UV Response, EB-Gain Stability of Back Side Illumination CCDs

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Abstract

We have been investigating back side CCDs which have high sensitivity for UV light and electron beam. When the back side CCDs are developed, there are three key points. These are thinning, protection and activation. The silicon material has to be thinned down to 10~15μm. Therefore, when the back side activation is applied, some protective construction must be given. And this thought would lead to a necessity of a low temperature activation. It will be so wasteful of time and cost if genuine CCDs are used to find the activation condition. We tried to use photodiodes instead of the CCDs to find the best process for the back side CCDs. The photodiodes have almost the same structure with back side CCDs such as resistivity, thickness and dimensions. For the thinning and the protection of the membrane, we have developed and completed the process. Using simple photodiode, we could advance the experiments very efficiently.

Heretofore, two main methods have been introduced to give a back side activation. One is a deposition of some material on the incident back side and another is making a P+ region in the incident back surface by ion implantation. Regarding the a former methods, we tried to use several materials and methods. Concerning the latter methods, we optimized the impurity concentration and subsequent annealing methods. As the evaluation of these activations, we measured UV sensitivity and electron bombardment gain, and obtained promising results from both the deposition methods and the ion implantation methods.

Introduction

The CCDs feature very low noise, high sensitivity, high resolution for visible light. To take advantage of UV light and electron beam, a back side illumination type is indispensable. The purposes of this study are to get high and stable sensitivity for the scientific and the astrophysics applications.

Commercially available CCDs now are the front illumination type. The virtual phase CCDs has some possibility[1]. But it can't always meet the demands. The other way to get the sensitivity is depositing a scintillation phosphor on the incident side of the CCDs[2]. But handling of this organic material is very difficult.

The best way to obtain the sensitivity is to irradiate the rays from the back side of the CCDs[3][4]. On the back side, there is no obstacle such as poly-silicon electrodes or some passivation films. For the back side CCDs, thinning of the back side, protection of the membrane and activation of the back side is necessary.

A common characteristic of UV light and electron beam is that these two rays are absorbed at the surface of the incident material. So, the photo-carrier-transfer is important matter. The factors which determine the photo-carrier transfer are the membrane thickness and the activation of the back side.

The preferable thickness of the membrane is 10 ~ 15μm. This thickness is fitted for the photo-carrier's diffusion length and the resolution of an image. Before this step, a solid support for the membrane must be employed lest the membrane should be broken during the thinning process or subsequent activation process.

Then a back side activation is done. In the back side CCDs, the word of "activation" means a "built-in potential in a CCD" which drives photo-carriers off the back surface and sweep them to the CCD's signal accumulation region. Until now, two main categories have been introduced to make the built-in potential. One is deposition of some materials on the incident back side and make a accumulation layer. Another is making P+ thin region in the back side by ion implantation.

The representative methods of the deposition are so called flash-gate and photon-emission-charging[5][6]. On the point of a low temperature process, these methods are attractive. But there might be some problems especially in terms of a stability. Here we'd like to propose a new method which might belongs to this category. That is deposition of a wide band gap semiconductor on the incident silicon material.

The ion implantation methods are thought to be a steady activation[7][8]. In the past, a high temperature process was used as the anneal. But as mentioned before, annealing process after the ion implantation must be done under 500℃. We made use of a low temperature anneal and a excimer laser anneal.

We procured promising results from the deposition of the wide band gap semiconductor, ion implantation with the low temperature anneal and ion implantation with the excimer laser anneal.

1.Activation of the back side

A certain protective construction for the membrane has already been adopted, the activation for the incident back side must be done under 500℃. To avoid the degradation of the aluminum, a thermal treatment under 500℃ is necessary.

For the deposition methods, a P-type wide band gap semiconductor was accommodated as the deposition material and deposited on the P-type incident back side silicon. For comparison, a sample which deposited a scintillation phosphor was also prepared.

For the implantation methods, "Boron I.I. + low temperature furnace anneal (LTA)", "Boron I.I. + excimer laser anneal (ELA)" was examined. "Boron I.I. + high temperature furnace anneal (HTA)" was also tested for comparison. The specification of each samples is as follows.

A lumogen yellow was used as a scintillation phosphor. This is the most brief way to get the UV sensitivity. The lumogen yellow absorbs 200～500nm photons and emits 500～600nm light.

