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Diffusion of buried contact grooves with spin-on source

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스핀 온 소스를 이용한 함몰형 전극 형성을 위한 확산

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Abstract The present processing sequence for solar cells is very elaborate and adds to the cost of the fabricated cells. This processing cost, which accounts for about 30 % of the total cost, can be reduced if the many high temperature sequences can be reduced without significantly reducing the cells energy conversion efficiency. By using the spin-on glasses (SOG) in conjunction with the conventional tube furnace (CTF) or rapid thermal annealer (RTA), the many high temperature processes can be reduced to only one. In order to achieve efficiencies similar to the standard high temperature sequences using the solid or liquid sources, some basic characterization of the groove diffusion is necessary to ascertain the its suitability. This paper describes the work done in diffusing the buried contact grooves using the phosphorus SOG.

요　약 태양전지의 공정중 고온공정을 줄여줌으로서 최종 태양전지의 가격을 저가화할 수가 있다. 이 논문은 점액 상태의 인을 희석시켜서 접촉 홈에 확산공정을 마친 후, 그 기본 특성을 조사하였다. 점액상태점의 희석도와 스핀속도가 산화막의 두께에 영향을 미치는 것이 확인되었다. 희석도가 높을수록 산화막은 두꺼워지고 균일도는 낮아졌다. 희석도 60 %의 인이 홈에서의 균일도와 깊이를 고려할 때 가장 적당한 것으로 사료된다.

1. Introduction

The doping of semiconductors by diffusion from oxide layers is a well established technique in semiconductor processing [1-3]. The doped oxide layer is normally deposited on the semiconductor surface by spin-on process and driven-in at temperatures between 800~1000℃ at a pre-determined time. However, the application of the silicon dioxide films containing controlled amount of electrically active dopant impurities to solar cell processing is receiving considerable attention in recent time because of the need to reduce the cost of solar cell fabrication. Especially, the application of these films to opposite sides of the wafer permits both the top (emitter formation) and bottom (back surface field) diffusions, thus, the simultaneous diffusions of dopants with one high temperature [4]. This effectively cuts in half the time and thermal energy expended for the diffusions necessary for the processing of solar cells by the conventional practice. The drive-in step is usually carried out in a conventional tube furnace (CTF) but in recent time, the RTA is desired because of the need to further cut down cost on thermal energy budget.

The RTA relies on high intensity visible radiation produced by tungsten-halogen lamps, although there are variations employing the infra-red and ultra-violet spectrums. Extremely fast heating rates of the order of 200℃/s are possible with this technique, resulting in processing times measured in seconds or at the most minutes. Such short time periods allow low overall thermal budgets and power consumption. Results with RTA indicate that the quality of junctions formed can be as good as those obtained with the CTF [5].

The use of RTA and spin-on sources for groove diffusion has not been done prior to this work, but the use of CTF and spin-on sources for solar cell fabrication was reported by Ebong et al [4]. The low open circuit voltages (V_{oc}) and efficiencies reported in that work were blamed on the possible non-uniformity of the groove diffusion which might have been caused by high viscosity of the spin-on sources. In order to properly ascertain this fact, the diffused region of the grooves needed to be characterized with reduced viscosity of spin-on sources by dilution with isopropyl alcohol. Also, the uniformity of spin-on on planar surfaces using various dilution levels needed to be investigated for the case of lightly doped emitter. This paper discusses the groove diffusion (both uniformity and depth) using phosphorus spin-on diffusion source diluted to different dilution levels. Also discussed is the drive-in step as done in both RTA and CTF.

2. Buried contact groove diffusion

One of the most distinguishing features of the buried contact solar cell (BCSC) [6] is the heavily diffused grooves for metal contacts. The groove diffusion is carried out to isolate the active regions of the cell from the metallized areas in the grooves. It also provides a low ohmic contact resistance between the silicon and metal in the grooves. The very low recombination rate of the minority carriers in the grooves enhances the high open circuit voltage capabilities of this structure.

