characteristic 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 steps (a)/ (b) as follows.

(a)Buried P-N junction formation in Photo Diode (PD)

(b)Contact hole etching.

MWA treatment were carried out in the temperature ranging from 650 ℃ to 800 ℃ and adjusted the annealing conditions in order to compare the dark characteristics with FA at 800 ℃. An annealing temperature was monitored directly using an infrared pyrometer measurement system from the backside of wafers.

In order to clarify the effectiveness in dark characteristics of MWA process, the amount of white spot was evaluated for MWA and conventional annealing method. In addition to the image sensor dark characteristics, thermal wave (TW) for damage recovery, sheet resistance (Rs) for dopant activation and secondary ion mass spectroscopy (SIMS) for dopant diffusion and so on were also evaluated as basic characteristics.

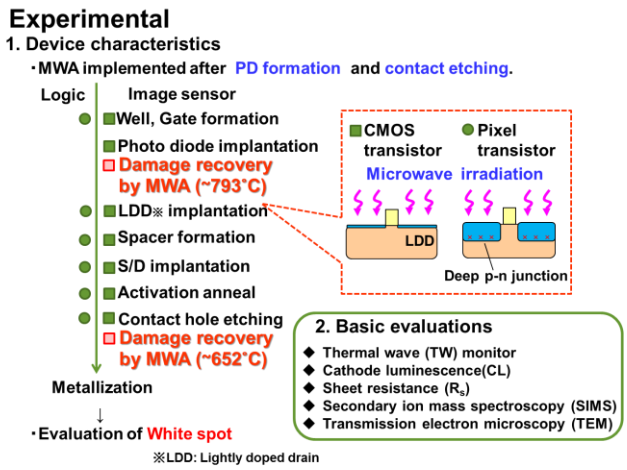

Figure 3. Experimental process flow and contents of evaluation for MWA.

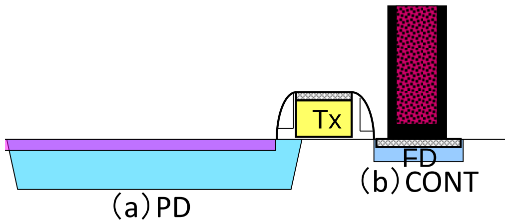

Figure 4. The cross-sectional view of CIS devices structure for this evaluation.

3. Results and Discussion

Fig. 5 shows a comparison of the amount of normalized white spot for each annealing condition after the implantation of PD (photo diode) formation. The white spot induced by implantation damage can be reduced by annealing process. The soaking time for both annealing method are almost the same, and the total thermal budget of FA is supposed to be larger than MWA. But in this case of MWA adoption after PD formation , the white spot of MWA at 793 ℃ is reduced about 22 % compared with that of FA at 800 ℃. This result indicates that MWA has the ability to repair the crystalline defects induced by ion-implantation for PD formation more than that with conventional FA method.

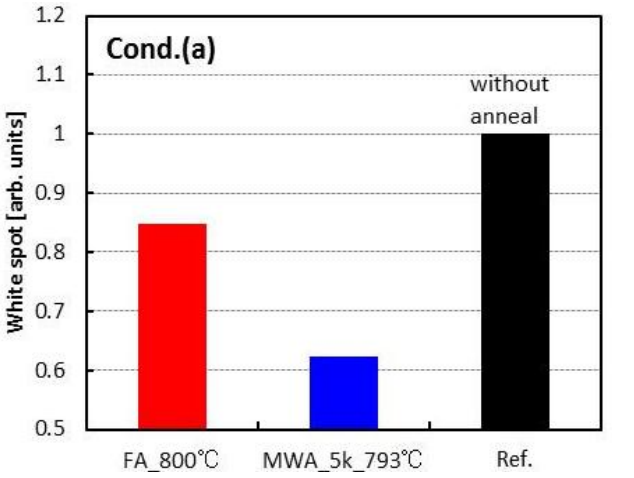

Figure 5. Comparison of the crystalline defects on each annealing condition after PD formation.

