Deep trench isolation via PLAD B_2H_6 passivation process for pixel scaling in advanced CMOS image sensors

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Abstract

In recent times, there has been explosive growth in use of cameras for hand-held devices as well as automotive applications, which is driving the demand for high-end CMOS image sensors (CIS). Furthermore, it is critical to improve the performance of image sensors as new applications continue to evolve. One of the key approaches to improve CIS performance and device density is pixel scaling, however, this poses some major challenges, e.g. narrowing the CD, increasing the depth of pixels and increasing the pitch can result in increased cross talk and higher dark current. Typically, deep trench isolation (DTI) scheme is utilized for passivation of the trench sidewalls to minimize dark current as well as cross talk. PLAD process (VIISTa^{TM} HVMS) has been successfully integrated for front side DTI (FS DTI) scheme and enables significant gain in key CIS device parametrics by effectively passivating the interface along the trench sidewall.[3] In this work we have evaluated PLAD technique for a back side DTI (BS DTI) scheme for the first time. Initial results demonstrate that PLAD technique can provide effective passivation for BS DTI flow, eventhough the overall thermal budget is low. Additionally, we will also discuss some of the recent developments in sidewall doping characterization techniques and the key mechanisms to further optimize conformality for high aspect ratio (HAR) trench doping.

Introduction

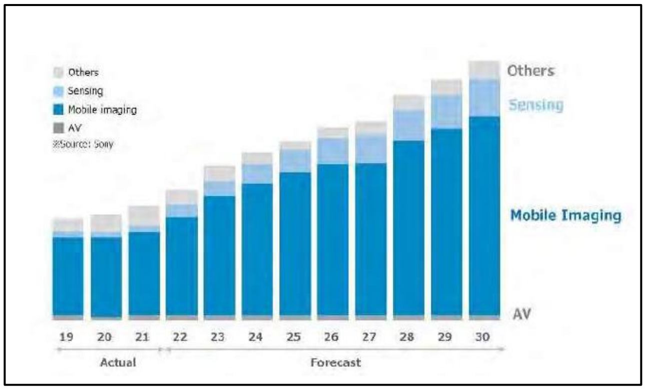

Figure 1 CIS market growth trend, mainly driven by mobile device usage. [1]

In recent times, there has been explosive growth in use of cameras for hand-held devices as well as automotive applications, which is driving the demand for high-end CMOS image sensors (CIS). Fig. 1 shows that CIS market will grow significantly over next several years.[1] Furthermore, it is critical to improve the performance of image sensors as new applications continue to evolve. One of the key approaches to improve CIS performance and device density is pixel scaling, however, this poses some major challenges, e.g. narrowing the CD, increasing the depth of pixels and increasing the pitch results in increased cross talk and higher dark current. Typically, deep trench isolation (DTI) scheme is utilized for passivation of the trench sidewalls to minimize dark current as well as cross talk. To further enhance the DTI performance of these advanced devices and increase the full well capacity (FWC), doping of sidewall using plasma doping (PLAD) has been developed.[2] PLAD process (VIISTa^{TM} HVMS) has been successfully integrated for front side DTI (FS DTI) scheme and enables significant gain in key CIS device parametrics by effectively passivating the interface along the trench sidewall.[3] In this work we have evaluated PLAD technique for a back side DTI (BS DTI) scheme for the first time. It is to be noted that BS DTI scheme has a much lower thermal budget requirement compared to the FS DTI process, thus achieving desired dopant activation level to improve the passivation performance can be quite challenging. Here we report on the process flow to incorporate PLAD process in the BS DTI flow, details of methodology to characterize interface passivation, dopant distribution along the sidewall.

Initial results demonstrate that PLAD technique can provide effective passivation for BS DTI flow, eventhough the overall thermal budget is low. Additionally, we will also discuss some of the recent developments in sidewall doping characterization techniques and the key mechanisms to further optimize conformality for HAR trench doping.

Experimental:

PLAD is considered one of the leading doping techniques for applications requiring conformal doping of HAR trench structures.[3-4] It has been in high volume manufacturing for multiple nodes in logic FinFET type devices as well as CIS devices. In this work we have evaluated PLAD technique for BS DTI using a trench MOSCAP device. Fig. 2 shows the chamber configuration for this PLAD process. Plasma is generated using a RF source and the precursor used is B2H6 gas. For implanting trench sidewall bias is applied to the wafer.