Deposition of a wide band gap semiconductor on the thinned back side is really a brand new method. The deposited semiconductor must have a larger work function rather than silicon as well. We have tried "P-type a-Si (Eg = 1.65eV)", "P-type a-SiC (Eg = 1.9eV)" and "P-type c-CdTe (Eg = 1.45eV)". The leading candidate for UV light was the "P-type a-SiC". The deposition of the a-SiC is capable of around 300℃. When the P-type a-SiC is deposited on the P-type c-silicon, the conduction band of the P-type silicon is bent to upward and preferable built-in potential for photo-electrons is made. Thus the photo-electrons generated near the back surface are naturally flow into the CCD's signal accumulation well.

The "LTA" was carried out. At first, a 900 angstroms buffered SiO_2 was grown. Then boron was implanted at room temperature. The energy was 33 keV and the dosage was 1×10^{15} cm^{-2}. At last, a anneal was done for 60 minutes in a 500℃ furnace.

The "ELA" was carried out. The condition of the implantation was exactly the same as "LTA" sample. A anneal was done by excimer laser (Hamamatsu; 248nm, 1.2 J/cm^2/shot). Because the area of a shot was about $1mm^2$, a scanning function was necessary.

The "HTA" was achieved. The condition of the implantation was exactly the same as "LTA" and "ELA". A high temperature anneal was done for 30min. in a 1000℃ furnace.

2.UV sensitivity enhancement by deposition.

Fig.1 shows spectral response curves of the UV sensitivity enhanced by depositions.

The lumogen yellow expresses relatively high UV sensitivity. The sample of a thin a-SiC deposition reveals very high UV sensitivity. And this method completely overcomes with the lumogen yellow's faults.

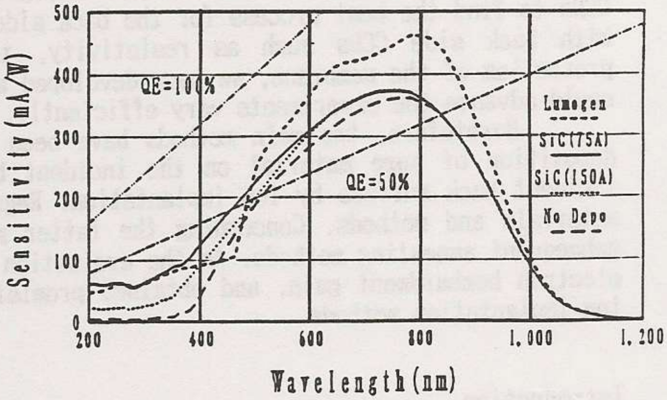

Fig.1 Spectral response curves for UV enhanced deposition samples.

Fig.2 represents UV sensitivity degradation after a irradiation of the D_2 lamp. The luminosity of the D_2 source was approximately $1mW/cm^2$, then this was accelerated life tests.

Very thin a-SiC deposition(≦ 100 angstroms) shows relatively rapid deterioration of the UV sensitivity. But as showed in fig.2, the a-SiC thickness over 100 angstroms gives a constant UV sensitivity. The thickness of the a-SiC in fig.2 is 200 angstroms. While the lumogen yellow sample gradually loses the UV sensitivity according to the increase of the D_2 exposure.

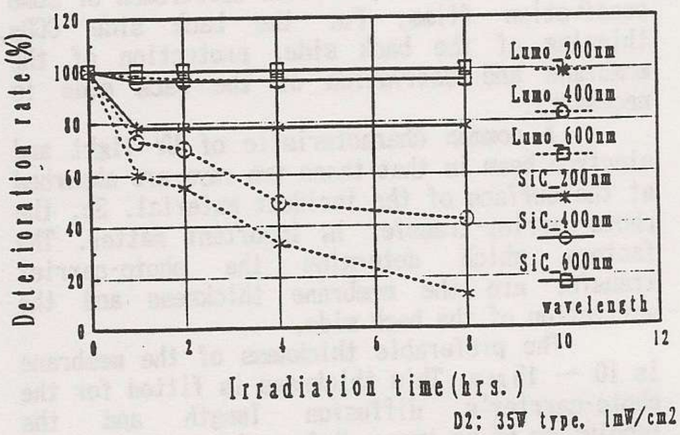

Fig.2 UV sensitivity deterioration

3. Enhanced UV sensitivity and EB-gain by ion implantation.

3.1 UV type

Fig.3 expresses spectral response curves. The incident side of these samples have boron implanted activations. Ion implantation requires subsequent heat treatment in order for both the activation of the impurities and the annealing of the implant damages.

