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Emitter Passivation Properties of PECVD Silicon Nitride on Silicon Solar Cells

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Abstract

As industrially produced solar cells become thinner and more efficient, silicon nitride (SiN) films are becoming increasingly important. At present, the favored means of producing these films is by remote plasma-enhanced chemical vapour deposition (RPECVD). In this paper, using films produced by an industrial Roth & Rau SiNA RPECVD reactor, we investigate the surface passivation qualities of SiN films on phosphorus emitters. In industry, these SiN films are regularly subjected to anneals during metalisation. As such, we have endavoured to understand the effect that annealling has on the SiN films and seek to determine the most appropriate annealling conditions to optimise the surface passivation qualities of SiN on phosphorus emitters. Inital annealing results have shown an average 64% increase in surface passivation across the range of refractive indices tested. In addition, a decrease in the standard deviation of the results indicates that annealing increases the uniformity of the surface passivation of all films. Our best result is J_{oE}=60fA/cm^2, for an emitter with R_{sheet}=64Ω/sq, which corresponds to a potential V_{oc}=707mV. Of most significance to industry is our worst result. With a J_{oE}= 167fA/cm2, even our worst surface passivation is well above what can is achieved with the standard industrial solar cell .

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Additional Information

In many ways, SiN films are seen as a silver bullet to many solar cell production problems. With near ideal anti-reflection properties, surface and bulk passivation properties, the ability to prevent shunting of the pn junction during metallisation, and a simple means of incorporating it into the fabrication process, the urge to introduce this technology into silicon solar cell production is great. However, despite the many papers published on the virtues of SiN films, our understanding of the optimal production and processing of these films is sadly lacking. To make matters more complex, the properties of all SiN films can change drastically depending on their means of depostion. Keeping in line with current industry trends, we have used the state-of-the-art technology available to industry in the form of a Roth and Rau SINA RPECVD reactor for our experiments. Remote PECVD reactors are renown for their excellent surface passivation properties, and this particular reactor incorporates this feature with the industrial requirements of high throughput and excellent uniformity. As such, our results will be directly benefial to the industrial cause of producing more efficient solar cells.

Though many papers have been published about SiN's passivation qualities on silicon wafers (Cuevas et al 2003, Lauinger et al 1997, Mackel ad Ludermann 2002, Winderbaum et al 2004), of more immediate relevance to industry is SiN's capability to passivate phosphorus diffused emitters. To investigate this, our experiments were conducted with p-type 300μm thick, 4", 100Ωcm, <100>, Float-Zone (FZ) wafers. FZ wafers were used because their bulk lifetime is sufficiently high to ensure that any changes in the effective lifetime (τ_{eff}) would be directly related to changes in the surface passivation of the sample. The sample wafers were diffused with $POCl_3$ at 820°C for 30mins to create emitters with sheet resistances between 60-70Ω/sq. These medium diffusions ensure that the samples remain sensitive to changes in the surface passivation, while reflecting emerging industrial trends in the production of n+ emitters. 9 different SiN layers were then deposited on the front and back of the wafers to passivate the surfaces. The wafers were labelled and quartered. Lastly, effective lifetime (τ_{eff}) and emitter saturation current (J_{oE}) were characterized for all samples under high injection conditions (Δn=1e15cm^{-3}), using Quasi-Steady-State-Photoconductance (QSSPC) (Sinton and Cuevas 1996). The more important parameter for our studies was the J_{oE}, as it is a simple means of determining the combined recombination at both the surface and doped emitter regions. The use of high resistivity wafers facilitates the measurement of J_{oE}. As emitter recombination is the dominant form of recombination within these wafers under high injection conditions, with the majority of this occurring at the surface (due to our low emitter doping density), J_{oe} provides a direct assessment of the surface passivation quality of our SiN films.

Initial results from the as-deposited films were disappointing, but after annealing, the passivation provided by all our tested films improved dramatically. Samples were subjected to two separate annealing conditions; 400°C Forming Gas Anneal (FGA) in a conventional furnace and 750°C Rapid Thermal Annealing (RTA). (See Figure 1) On average, our samples showed a 64% decrease in Joe after both 140mins of FGA and 1sec of RTA (Georgia tech reference), which is contrary to other published results (Arbele 1999, Cuevas et al 1999), though those results were based on optimised as-deposited films. (See Figure 2) Interestingly, these results do not show a trend between surface passivation effectiveness and refractive index of the SiN layer. Instead, our results showed an increase in the surface passivation uniformity across all the films post anneal. This was exhibited by the decrease in the standard deviation of the results from 43.7 prior to annealing to 31.64 post anneal. Further annealing work will hopefully provide a better indication of the optimum annealing conditions required for maximum surface passivation of the phosphorus emitters. In addition, Fourier Transform Infra-Red spectroscopic measurements should help to identify the changes in the SiN film post anneal, and thereby provide an indication of how the films are providing the improved surface passivation.