These grooves, however, have been diffused using, only the CTF with the solid or liquid sources except the last work reported by Ebong et al [4] which made use of spin-on diffusion sources in the CTF. This often lead to extensive processing time which normally adds to the cost of solar cell production. The use of spin-on glasses which would lead to only one single high temperature processing is of great importance, especially now, with the need to reduce the cost of a solar cell to make electricity generated by the device very cost effective.

3, Experimental

It is very important for the groove diffusion to be uniform in order to uniformly isolate the metal contacts from the active region of the cell. It is also important to have a uniform emitter for the fabricated cell. These requirements for solar cell fabrication necessitated the investigation of the uniformity of the spun planar surfaces as well as the groove regions with various dilution levels. In thess experiments 2.25 inch planar, p-type, 5 Ω·cm, substrates were use.

3.1. Uniformity of spun planar surface

The wafers were cleaned in the RCA 1 and RCA 2 solutions before the spin-on (phosphorus) source diluted with isopropyl alcohol to diffusion dilution levels including 10 %, 20 %, 60 %, 80 % and 100 % (pure source without alcohol), was spun at 3500 rpm (revolution per minute) for 15 seconds. The wafers were then baked in an oven flushed with nitrogen gas at 150℃ for 20 minutes to remove all the liquid in the spun film, and finally driven-in using both the CTF and TRA. The drive-in temperature varied from 800℃ to 1100℃.

3.2. Groove diffusion depth

The wafers used were cleaned and oxidized at 980℃ for oxide thickness of 3000~3500 Å. The grooves on the wafers were scribed using the laser (Nd-YAG), chemically etched with KOH to remove any silicon debris in the grooves, and then cleaned to neutralize any contaminants present on the wafers. The spin-on sources (from Emulsitone company in USA) in liquid form were used for the groove diffusion. The concentration for phosphorus spin-on source was 1×10^{20} atoms/cm^3 and dilution to various levels was achieved with the use of isopropyl alcohol. The wafers were then placed on the spinner and three drops of the spin-on source was applied and then spun at 3500 rpm for 15 seconds to cover the wafer surface with the dopant. It was then baked in an oven (in nitrogen ambient) at 150℃ for 20 minutes to get rid of the alcohol before the drive-in step.

The high temperature drive-in was carried out in both CTF and RTA. The RTA used for this work was HEATPULSE 410, manufactured by AG Associates. It employs upper and lower tungsten-halogen lamps for heating wafers of various sizes. Wafers spun with various dilution levels of phosphorus were kept in the conventional tube furnace for 3 hours and RTA for 60 seconds at two diffusion temperatures, namely 900℃ and 1000℃. Samples were then cut into pieces (5×10 mm) with each piece containing some grooves to be characterized.

The technique used for the characterization comprises of epoxy mounting, beveling and staining as described by Huang et al [7]. The staining method is designed specifically for semiconductor junction depth measurement. The resin, Araldite D and hardener, HY 956 were thoroughly mixed together at room temperature to mount the sample at a known angle in one or two dimensions. Samples were beveled to expose the junctions and a conventional Safe-T-Stain solution (copper sulphate solution) was applied to delineate the region of a p-n junction under illumination. The solution stains n-type silicon dark and leaves p-type silicon unstained. The depth of the groove diffused region was then calculated by using a calibrated microscope after delineation.

The depth of groove diffused region was calculated according to [6] by the formula

$$T_{diffusion} = (W_{diffusion}/W_0)T_0$$

Where $T_{diffusion}$ and $W_{diffusion}$ are the actual depths of groove and groove diffused region. T_0 and W_0 are the depths of groove and groove diffused region measured under the microscope.

This method of diffusion depth measurement has got some difficulties as explained by Huang et al [7]. However, this method was applied here as a rough estimate and may not be free from errors. The objective of this work was not the accurate measurement of the groove diffusion depth but an estimate of the exent to which the dopants might have diffused and the overall uniformity to ascertain the complete isolation of the metal contacts.

