Fundamental Ion Implantation Technologies for Image Sensor Devices

G. Fuse, and M. Sugitani
SEN Corporation, 1501 Imazaike, Saijo, Ehime, 799-1362 Japan,
Phone: +81-50-3383-2078 E-mail: *fuse_gns@senova.co.jp*

Introduction

Ion implantation (I/I) is one of the essential technologies for image sensor fabrication. Generally it has excellent characteristics with good uniformity in dose controllability and concentration in wide ranges from 10^{15} to 10^{21}/cm^3 in implant dose and a few nm to several μm in depth. However, it shows undesirable behaviors as side effects, especially influencing to dark current and white pixels. Figure 1 shows some critical positions in CIS structure. We discuss about several fundamental contents on I/I technology for image sensor fabrication, including further demands for ion implanters.

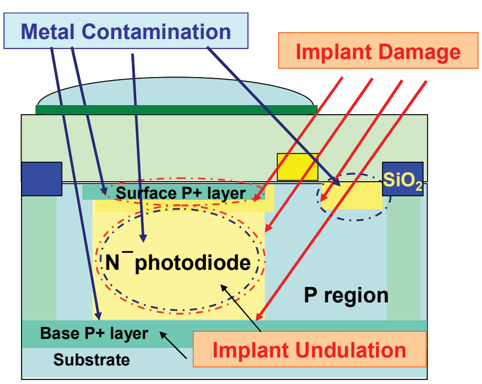

Fig. 1 CIS standard structure and issues around photodiode related to ion implantation

I. Metal contamination

Metal contamination through I/I is inevitable and very critical for image sensor devices because of enhancing dark current and white pixels. Metal contamination through I/I can be categorized in two types. One is energetic metal ions and the other is metal atoms induced by ion knock-on. How to reduce the contamination is one of the key issues of image sensor fabrication.

Metallic materials of an ion source arc chamber could be an origin of energetic metal contamination in case of BF_2 implant. If the chamber is made of molybdenum (Mo), Mo atoms is directly implanted to a substrate as doubly charged Mo ions. [1] In case of a tungsten (W) chamber, W atoms are also directly implanted to a substrate through charge exchange phenomena. [2] Since Mo contamination can not be removed Mo can not be used for image sensor I/I. On the contrary, W contamination can be rejected by a special beam line design like the MC3 series. [3] Graphite (carbon) arc chamber is desirable from a contamination point of view but it has very poor source lifetime.

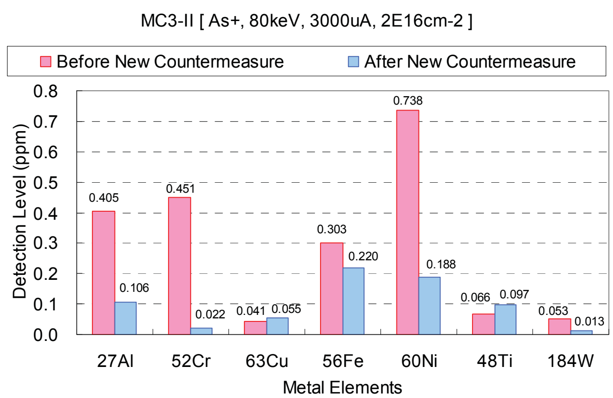

Fig. 2 One example metal data by ICPMS before and after countermeasure of metal reduction at medium current implanter, MC3-II [Ref 3]

Most metal atoms to be knocked on come from an ion implanter beam line. Figure 2 shows an improvement result of metal reduction through ion beam line modifications. Significant metal reduction was obtained as shown in Fig. 2. Results of Ti and Cu are considered to be due to difficulty of measurement in this level with ICP-MS. In order to obtain such precise ICP-MS data, special cares must be taken with many trials and errors.

Measurement accuracy is another challenge for metal contamination reduction.

In spite that an electron shower (ES) function is inevitable for beam charge-up suppression, ES is a strong source of metals due to its hot metal filament. Filament-less ES, such as radio frequency (RF) ES shown in figure 3, is a powerful solution against metal contamination.