Another important aspect of our results to date is the range of J_{oE}'s produced. Although our lowest result (60fA/cm^2) is quite comparable to other researchers best results (see Table 1), more importantly our worst recorded J_{oE} (post anneal) was still only 163fA/cm^2. The level of surface passivation implied by this number, is well above the current needs and capabilities of standard industrially produced silicon solar cells. As such, the implementation of SiN films over more established anti-reflection coatings should result in an immediate increase in the efficiency of standard screen-printed cell designs.

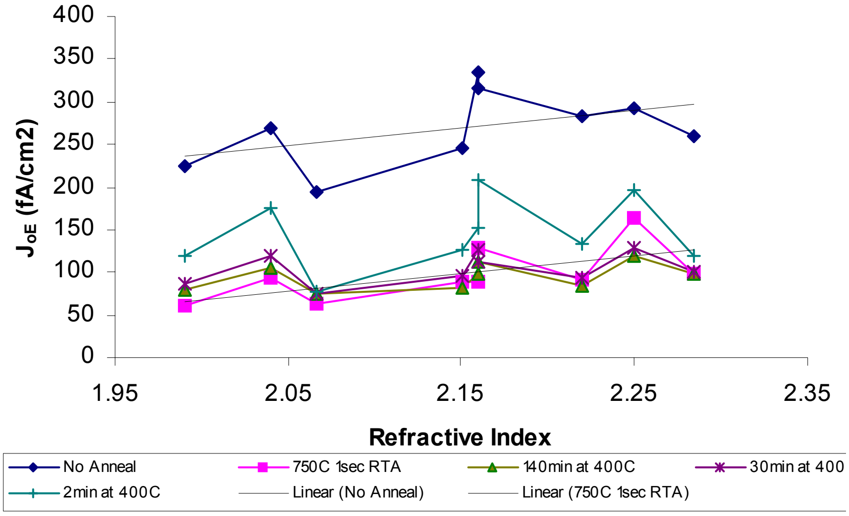

Figure 1 - Comparative results of the J_{oe} of annealed SiN layers

Reactor	η	Deposition Type	Annealed	Sheet Resistance (Ω/□)	J_{oe} (fA/cm^2)	Reference
Lab Remote SiN	2.3	Static	No	100	100	Aberle 1999
Lab HF Direct SiN	2.3	Static	No	100	140	
Lab HF Direct SiN	1.9	Static	No	100	200	
Lab HF Direct SiN	1.9	Static	No	55	57	Kerr 2001
	1.9	Static	No	100	40	
	1.9	Static	No	120	30	
Lab HF Direct SiN	2.1	Static	No	100	82	Moschner et al. 2004
	2.4	Static	No	100	78	
Semi-Industrial Inline Remote	2.1	Dynamic	No	100	93	Moschner et al. 2004
	2.4	Dynamic	No	100	73	
	2.1+2.1	Dynamic	No	100	74	
	2.4+2.1	Dynamic	No	100	65	
Industrial Inline Remote	2.0	Dynamic	Yes	64	60	This work
	2.07	Dynamic	Yes	62	63	
	2.15	Dynamic	Yes	66	90	
	2.28	Dynamic	Yes	66	99	

Table 1 - Comparative results of J_{oe} for different SiN depositions

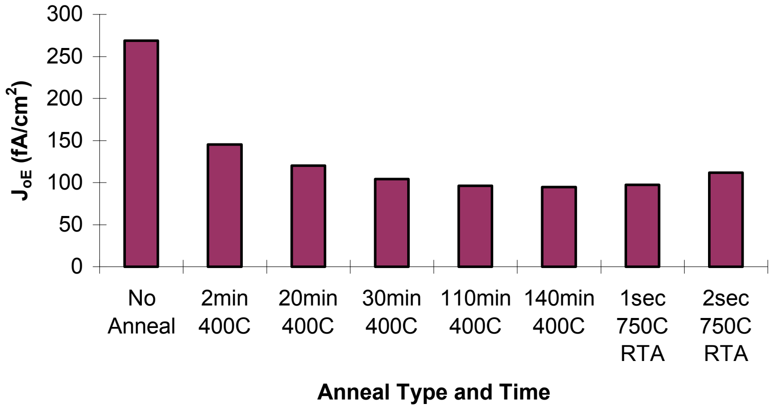

Figure 2 – Comparison of the efficacy of different annealing times and conditions