4. Results and analysis

4.1. *Spun surface uniformity*

The sheet resistivity for each sample was measured at five different points and the average value recorded. The variation of the average sheet resistivity as functions of the drive-in temperature and dilution levels are shown in Fig. 1 to 3. Figures 1 and 2 are those for the CTF while Fig. 3 is for RTA. The most important observation made here was that, the higher the viscosity of the spin-on source, because the spun oxide in thick-

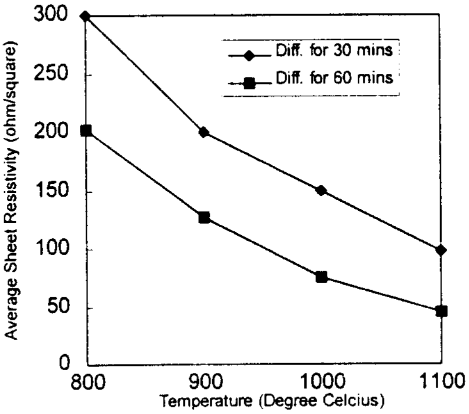

Fig. 1. Variation of average sheet resistivity with drive-in temperature in a conventional tube furnace.

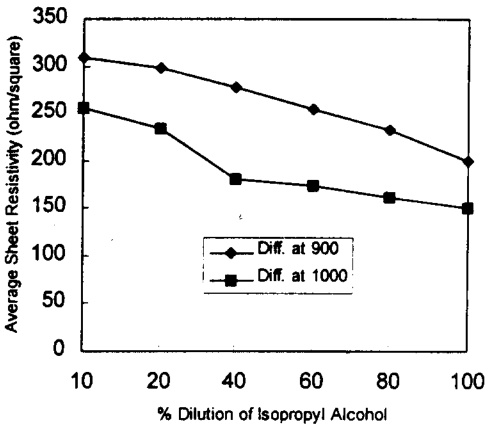

Fig. 2. Variation of average sheet resistivity with percentage of dilution for phosphorus spin-on diffusion source (drive-in was done in a conventional furnace).

er, the poorer the surface unifromity and the heavier the doping as indicated by all the three graph.

Comparing Fig. 2 and 3, the trend in the average sheet resistivity versus temperature and dilution levels for both conventional tube furnace and RTA are the same. The lower the dilution level (that is with more phosphorus in the source than alcohol) the higher the sheet resistivity. At 900℃ temperature, both the RTA and CTF diffusion gave identical sheet resistivities for the 100 % phosphorus. However, at 1000℃, the sheet resistivity for the RTA process was lower than the conventional tube furnace. Thus, a short time of 30 seconds with RTA is good enough, at 1000℃, to produce the same effect as that obtained with the conventional furnace for 30 minutes.

Thus, by using a 10 % phosphorus solution (90 % dilution with isopropyl alcohol)

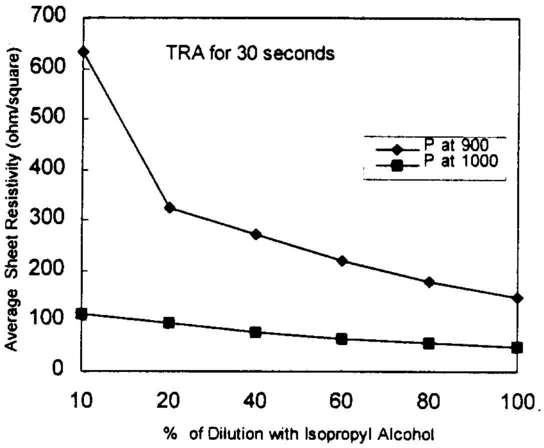

Fig. 3. Average sheet resistivity as a function of dilution level of phosphorus spin-on using RTA.

and RTA at 1000℃ for 30 seconds, it is possible to obtain sheet resistivity in the vicinity of 113 Ω/□, which is suitable for solar processing. This means that, the simultaneous formation of both emitter and back surface field could be done in RTA with results similar to those of CTF.