As is evident, the "HTA" reveals high UV sensitivity. On the contrary, no UV response was procured from the "LTA" sample. Fig.4 represents spreading resistance measurements. For the "LTA", the dosage rate is extremely low compared with the "HTA".

The sample of the "ELA" shows 50～100mA/W UV response. Notice that across the whole wavelength, the sensitivity of the "ELA" sample exceeds the "HTA" sample.

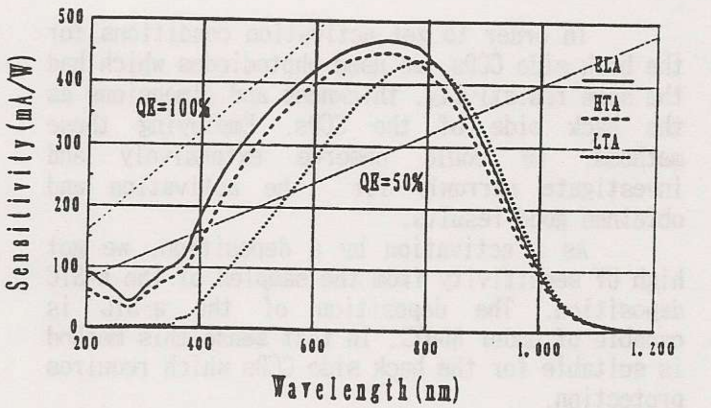

Fig.3 Spectral response curves for UV enhanced ion implantation samples.

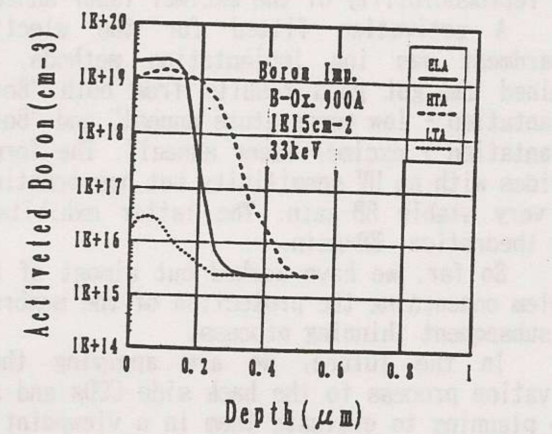

Fig.4 Spreading resistance measurements

3.2 Electron bombardment (EB) type

Fig.5 expresses EB-gain vs incident electron energy for different samples. The "LTA" activation wasn't suited for the UV high sensitivity type. But the "LTA" is applicable for the EBS type.

The "ELA" samples has near theoretical EB-gain than the "HTA" samples. Fig.6 reveals initial EB-gain aggravations. The total incident charges of the electron irradiation was 1.5×10^{-5} C/mm². The energy was 10keV. The "LTA" and the "ELA" samples indicate very stable EB-gains. In comparison, the "HTA" sample shows relatively rapid deterioration of the EB-gain. The dopant redistribution at the surface caused by the high temperature anneal might lead to the rapid deterioration. A sample without back side activation (no implantation) shows less EB-gain at initial and rapid degradation of the EB-gain after the irradiation.

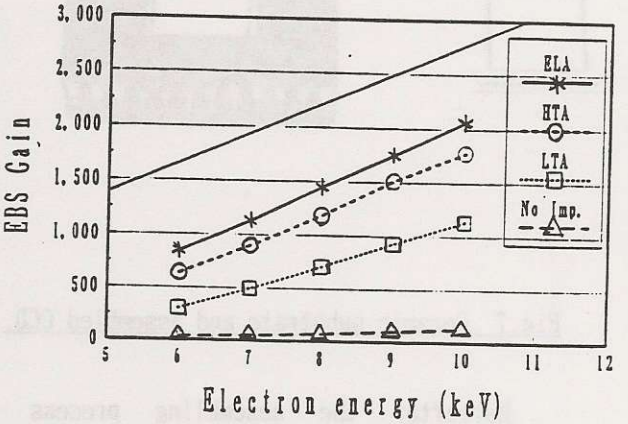

Fig.5 EB-gain vs incident electron energy.