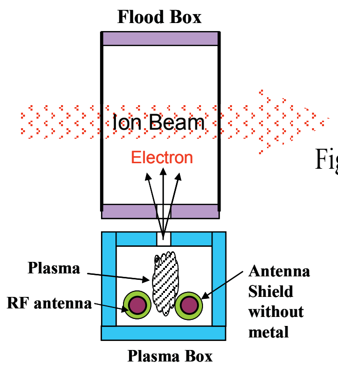

Fig. 3 Schematic drawing of a filament-(metal)-less RF-ES.
RF antenna is shielded by a non-metal dielectric material.

Metallic atoms coming from the beam line onto silicon surface are considered to be knocked on by incident ions. Figure 4 shows TRIM simulation results of a metal knock-on effect into a silicon substrate from a 3nm-thick aluminum film with two different incident ion energies. [4] At energy as high as MeV, knocked-on metal atoms are less than those at a lower energy. This fact suggests lower energy implants require a severe metal contamination control.

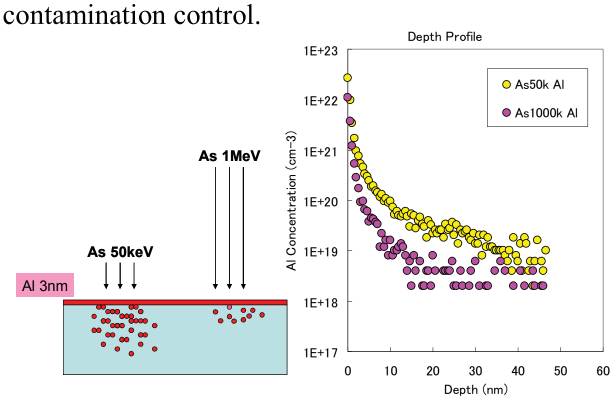

Fig. 4 Aluminum profiles of metal knock-on effect in case of silicon substrate with a 3nm-thick aluminum film simulated by Monte Carlo method (TRIM [4]) with the same dose and different energies

II. Implant damage

Implant damage also influences to dark current and white pixels. [5] While it is not well-known direct relation among initial damage level induced by I/I, the number of white pixels and a level of dark current, there is an apparent difference of the damage level induced by batch-type and single-wafer implanters. The damage created by batch implanters is much less than that by single wafer implanters as shown in Fig. 5. [6]

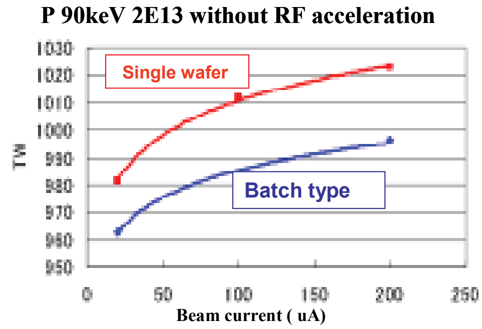

Fig. 5 Therma Wave (TW) values depend not only on beam current but also on an implanter type, single-wafer or batch-type

Figure 6 describes comparison of damage creation on a wafer by batch-type and single-wafer implanters. As well as the damage level damage distribution within a wafer by a batch-type implanter is more uniform over a wafer. In case of a single-wafer implanter, damage at the center of a wafer is different from that at both right and left sides because of reciprocal beam scan.

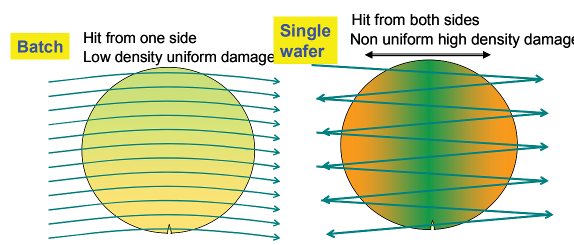

Fig. 6 Damage distribution schematic figures within a wafer by batch-type (left) and single-wafer (right) implanters

III. Dose undulation within a chip induced by beam scan

Beam scan overlap is another serious issue, influencing to micro uniformity which causes in periodical undulation in sensitivity in a chip.

Because the scan speed of single-wafer implanters is one order faster than the batch-type implanters, control of the beam shape and scan on batch-type implanters must be designed to minimize such undulation. Figure 7 shows one example for beam shape control on batch-type high-energy implanters to reduce the undulation amplitude. Slower mechanical scan is also very effective to suppress the scan undulation.