4.2. Groove diffusion depth

Figures 4 and 5 give the variation of average groove diffusion depth with spin-on dilution levels for CTF and RTA respectively. It should be noted that, the depths of the diffused groove regions are average, as some portions of the grooves are thinner than others and some, especially the undiluted (100 % dilution) spin-on, did not even show any evidence of phosphorus diffusion. It was also observed that, the higher the dilution level, the better the uniformity

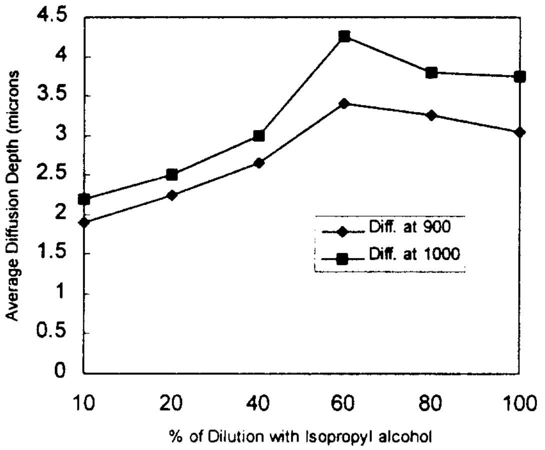

Fig. 4. Groove diffusion depth as a function of dilution level for CTF.

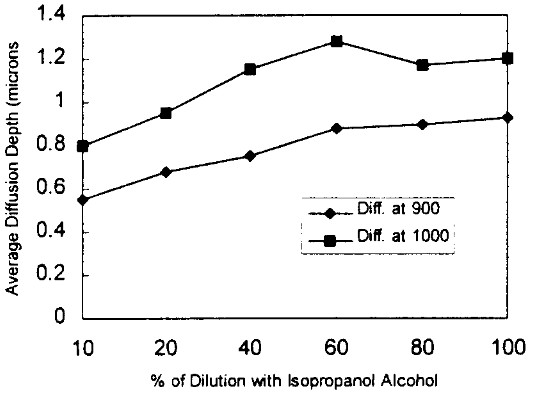

Fig. 5. Groove diffusion depth as a function of dilution level for RTA.

of diffusion in the grooves. Also, the groove depth decreases with increasing dilution level. However, the best uniformity and groove depth was obtained with the 60 % dilution level. This could be explained by the fact that, at this dilution level, the viscosity of the spin-on source is such that it penetrates uniformly well into the grooves and the dopant was adequate during the drive-in step.

It would be expected that the higher concentration spin-on (100 % level) would give a greater junction depth by virtue of the 'phosphorus push'. This is where a high surface concentration of phosphorus helps drive it further into silicon. Since this dilution level did not give the maximum groove diffusion depth, then, some other mechanism must come to play. One possibility is that, the higher concentration spin-on source did not penetrate well enough into the grooves (which were only 25~30 μm wide) because of the increased viscosity relative to the 60 % dilution level. The fact that the 10 % dilution level samples gave the lowest groove diffusion depth could be explained by the lack of sufficient dopant present in the source (90 % of which was isopropyl alcohol). This dilution level could be good enough for the emitter formation which needs to be very light and not groove that requires at least two microns depth to properly isolate the metal from the active region of the cell.

5. Conclusion

The characterization of the spin-on source by diluting it to different levels have indicated that, the 10 % dilution level is quite good for emitter formation. This trend was common to both the CTF and RTA. Differences in the dilution levels of the spin-on source may also account for some of the groove diffusion non-uniformity. As in the case of groove diffusion depth, the viscosity of the liquid reduces with increasing dilution. Thus, while the application of an undiluted dopant may result in insufficient dopant entering the grooves, a highly diluted (10 % for instance) might result in the liquid sitting at the bottom of the grooves with very little of it remaining at the top. A 60 % phosphorus level is therefore probably the best choice regarding the groove diffusion uniformity and depth.

The study has enabled us to have some information on the effect of the spin-on source viscosity on the uniformity of the spun planar surfaces. This effect had been reduced by diluting the source to a level applicable to a particular process as may be necessary. It should be noted that, the dilution level of the spin-on source as well as the spinner speed affect the oxide thickness. Thus, the higher the dilution level, the thicker the oxide and the poorer the uniformity and vice versa.

The results from this work is very promising, even though the values given for the groove depth may not be to accurate but could be considered as pointer to what is required to diffusing a groove when using spin-on sources. Most importantly, the similar trends in groove diffusion for both the CTF and RTA would lead to a cost effective one high temperature processing of the buried contact solar cell.

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