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Abstract

Passivating contact, which is proposed to reduce surface recombination at metal-semiconductor interface, has been improved throughout Si solar cell development. The metal-semiconductor direct contact has been minimized as much as possible in PERC (passivated emitter and rear contact) solar cells. However, TOPCon (tunnel oxide passivated contact) has been received a lot of attention for its simple processing and high efficiency which achieved by its full passivated contact using an ultra-thin oxide and heavy-doped silicon layer. Cat-CVD (Catalytic Chemical Vapor Deposition) is suitable for making passivation films for its nature of no plasma-induced damage. Compared with the oxide films forming methods of TOPCon, single-sided film formation is a merit of Cat-CVD silicon nitride (SiNx). Considering the difficulty of Cat-CVD oxide film deposition, we use Cat-CVD SiNx films as the tunneling layer for a new type called TNPCon (tunnel nitride passivated contact).

The first step is to correctly evaluate the thickness of SiNx films. TEM images show that the actual thickness is thinner than the results of ellipsometry. However, the deposition rate can still be confirmed by massive data from ellipsometry. After evaluating the thickness of ultra-thin SiNx films, symmetrical TNPCon samples were made to study its passivation quality and conductivity. The relationship between contact resistance (ρC) and SiNx thickness indicates that the tunneling effect dominates the conduction of TNPCon below 2.5 nm and is drastically weakened by thicker SiNx films. In addition, the SiNx thickness also affects the passivation quality of TNPCon. TNPCon samples with 1.6 nm SiNx films achieved an effective minority carrier lifetime (τeff) of more than 800 ms. TNPCon samples with thicker SiNx films show lower τeff, one possible reason is due to phase separation in SiNx films during high temperature annealing. In addition, SiNx films prevent the diffusion of phosphorous (P), which shows in the higher sheet resistance of TNPCon samples with thicker SiNx films. With introduction of H2 during deposition, the crystallinity of the heavily doped silicon (n+-Si) films increases, which is considered to be n+-μc-Si containing a small amount of hydrogen. From the SIMS depth profiles, the P doping concentration was determined, and the optimal doping concentration for TNPCon is about 2%, because over doping would lead to the degradation of n+-Si films. It is also necessary to ensure that the thickness of n+-Si is greater than 12 nm which is related to the carrier selectivity of n+-Si films. In addition, the optimal annealing condition was also confirmed, which is annealing at 850 °C for 1 hour.

In order to further improve the passivation quality of the TNPCon, catalytically generated atomic hydrogen (Cat-H) was used for its hydrogenation process. Cat-H has a strong etching ability on silicon, regardless of crystal from of silicon. If there were no surface thermal silicon oxide films formed during high temperature annealing, n+-Si layer of TNPCon/TOPCon will be etched away. But this unexpected thermal oxide films protects n+-Si layer and does not block the diffusion of hydrogen atoms. From the SIMS depth profiles of TOPCon samples, the H diffusion curve is interrupted at the Si/SiO2 interface where a large amount of hydrogen atoms accumulate. H accumulation indicates termination of defects in Si/SiO2 interface which is thought to be responsible for the improvement of passivation quality. However, the improvement of TOPCon is far more obvious than that of TNPCon. After comparing their P diffusion depth profiles, the increased Auger recombination caused by thicker n+-Si layers was considered the most likely reason.

In Cat-CVD apparatus, ammonia decomposed species (Cat-N) lead to direct surface nitridation of Si, which is also used to prepare ultra-thin SiNx films in TNPCon. Insufficient thickness of Cat-N SiNx films and heavily doped Si layer caused unprecedented low sheet resistance of TNPCon samples. Considering that the Auger recombination in n+-Si layers will damage the quality of passivation, the SiNx film with the ability to prevent P diffusion during high temperature annealing becomes the purpose of further research. One direction is to increase the substrate temperature during Cat-N nitridation, which can also improve the current problem of insufficient film thickness. Another direction is to change the deposition conditions of SiNx films.

Keywords: Passivating contact, Cat-CVD (Catalytic Chemical Vapor Deposition), Ultra-thin silicon nitride, TNPCon (tunnel nitride passivated contact), Cat-H (catalytically generated atomic hydrogen) hydrogenation, Direct nitridation.