Project full title: "Nanowire based Tandem Solar Cells"

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Report on realization of integrated light trapping structures into bottom cell

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Executive Summary

Rear side light trapping structures were successfully produced by nano-imprinting of a diffractive crossed grating in a way that is compatible with p-type passivated selective contacts. This arrangement creates an electrically flat, but optically rough rear side that allows for simultaneously achieving high voltages (passivation) and high currents (additional light trapping). This structure enhanced short-circuit current density by more than 1 mA/cm^2 in a III-V silicon multi-junction solar cell, successfully eliminating the current limitation otherwise imposed by the silicon solar cell in the overall device.

Assessment of Light Trapping Structures

In the first step, we have assessed the applicability of two already developed rear side light trapping structures in the context of III-V nanowires on silicon tandem solar cells. Both structures are based on diffractive gratings that are electrically decoupled from the solar cell by a thin dielectric passivation layer. This arrangement creates an electrically flat, but optically rough rear side that allows for simultaneously achieving high voltages (passivation) and high currents (additional light trapping).

One structure features a binary grating with a period of 1 µm and is produced via nanoimprint lithography and plasma etching of amorphous silicon (Figure 1 left). Electrical contacts at the rear were formed by aluminum-foil-based laser fired contacts. Due to the air gap between the foil and the grating this is an optically very favorable configuration with low parasitic absorption losses. As a result, short-circuit current enhancements well above 1 mA/cm^2 were achieved, with a top value of 1.8 mA/cm^2 for a 100 µm thick solar cell. The formation of the laser-fired contacts entails the indiffusion of aluminum into the silicon, where it acts as a positive dopant. In consequence, this process is only applicable on a p-type rear side, where the additional positive doping improves the contact. On an n-type configuration, a diode would emerge that would block the current flow. Fortunately, the direct growth method developed at IBM requires a negatively doped front and positively doped rear side. Hence, the investigated light trapping structure should be fully applicable to the overall III-V nanowires on silicon tandem solar cells.

