Fabrication of Si//patterned metal layer/Si junctions for hybrid multijunction solar cells with improved bonding interface properties

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Abstract— **We successfully fabricate a p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junction by surface-activated bonding (SAB) of a p^+-Si substrate and a patterned Al layer. We find that the interface resistance, which is 0.025 Ω·cm² in a junction annealed at 300 °C, is much lower than p^+-Si/p^+-Si junction by SAB. This result shows the superiority of junctions using patterned metal layer to directly-bonded semiconductor.**

Keywords- surface-activated bonding, patterned metal, semiconductor junction in fabricating hybrid multijunction solar cells

I. Introduction

III-V-on-Si multijunction solar cells are promising as high-efficiency and low-cost photovoltaics. We previously fabricated InGaP/GaAs//Si triple-junction cells by using surface-activated bonding (SAB) and achieve a high efficiency (~26 %) [1]. However, it was found that damages were introduced to the bonding interface by Ar beam irradiation in the surface-activating process. This led to the increase in the interface resistance [2]. A practical solution is likely to be provided by using a patterned ohmic metal in alignment to passivation layer on the Si bottom cells and fabricating III-V solar cell//patterned ohmic metal junctions.

In this work, as preliminary study, we fabricated a p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junction by SAB of a p^+-Si substrate and a patterned Al layer, and investigated its electrical and structural properties.

II. Experiments

We prepared two heavily doped p^+-Si substrates (2.6×10^{19} cm^{-3}). A 60-nm thick SiO_2 was formed on a surface of one p^+-Si substrate by wet oxidation. A 100-nm thick patterned Al layer was fabricated by etching the SiO_2 layer using buffered HF, evaporating Al, and lift-off. A layout for emitter contact of 4 mm² solar cell was used in patterning Al layer. The coverage by the patterned Al layer was 10.6 %. A top view of the patterned Al layer is shown in Fig. 1. Ohmic contacts were formed on backside of both substrates by evaporating Al/Ni/Au multilayers. Then, we bonded the patterned Al layer to the other p^+-Si substrate by using SAB. The bonded sample was diced into 4 mm² pieces. The entire process sequence for preparing samples is schematically shown in Fig. 2. We

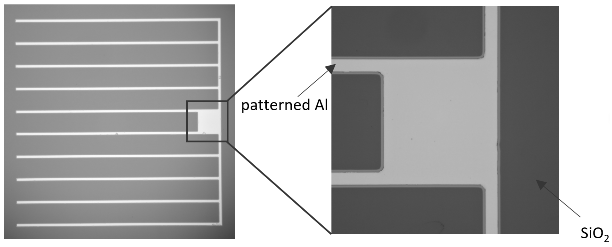

Fig. 1 A microscope image of a patterned Al layer in alignment to SiO_2 mesa on a Si substrate.

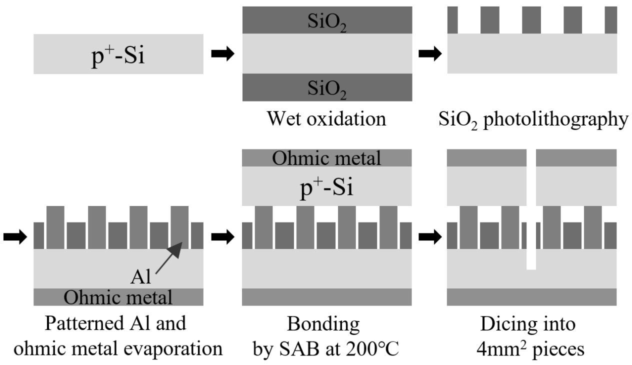

Fig. 2 Process sequence for preparing of a p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junction.

measured their current-voltage (*I–V*) characteristics using an Agilent B2902A at room temperature after annealing at various temperatures in a nitrogen ambient. In addition, we fabricated a p^+-Si//500-nm thick patterned Al in alignment to SiO_2/p^+-Si junction and investigated the bonded interfaces using a field emission scanning electron microscope (FE-SEM) (JEOL JSM6500F).

III. Reseut and Discussion

Figure 3 shows an FE-SEM image of the p^+-Si//500-nm patterned Al in alignment to SiO_2/p^+-Si bonding interface. It is found that the two substrates were fairly attached to each other at the Si/patterned Al interface.

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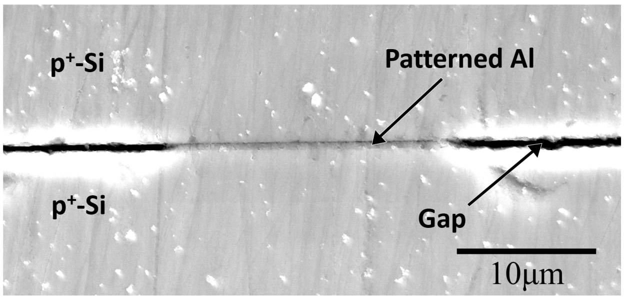

Fig. 3. An SEM image of a p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junction.

The *I–V* characteristics of p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junctions are shown in Fig. 4. The current was normalized to a die area (4 mm^2), not the area of patterned Al. The interface resistances were found to be 0.042, 0.025, 0.059, and 0.048 $\Omega\cdot cm^2$ for junctions annealed at 200, 300, 400, and 500 °C, respectively, by least-squares fitting around 0V. The lowest interface resistance that we observed in this work is 12 % of that of a p^+-Si/p^+-Si junction fabricated by using SAB [2]. It is also notable that the interface resistance of p^+-Si//patterned Al junction was less sensitive to temperatures of post-bonding annealing in comparison with the resistance of Si//ITO/Si junctions [3]. These results indicate that semiconductor//patterned metal junctions are promising in fabricating hybrid multijunction solar cells with lower bonding interface resistance.

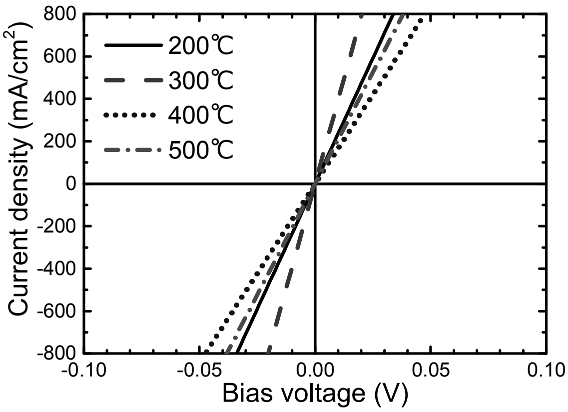

Fig. 4. *I-V* characteristics of p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junctions annealed at various temperatures.

IV. Conclusion

We fabricated p^+-Si//patterned Al in alignment to SiO_2/p^+-Si junctions using surface-activated bonding and found that the interface resistance was as low as 0.025 $\Omega\cdot cm^2$ with annealing at 300 °C. Such a low interface resistance indicated that semiconductor//patterned metal in alignment to surface passivation junctions were applicable for bonding subcells in fabricating hybrid multijunction cells.

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