Nanowire device concepts for thin film photovoltaics

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The realization of one-dimensional (1D) nanostructures, e.g. silicon nanowires (SiNWs) has opened up a new area for device applications in electronics, optoelectronics, thermoelectronics, photocatalysis, photovoltaics and sensing. Key issues for all device concepts based on SiNWs additional to the crystal structure, dopant concentrations and impurity levels are geometric properties like aspect ratio, pitch, alignment of SiNW with respect to the substrate etc. and the interfacial properties between the SiNW and the substrate as well as between the Si core and potential coatings.

Large-area aligned Si nanowire (SiNW) arrays are fabricated on Si wafers and glass substrates via a metal-catalyzed wet chemical etching (WCE) process with or without the use of densely packed diameter-reduced polystyrene (PS) spheres as a mask. The diameter, length, packing density, and even the shape of SiNWs could precisely be controlled and tuned by adjusting either plasma etching duration or chemical etching conditions and the nominal diameter of the PS spheres. The anti-reflective properties of SiNWs and thus the extremely high absorption in thin SiNW layers are essential for NW based next generation solar cells. Several cell concepts with SiNWs are realized including most interesting ones:

(i) a hybrid organic/inorganic solar cell using SiNWs as absorber and PEDOT:PSS as a conducting polymer.

(ii) a semiconductor-insulator-semiconductor (SIS) cell concept with SiNWs as absorbers and a tunneling barrier for charge carrier separation. The thin tunneling oxide is Al_2O_3 with a thickness of only a few Å and a transparent conductive oxide (TCO – here: Al:ZnO) are both grown conformally around the SiNWs using atomic layer deposition (ALD).

The first solar cell prototypes of 1-2cm^2 area on glass substrates reached (i) open-circuit voltage of 525 mV, a short-circuit current density of 22 mA/cm^2 and efficiencies >5% and (ii) an open-circuit voltage of 550 mV, a short-circuit current density of 33 mA/cm^2 and efficiencies >9%.

The influence of the thickness, chemical nature of the tunneling oxide and back and front contact's structure in the SIS cell will be discussed in detail.

Advanced analytical techniques will be applied to materials and device improvements: (i) the proper charge carrier separation is studied by electron beam induced current (EBIC); (ii) Glow discharge optical emission spectrometry (GDOES) permits to determine the free surface area of the SiNWs that strongly influences the open circuit voltage. All elements from hydrogen to uranium can easily be detected simultaneously, and GDOES offers limits-of-detection down to the ppm range.

Further optimization of the cells are realized (i) by using alternative TCOs as electrodes such as graphene ore silver nanowire webs. Preliminary electrical measurements will be shown. (ii) by modelling using numerical simulations and realization of enhanced absorption at reduced SiNW surface areas.

We see a real potential of the SIS SiNW based thin film cell on glass for further improvement of cell parameters such as V_{oc} to 600-700 mV and a power conversation efficiency of >15%.