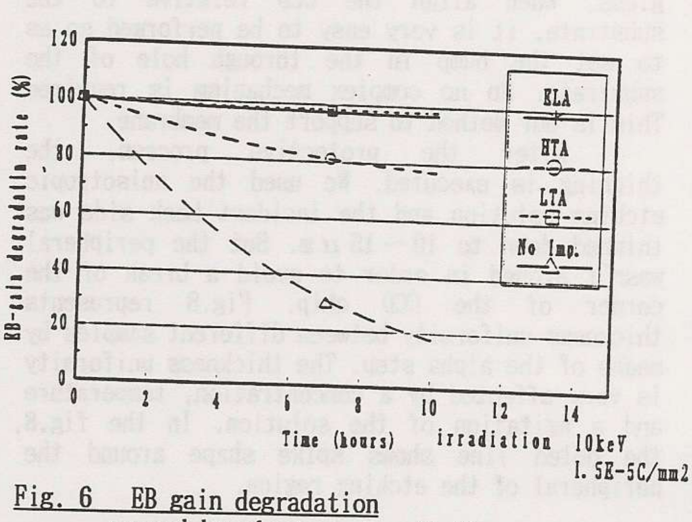

Fig. 6 EB gain degradation caused by electron irradiation.

4. A protection of the membrane and subsequent thinning process.

After certain protection is supplied, a thinning and activation for the back side should be done. These experiments were performed by CCD chips. The protective process we want to employ is as follows.

The CCD chip which includes aluminum interconnection on the front side glues on a ceramic substrate. A substrate has metallize small through holes according to the place where exist bonding pads of the CCD. Fig.7 shows the CCD affixed to the substrate and the assembled back side illumination CCD.

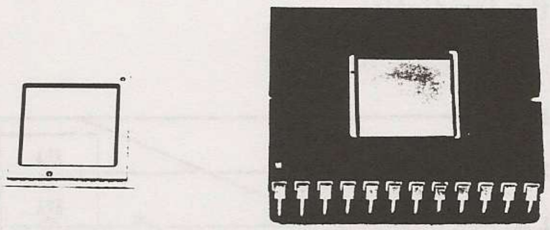

Fig.7 Ceramic substrate and assembled CCD.

Hereafter the assembling process is explained. First of all, gold bumps are laid on the bonding pads of the CCD. Then the CCD glues on the substrate by the low temperature fusing glass. When align the CCD relative to the substrate, it is very easy to be performed so as to set the bump in the through hole of the substrate. So no complex mechanism is required. This is our method to support the membrane.

After the protective process, the thinning is executed. We used the anisotropic etching solution and the incident back side was thinned down to 10～15 μm. But the peripheral wasn't etched in order to avoid a break of the corner of the CCD chip. Fig.8 represents thickness uniformity between different samples by means of the alpha step. The thickness uniformity is very affected by a concentration, temperature and a agitation of the solution. In the fig.8, the doted line shows spike shape around the peripheral of the etching region.

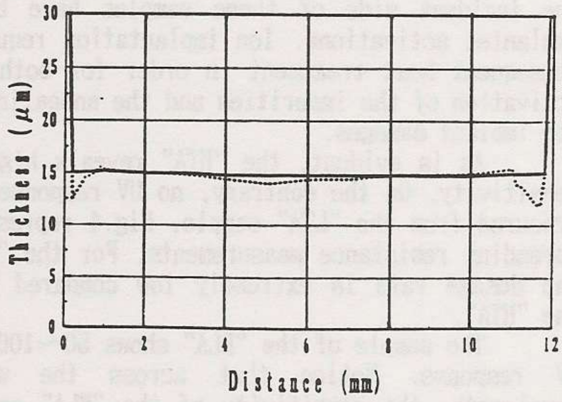

Fig.8 Thickness uniformity of membrane

5.Summary

In order to get activation conditions for the back side CCDs, we used photodiodes which had the same resistivity, thickness and dimensions as the back side of the CCDs. Employing these methods, we could observe extensively and investigate narrowly for the activation and obtained good results.

As a activation by a deposition, we got high UV sensitivity from the samples of the a-SiC deposition. The deposition of the a-SiC is capable of under 300℃. In that sense this method is suitable for the back side CCDs which requires protection.

As a activation by means of a ion implantation, results were dependent on the anneal methods. The excimer laser anneal sample expressed excellent UV sensitivity. Now we are trying to investigate the sensitivity uniformity and reproducibility of the excimer laser anneal.

A activation fitted for the electron bombardment was ion implantation methods. We examined and got good results from both "Boron implantation + low temperature anneal" and "Boron implantation + excimer laser anneal". The former provides with no UV sensitivity but has practical and very stable EB-gain. The latter exhibits a near theoretical EB-gain.

So far, we have worked out almost of the problem concerning the protection of the membrane and subsequent thinning process.

In the future, we are applying these activation process to the back side CCDs and are also planning to evaluate them in a viewpoint of images.

6. Acknowledgement

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