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Passivation quality control in poly-Si/SiO_x/c-Si passivated contact solar cells with 734 mV implied open circuit voltage

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ABSTRACT

Passivation quality of poly-Si contacts with different phosphorus doping concentration were investigated in this study. Intrinsic poly-Si layers were deposited by LPCVD on a tunnel oxide surface, followed by n + poly-Si doping and hydrogenation. For lightly doped poly-Si contacts with phosphorus concentration of 2.1×10^{19} cm^{-3}, higher temperatures and longer times increased iV_{OC} achieving maximum value of 734 mV, as poly-Si grain size increases from 13 nm to 40 nm. However, for heavily doped poly-Si contacts with phosphorus concentration of 1.1×10^{20} cm^{-3}, iV_{OC} decreased from 731 mV to 696 mV as annealing time increased from 10 to 60 min because Auger recombination rate increased from 9.3 fA/cm^2 to 21.6 fA/cm^2 as phosphorus in-diffusion occurs. The contact resistance of poly-Si contacts was also investigated to achieve a high fill factor. Finally, a poly-Si/SiO_x/c-Si passivated contact solar cell using a poly-Si contact on the back and boron diffused emitter on the front was fabricated. As a result, high efficiency of 21.1% solar cell was achieved with V_{OC} of 665 mV, J_{SC} of 40.6 mA/cm^2, and fill factor of 78.3%.

1. Introduction

Recombination losses at the interface between the metal contact and doped-semiconductor region is a major efficiency-limiting factor in solar cells. To reduce losses from metal-semiconductor contact recombination, the concept of passivated contact was introduced. A tunnel oxide passivated contact (TOPCon) solar cell [1] is composed of a n + poly-Si/SiO_x/c-Si contact on the rear side and boron doped emitter on the front side, and has a reported highest efficiency of 25.8% [2,3]. One major method to form poly-Si/SiO_x/c-Si passivated contacts is to deposit an amorphous silicon layer (a-Si) and crystallized a-Si onto poly-Si with subsequent annealing. Another way is to use the low-pressure chemical vapor deposition method (LPCVD) for poly-Si deposition, which provides better crystallinity. Using LPCVD-deposited poly-Si/SiO_x/c-Si passivated contact (hereafter, poly-Si contact), some groups reported poly-Si contact solar cells using $POCl_3$ diffusion method and the highest efficiency was 21.5% [4,5]. Also, some groups reported poly-Si contact solar cells formed by ion implantation method to form n + doping on i-poly-Si layer which achieved the highest efficiency of 21.2% [6–10]. About iV_{OC} values, about 730 mV was obtained using crystallized a-Si passivated contact [9,11] and LPCVD deposited poly-Si passivated contact [12]. The highest iV_{OC} of 749 mV was reported by ISFH [13] for the latter with phosphorus implantation. Although many groups involved poly-Si contact, the relation between the poly-Si layer and passivation is still unclear because researchers focused on the tunnel oxide quality. However, characteristics of the poly-Si layer also affect on passivation quality of poly-Si contacts according to its annealing condition and doping concentration. Thus, we focused our study, to better understand the effect of the poly-Si layer on passivation quality, on the grain-size growth and phosphorus in-diffusion. High efficiency was achieved with a tunnel-oxide-passivated contact solar cell with a homogeneous boron emitter on the front and poly-Si contact on the rear.

For the experiments, the poly-Si contacts were annealed at different temperatures and times, and with different phosphorus doping concentrations, in the poly-Si layer. Passivation quality was determined using iV_{OC} and J_0 measured by the quasi-steady-state photoconductance (QSSPC) method [14]. The J_0 values are determined under the high

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