Fig. 6 shows a comparison of white spot for annealing condition after the process step of contact hole etching. Generally, FA is difficult to employ due to logic transistor performance degradation of excessive dopant diffusion as thermal treatments after contact hole etching. Therefore, the dark characteristic of MWA is compared with RTA not FA for contact formation process. The recovery effect of process damage by MWA at 652 ℃ is reduced about 15 % compared with that of RTA at 800 ℃ as shown in Fig.6.

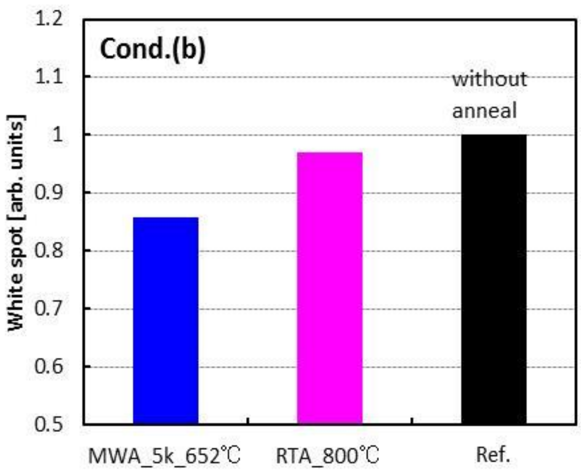

Figure 6. Comparison of the crystalline defects on each annealing condition after contact hole etching.

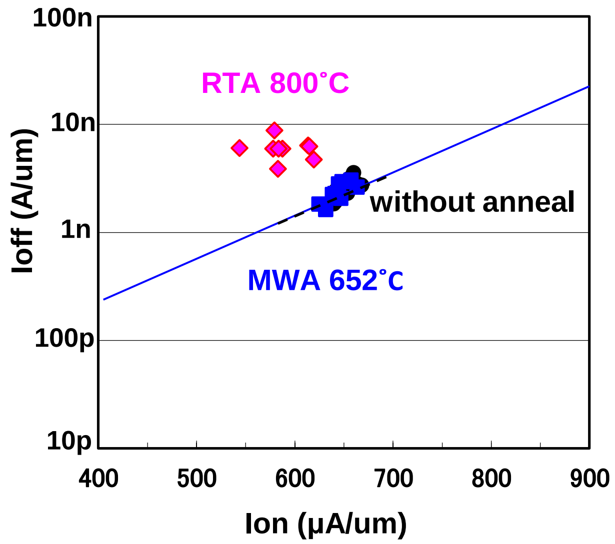

Figure 7. Ion-Ioff characteristics on each annealing condition after contact hole etching.

Fig. 7 shows Ion-Ioff characteristics for drain current of logic transistor on each annealing condition after contact hole etching. In case of RTA, the degradation of Ion-Ioff characteristic for logic transistors is observed due to its high temperature treatment. On the other hand, the dark characteristics of MWA are same as the case without additional annealing treatment, and its variation is also same tendency.

In addition, The $CoSi_2$ resistance on P^+ Poly-Si gates of the sample applied with RTA shows higher resistivity compared with MWA or reference as shown in Figure 8. It is concluded that low temperature MWA can be recovered the crystalline defects without device degradation even after silicide formation.

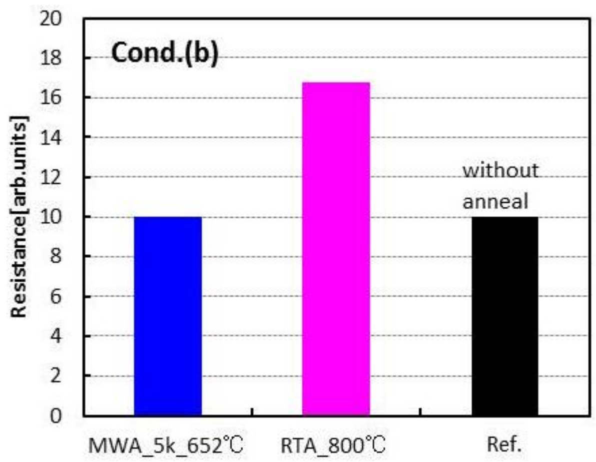

Figure 8. $CoSi_2$ resistances on P^+Poly-Si gates for by contact hole etch annealing.