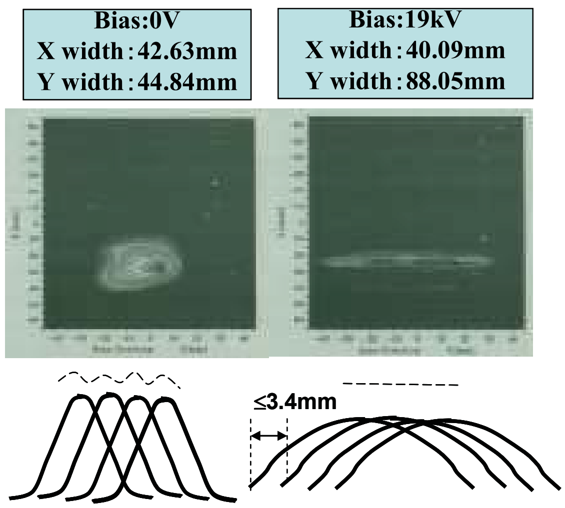

Fig. 7 Beam shapes controlled by bias voltage of Quadrupole Lens changes amplitude of undulation. Broader beam makes less undulation.

Not only affecting the undulation strength it was also reported that dark current of CCD can be decreased by this method, reducing the implant damage level. [5]

IV. Implant angle

Implant angle accuracy is also essential to avoid shadowing and to level lateral junction formation. Figure 8 shows an example of angle measurement system of a medium current implanter. Accuracy of the measurement system determines total performance of angle control.

Systematic angle deviation on batch-type implanters is well-known [7] and undesirable. However, it can be suppressed, introducing a smaller pad angle disk as shown in Fig. 9 although single-wafer implanters can provide smaller angle variation.

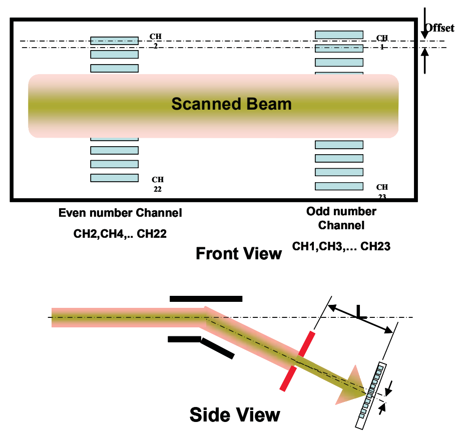

Fig. 8 Vertical beam angle monitor of single wafer implanters

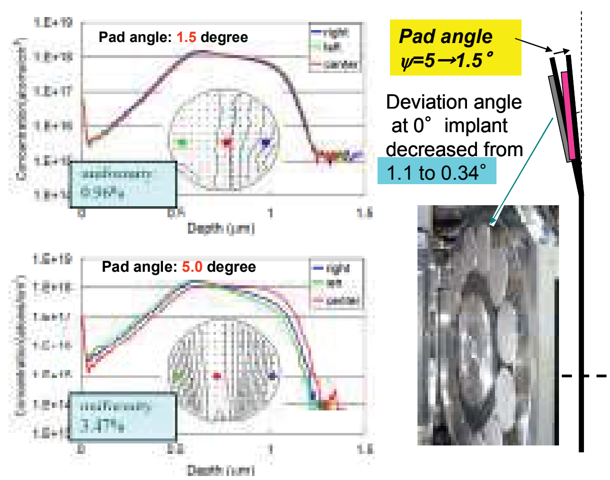

Fig. 9 Channeling profile changes in batch type implanters by reducing a pad angle from 5° to 1.5°

V. Ultralow-energy medium-dose implant

An ultralow-energy, 2 keV down to 200 eV, medium-dose, around 10^{13} atoms/cm^2, implant is expected for a surface P-type layer formation in buried photodiode fabrication. It was out of coverage of ordinary ion implanters because the energy is so low for medium current implanters and required dose uniformity is so demanding for high current implanters. Currently, a high current implanter of beam-scan type like the SHX series [8] can provide high productivity with good uniformity even in a low energy region down to 200eV or lower and in a low dose range down to 10^{12} atoms/cm^2.

