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Improved photovoltaic cell performance based on Ge islands embedded into the intrinsic layer

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Researchers around the world continue to explore new approaches in improving photovoltaic device efficiencies. One of the options being seriously considered is the utilization of sub-band gap light. We showed previously that silicon photovoltaic cells with Ge islands embedded into the intrinsic layer efficiently absorbed the low-energy photons [1,2] thus response of external quantum efficiency was enhanced in the near-infrared region. This promising result might be one of the solutions to the existing high-efficiency solar cell problem. In this presentation, we show that incorporation of Ge islands in the intrinsic layer showed a substantial increase of the short circuit current compared to Si-photovoltaic device while maintaining a minimal reduction of open circuit voltage due to the presence of Ge having a lower band gap.

The investigated solar cells were grown on *p*-type Si(100) with a resistivity of 1-10 Ω.cm substrate using a gas-source MBE (AirWater VCE S2020) system. Pure Si_2H_6 and GeH_4 were used as source gases. The base pressure in the growth chamber and temperature of the substrate were kept at around 1×10^{-10} Torr and 700°C, respectively. Prior to Ge depositions, a 100-nm Si buffer layer was grown on the substrate, then self-assembled Ge islands (8 monolayer) stacked in a 50, 100 and 150-layer structure were grown via Stranski-Krastanov growth mode separated by 39-nm Si spacers and finally capped with 600 nm of Si. The emitter junction was formed through thermal diffusion of phosphorous at 900°C. Al and Ag served as back contact and front fingers, respectively.

Figure 1 shows the ratio of the short circuit current and the open circuit voltage of the photovoltaic device with Ge islands embedded into the intrinsic layer with respect to the Si-reference cell. It clearly shows that substantial increase of short circuit current was observed for 50 and 100 layers of stacked Ge islands. This superior increase maybe attributed to the effective carrier generation in the Ge dots and efficient separation by the internal electric field without considerable recombination in the intrinsic layer thus, photocurrent enhancement was observed. However, the short circuit current of the sample having 150-layer of stacked Ge islands decreases. This decrease maybe due to enormous recombination of photogenerated carriers occurred in the thicker intrinsic layer. On the other hand, negligible decrease of open circuit voltage can be observed. This slight decrease can be accredited to the presence of Ge islands.

The external quantum efficiency of the photovoltaic cells in the near infrared region is depicted in Figure 2(a). It is very obvious that enhanced EQE response of the photovoltaic cells is extended in the near infrared regions for the samples having Ge islands in the intrinsic layer and the EQE increases with increasing number of stacking. However, spectral response of the Si-reference cell is up to 1.2μm only which corresponds to the band edge of silicon. Fig.2(b) shows the TEM image of the lowermost portion of the 100-layer sample. It clearly shows that high quality of Ge crystals are grown with well-defined vertical ordering due to the influence of strain energy of the buried islands. Further evidence, which suggests that the stacked Ge islands are dislocation-free (i.e. no D-line related peaks), is shown in Fig.2 inset (PL spectra). The peak around 1100meV corresponds to Si, several additional peaks can be seen at lower energies and these can be assigned to no-phonon (NP) and transverse optical (TO) phonon Ge islands and wetting layers. When the sample is annealed at higher temperature, blue shift of photon energies could be observed that would result in the decrease spectroscopic response. This suggests that intermixing of Ge islands and the Si spacer layers occurred. Further annealing might result to the disappearance of Ge islands and probably transformed into inhomogeneous SiGe quantum well. This suggests that formation of emitter junction should be carried out at temperature similar to the Ge islands growth temperature to observe maximum spectral response.

In summary, we reported an alternative approach to enhance the performance of the photovoltaic cells. This may provide direction towards the solution of the existing high-efficiency solar cell problem.

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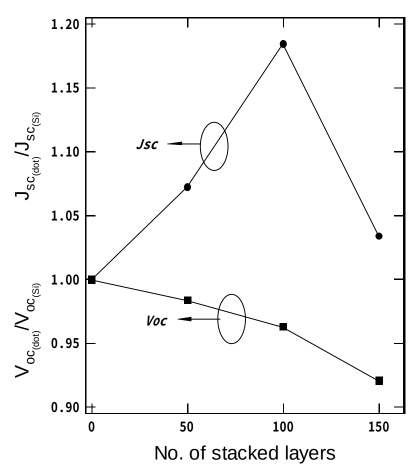

Fig. 1. The ratio of short circuit current and open circuit voltage of photovoltaic cells with Ge islands over Si-reference cells.

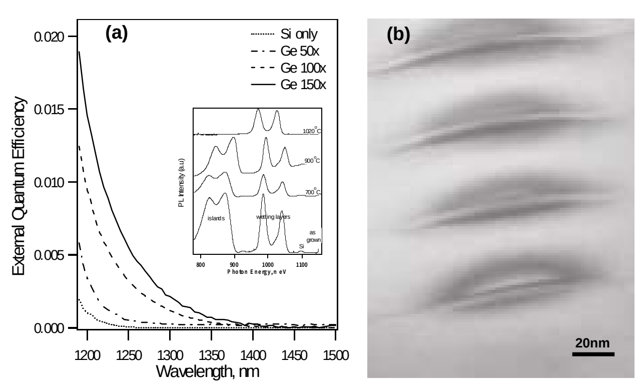

Fig. 2. (a) External quantum efficiency of the solar cells with different number of stacked Ge island layers. (b) TEM image of the lowermost portion of the sample.