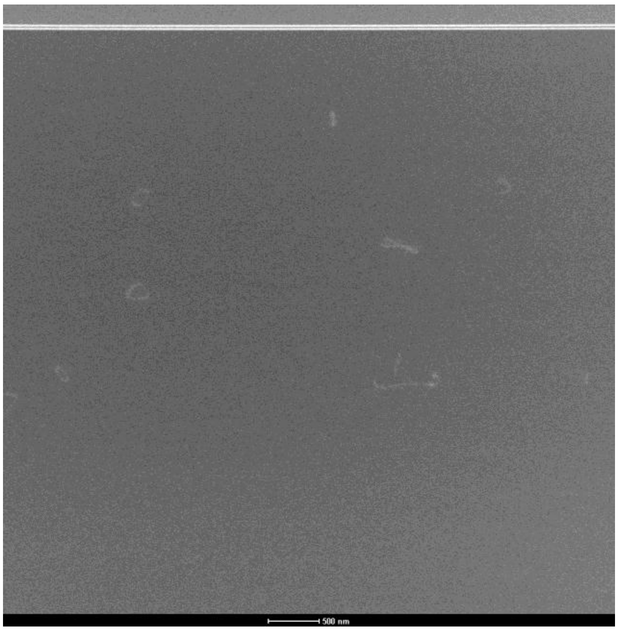

Figure 9. TEM microphotograph of RTA 1100℃ 30sec (some dislocations are observed.)

Figure 10. TEM microphotograph of RTA 1100℃ 30sec + MWA 800℃ 10min.

Fig. 9 and Fig. 10 show the cross-sectional TEM microphotograph of RTA only and RTA+MWA treatment for the well implanted samples. The dislocation loops can be clearly observed at the sample with RTA only. However these dislocations can perfectly be eliminated by utilizing MWA. The Behavior of implanted dopant after MWA treatment was presumed as Fig. 11. In the case of (a)as-implantation, lots of vacancy and interstitial-site Si are existed. The disarray of lattice absorbs the energy of MWA(b). There is the possibility of the acceleration for the replacement from vacancy to implanted ion.

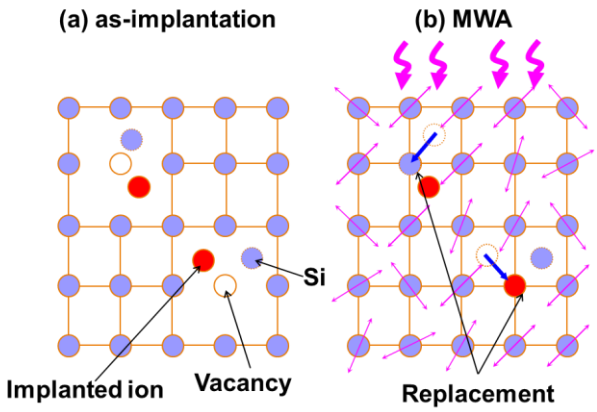

Figure 11. Behavior of implanted dopant after MWA treatment (presumption)

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 degradation. MWA is promising technique for repairing crystal defects in high performance image sensing devices with high frame rate, low power and excellent dark characteristics.

Acknowledgment

Authors would like to express their thanks to T. Tomimatsu and N. Murata for valuable discussion throughout this work. They also acknowledge A. Shida, and T. Ono for their continuous encouragement.

References

[1] F. Domengie *et al.*, IRPS (2010) pp.259-264
[2] T. Yamaguchi *et al.*, IWJT (2014) pp.19-22
[3] T. Iwai *et al.*, Proc. 36th DPS (2014) pp.135-136
[4] M. Iwane *et al.*, Proc. of 2007 International Image Sensors Workshop, pp.295-298