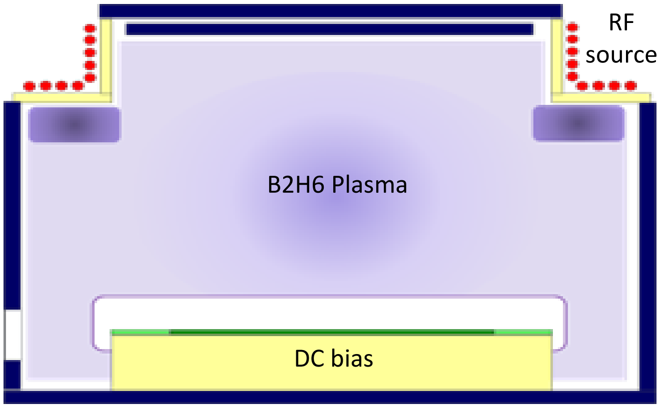

Figure 2 Schematic of PLAD chamber and process for conformal sidewall doping

Fig, 3 is a schematic of a trench MOSCAP device with the Al2O3 film as a reference dielectric to characterize sidewall passivation. In case of PLAD B2H6 based passivation, B doping is done prior to Al2O3 deposition. In this case we have systematically studied the dose sensitivity for optimal passivation. Once the B doping and Al2O3 deposition is done, metal deposition (TiN/W) is performed followed by contact pad formation for the e-test measurements.

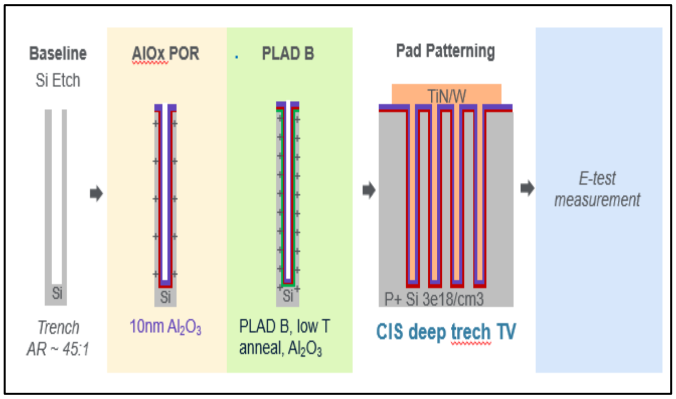

Fig. 3 MOSCAP test structure to integrate PLAD B process with CIS flow

In addition to the MOSCAP test structure, we also fabricated a trench structure for characterizing sidewall doping using PLAD B2H6 process. These were long trenches with comparable CD and HAR values. After PLAD B2H6 doping process, samples were cleaned and annealed using the reference process and then analysed using 1.5D SIMS. Initial results show this is a very effective technique to characterize dopant distribution on the trench sidewall.

Results and discussion:

Fig. 4a shows the 1.5D SIMS B profiles which demonstrates that PLAD process can conformally dope trench sidewall. It also shows that the PLAD process is tunable and retained dose increases with implanted dose. This is a unique capability which is independent of the thermal budget and critical for BS DTI type application.

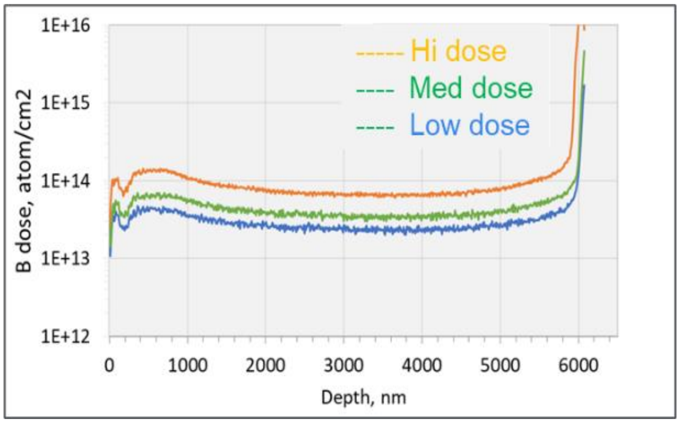

Fig. 4a 1.5D SIMS showing conformal of doping of sidewall with PLAD B_2H_6 process

Based on these initial learnings we performed detailed experiments to characterize effect of B doping on deep trench isolation performance. Preliminary results shown in fig. 5a demonstrate significant increase in hole(h) concentration can be achieved with PLAD B_2H_6 process and relatively low temperature anneal step. Hole conc. achieved with B doping is considerably higher than the performance achieved with the reference Al2O3 film. Additionally, it is evident from fig. 5b that increasing implanted B dose can shift the Gp/w peak voltage beyond typical photo diode operation voltage ~ 2.5V. Overall, this study demonstrates that PLAD is an effective solution for conformal doping of HAR trench sidewall structures and achieve excellent passivation.

