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Improvement of device performance of multicrystalline Si-based solar cells using multicrystalline SiGe with microscopic compositional distribution

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The low-cost casting method is widely used as a practical method to produce solar cells of Si multicrystals. The purpose of this work is to propose a solution for how to improve conversion efficiency usig the casting method. It is the use of SiGe binary multicrystals with microscopic compositional distribution [1,2]. The SiGe solar cells with microscopic compositional distribution have two important advantages. The first one is that the multicrystals can be grown by the practical and low-cost casting method. The second one is that Ge-rich regions with higher Ge composition in Si-rich matrix largely increase the photo-current of such SiGe solar cells in the longer wavelength region comparing to the photo-current of SiGe solar cells with uniform composition [2,3], even though the average Ge composition is same for both types of SiGe. The most important point is to confirm whether the increase of the short circuit photo-current can overcompensate the drop of the open-circuit voltage, and whether the efficiency of such SiGe solar cells becomes higher than that of Si solar cells.

It was estimated that the short-circuit photo-current of the SiGe solar cell with microscopic compositional distribution rapidly increases by adding a small amount of Ge, and open-circuit voltage decreases by adding Ge. A simple calculation predicts that the overall efficiency of the solar cells based on SiGe multicrystals could surpass that of Si solar cells within a specific average Ge compositional region since the increase of the short-circuit photo-current can overcompensate the drop of the open-circuit voltage. To realize such higher efficiency, we grew SiGe multicrystals with many Ge rich-regions in Si-rich matrix to increase the absorption coefficient in the longer wavelength region.

The SiGe multicrystals with microscopic compositional distribution were grown from Si-Ge binary melt by a small casting furnace. Such SiGe multicrystals have columnar structure. Ge-rich regions with Ge composition of more than 60% in the multicrystals can be obtained by using proper growth conditions even when the average Ge composition is only 5%. The Σ3 grain boundary is dominant in the multicrystals, and more than 50% of total grain boundaries is the Σ3 grain boundary. The absorption coefficient of the SiGe multicrystals increases in the longer wavelength region by adding a small amount of Ge, and it is expected that this gives rise to a remarkable increase of the internal quantum efficiency in the longer wavelength for the SiGe solar cells with microscopic compositional distribution.

We confirmed that the SiGe multicrystal solar cells with the average Ge composition of 1.0% have the response in the longer wavelength region up to 1.35μm, whose long wavelength cannot be absorbed by Si solar cells. We also found that such SiGe solar cells with microscopic compositional distribution have higher efficiency than Si solar cells mainly due to the increase of the total photo current over all wavelength regions by a factor of 1.2, when both types of crystals were grown by the same furnace and source materials, and both types of solar cell were prepared using the same process. The open-circuit voltage does not largely decrease within the average Ge composition lower than 5%.

In summary, we have shown that SiGe solar cells with microscopic compositional distribution could improve the conversion efficiency of the multicrystalline Si solar cells. This improvement was revealed to come from the increase of the total current by a factor of 1.2, which originates from the increase of the internal quantum efficiency at relatively longer wavelength region. The decrease of the open circuit voltage was found to be not critical to affect the overall efficiency when the average Ge composition is lower than 5%. These results imply that SiGe solar cells could be a very promising candidate for new solar cells with higher efficiency, especially when low-cost growth technologies are exploited.

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