VI. Ultrahigh energy implanter

Ultrahigh energy implanters are demanded to form deeper layers for higher sensitivity of photo-diodes. As shown in Fig. 10 boron implant at energy of 5 MeV and phosphorous implant at energy of 8 MeV reach 6.2 μm and 4.3 μm in depth, respectively.

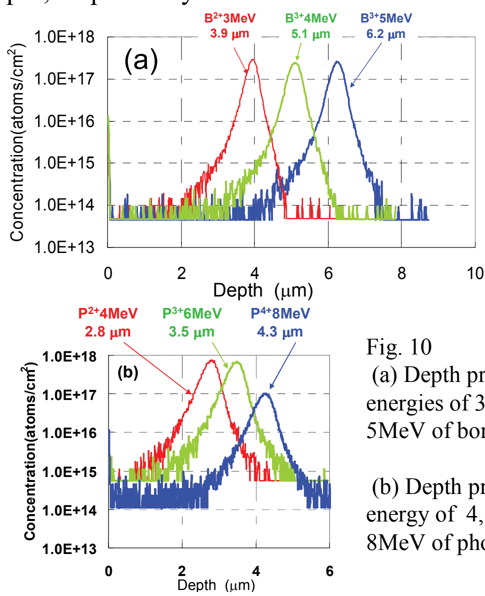

Fig. 10
(a) Depth profiles at energies of 3, 4 and 5MeV of boron,

(b) Depth profiles at energy of 4, 6 and 8MeV of phosphorous

The UHE's, radiation-free ultrahigh energy implanters with maximum energy of B and P/As are 5 MeV and 8 MeV, respectively, based on the RF acceleration technology [9] are already running in several image sensor production lines. While the UHE has a batch-type endstation, a singe-wafer type, S-UHE, will be available soon.

Conclusion

Several characteristics of I/I technology concerning image sensor fabrication are discussed. Implantation has many faces in actual use and most of them are critical for image sensor fabrication.

Even though I/I is an old technology and is able to provide superior controllability of process, evolution of devices reveals limitation of various parameters of I/I. Especially, since image sensor fabrication heavily relies on I/I, various aspects of I/I technology should be reviewed.

For instance, implanter architectures, such as batch-type or single-wafer, affect the final performance of photo cells in various aspects. The level of implant damage and accuracy of implant angles are strongly dependent on this difference. It is not discussed in detail here but there are different methods of beam parallelism and energy filtering. They are also strongly related to the level of metal contamination, the concerned level of which is now 10^8 atoms/cm^2 or less. A material of ion source arc chamber also influences to metal contamination.

Studying relations between such fundamental features of ion implanters and the final performance of photo cells, I/I technology should be fined down to meet advanced requirements from the image sensor fabrication.

Acknowledgement

Authors thank Dr. Kabasawa, Dr. M. Sano, Dr. S. Ninomiya, Mr. T. Morita, Ms. E.Oga, Mr. H. Kariya, Mr. M. Tsukihara, Mr. K. Watanabe, Mr. M. Ueno, and Mr. N. Suetsugu, for their great support and co-operation.

References

[1] Alfedo Cubina et al., Nuclear Instrument and Method B55 (1990) pp. 160-165

[2] Teuel B. Liebert et al., 11th International conference on IIT 1996 pp. 135-138

[3] M. Sugitani et al., Proc. 17th International conference on IIT 2008 pp. 269-272

[4] J. F. Ziegler, In Handbook of Ion Implantation Technology, J. F. Ziegler, Ed., Amsterdam, North Holland, 1992, pp.1-68

[5] E. Kanasaki et al., Ext. Abs. the 9th IWJT2009 S6.6 pp. 106-109

[6] G. Fuse et al., Nuclear Instrument and Method B 237 (2005) pp. 77-82

[7] Andy M. Ray et al., Nuclear Instrument and Method B55 (1990) pp. 488-492

[8] M. Sugitani et al., Proc. 17th International conference on IIT 2008 pp. 292-295

[9] N. Suetsugu et al., Proc. 18th International conference on IIT2010 pp. 369-372