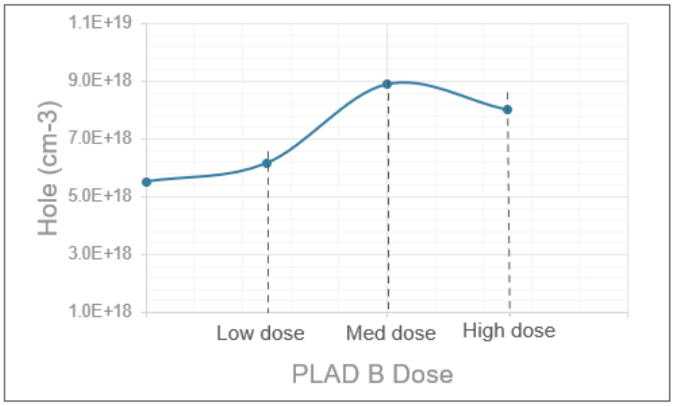

Figure 5a h conc. increases with PLAD B_2H_6 implanted dose, which indicates effective passivation of trench sidewall

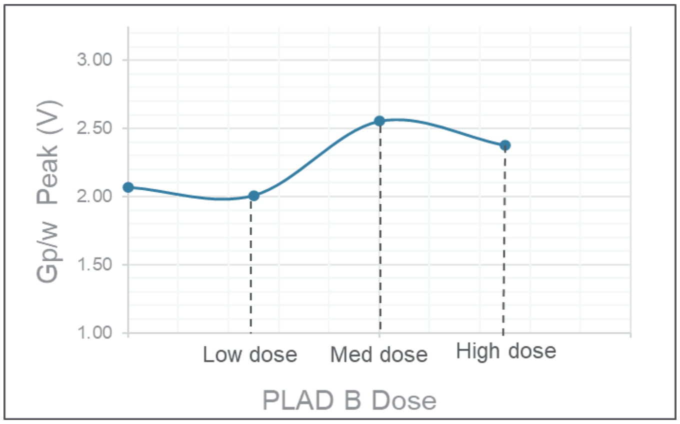

Figure 5b Gp/w peak voltage can be shifted >2.5V, which is typical image sensor operating voltage, confirms effective passivation of trench sidewall

Next we also evaluated effect of advanced anneal for this new scheme and results are shown in fig. 6. With the use of dynamic surface anneal (DSA) h conc. can be further increased as well as improve the dose sensitivity. PLAD B2H6 process along with low T anneal is an attractive solution for BS DTI application and further work is in progress to optimize the process flow.

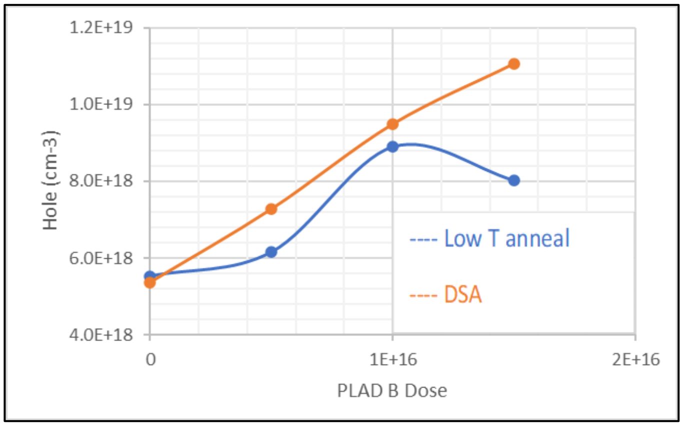

Figure 6 h conc. increases with PLAD B_2H_6 + DSA, which indicates further improvement in passivation of trench sidewall compared to the low T anneal process

Conclusion:

In this study a new integration scheme using PLAD B2H6 process for BS DTI has been evaluated and the results show significant benefit in terms of passivation performance. It is demonstrated that new

PLAD B2H6 based process flow yields higher hole concentration relative to reference process, which is attributed to effective B doping of trench sidewall. PLAD B2H6 has been adopted for FS DTI process for multiple nodes of CIS device manufacturing, albeit with high thermal budget. Its to be noted that for BS DTI scheme thermal budget is quite low, thus it's a significant development to be able to integrate PLAD B2H6 process for improving passivation performance. Latest 1.5D SIMS results show that PLAD process can conformally dope the trench sidewall. These results also show that the B profile and retained dose can be modulated with implanted dose, which is an unique capability for BS DTI type application with thermal budget constraints. Overall, this study demonstrates that PLAD is an effective solution for conformal doping of HAR trench sidewall structures and achieve excellent passivation. This new PLAD based approach is also scalable and critical for next generation CIS device development.

One of the key learnings from this work is that PLAD process offers wide process window for controlling B doping conformality. With the capability to optimize retained dose, conformality and depth profile offers an opportunity to address varied range of applications based on HAR structures. [4-6] Work is in progress to further improve DTI performance as well as new HAR trench sidewall doping applications.

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