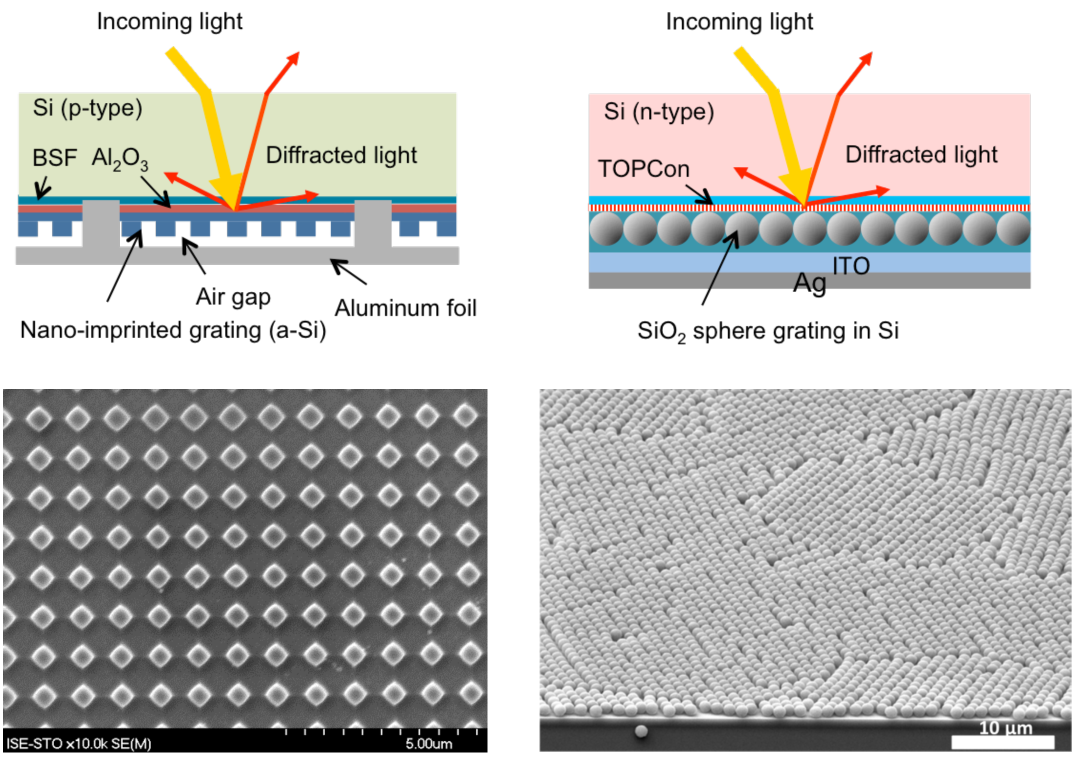

Figure 1: Two diffractive light trapping grating structures assessed for their use in overall III-V nanowires on silicon tandem solar cells. A binary grating produced by nano-imprint and etching (left) and a hexagonal sphere grating produced by self-organization. The sketches at the top show the overall rear contact configuration, while at the bottom (tilted) top views of the gratings are shown.

The other structure is a hexagonal sphere grating formed by self-organization of monodisperse SiO_2 spheres and subsequent filling of the voids with poly-silicon via atmospheric pressure chemical vapor deposition (APCVD) (Figure 1 right). A full area metal contact is then created by sequential deposition of indium tin oxide (ITO) and silver. Also the hexagonal sphere grating is an effective light trapping structure, and a short-circuit current enhancements of 1.4 mA/cm^2 was achieved for a 200 µm thick solar cell. Furthermore, these structures could be combined with a tunnel oxide passivated contact (TOPCon). Because this is a full-area contact the fill factor is very high (low resistance losses) and the voltage is very high, because of the excellent surface passivation. Unfortunately, this contact structure works well only on n-type silicon. Therefore, the applicability of this structure on p-type surfaces is limited, which would be required for the rear-side in the currently favored design of the III-V nanowires on silicon tandem solar cells.

Newly Developed Light Trapping Structure

To combine the advantages of the above structures (good light trapping, good surface passivation, large area contact, easy manufacturing) a new rear side light trapping structure was developed within the project. Because no nanowire tandem solar cells are available yet, the potential was demonstrated in a conventional wafer bonded III-V silicon tandem solar cell (Figure 2).

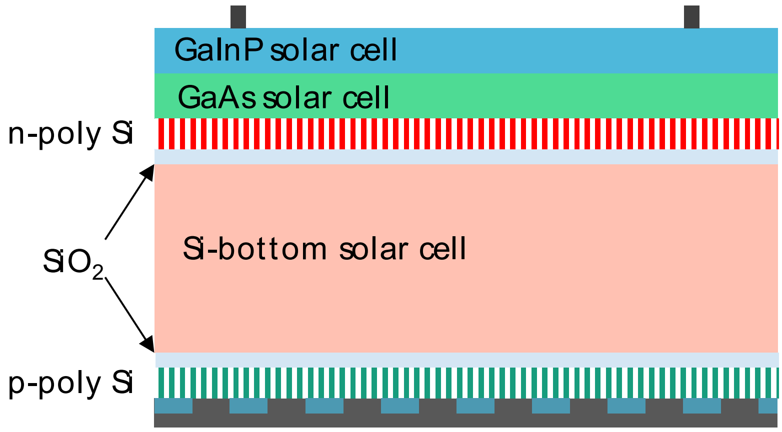

Figure 2: Schematic of the realized triple junction III-V silicon solar cell with additional rear side light trapping structure.

The rear side light trapping structure is produced by a simple nano-imprinting of a crossed grating in a way that is compatible with p-type passivated selective contacts. Short-circuit current enhancements above 1 mA/cm^2 were achieved, eliminating the current limitation otherwise imposed by the silicon solar cell in the overall device.