Speaker: Alain FAVE
Institut des nanotechnologies de Lyon (INL)

Si nanowires for Photovoltaic solar cells

Alain Fave1, Tetyana Nychyporuk1, Stéphane Bastide2, Mustapha Lemiti1, Noritaka Usami3
1 Institut des Nanotechnologies de Lyon (INL), UMR CNRS 5270, Université de Lyon
INSA de Lyon, Bât Blaise Pascal, 7, avenue Jean Capelle, 69621 Villeurbanne Cedex, France
2 Institut de Chimie et des Matériaux Paris-Est ; 2-8, rue Henri Dunant, 94320 Thiais, France
3 Institute for Material Research (IMR), Tohoku University, 2-1-1 Katahira, Aoba-ku, 980-8577, Sendai, Japan

Introduction

More than 80% of commercial solar cells are fabricated from crystalline silicon despite its low absorption coefficient. An efficient absorption of the solar spectra requires Si wafer thickness above 50-100 µm. This is a key point for further reduction of the cost of photovoltaic devices because Si material cost (especially purification process) represents about half of the final module cost. For this reason, the more recent developments in industrial PV focused on second generation solar cells based on thinner semiconductor efficient absorber layers such as amorphous silicon, CIGS and CdTe (2ndgeneration solar cells [1]). These technologies have contributed to lowering the cost in the recent years.
Moreover, the emergence of the so-called "3rd generation solar cells" is driven by the objective to demonstrate combination of high energy conversion efficiencies and low cost process: new materials, new concepts are under development to go beyond the efficiency limit for a single junction solar cell[2].
But crystalline Si still has some important potential for further cost reduction; beside the usual wafer based technology, where continuous improvements will soon lead to the grid parity in Europe, some new developments based on nanotechnologies are underway. One of the promising routes is the use of Si nanowires arrays: nanowires solar cells can provide some benefits compare to planar solar cells, like improved light trapping, increased material defects tolerance, and bandgap tuning. The scopes of Si nanowires that will be described here cover their use for the so called 2nd and 3rd generation solar cells.

Si nanowires for 2nd generation solar cells

The most interested technique for synthesis of arrays of Si nanowires is the growth from Vapor Liquid Solid mechanism. It uses a metallic nanoparticles catalyst (Au, deposited on Si substrate) that forms locally a liquid eutectic with Si. Upon chemical decomposition and dissolution into the liquid eutectic droplet, the solution becomes supersaturated and leads to precipitation of Si. Additional flux of Si leads to further precipitation and nanowires growth. Additionally, using such technique, there is possibility of direct growth on low cost (glass) and flexible substrates (metal foil). Nanowires in the 100-1000 nm range have beneficial optical absorption properties. For such dimensions, Si nanowires arrays can improve absorption (light trapping) for reduced Si material consumptions. Also, the high aspect ratio radial p-n junction wire geometry enables a decoupling of the direction of light absorption from that of carrier collection. Maximum efficiencies are predicted for devices in which the radius of the wire is approximately equal to the minority carrier diffusion length, which therefore provides a pathway to improve the efficiency of solar cells fabricated using lowerpurity Si [3].
Output efficiencies have steadily increased in the past 5 years up to 10%, but a number of unresolved questions must be answered before such materials can be used in commercial devices [4].

Si nanowires for 3rd generation solar cells

The solar cell efficiency limit, 29% for Si, is due to two power losses mechanisms. The first one isinability to absorb by solar cell the photons with energies less than the band gap of Si. Whereas the second one concerns the high energy photons generating the electron-hole pairs with energy greaterthan the band gap of Si. The excess of the energy is then dissipated mainly by heat losses. Among numerous concepts being proposed to enhance the conversion efficiency of solar cells, the tandem approach is the only one which has already permitted to realize photovoltaic structures with efficiency exceeding the limit for a single band gap device. Tandem cells are a stack of individual cells with different bandgaps each one absorbing the different band of the solar spectrum and thus assuring the optimal absorption of the whole solar spectrum.

It was shown that 2-cell and 3-cell tandem stacks with optimal bandgap could increase the efficiency limit up to 42.5% and 47.5%, respectively. Due to their excellent material quality and tunable bandgaps, III–V compound semiconductors are key components of such high efficiency solar cells. Actually, recent results on systems as GaInP/GaAs/GaInAs [5] or GaInP/GaInAs/Ge have demonstrated efficiencies above 40% under concentration. This approach however involves prohibitory expensive technologies of fabrication like molecular beam epitaxy (MBE), for example. "All-silicon" tandem solar cells based on band gap engineering is one of the promising approaches towards third generation silicon photovoltaic devices consisting to increase significantly the efficiency. To increase Si bandgap, nanoscale size dependent quantum confinement effect can be used. Different technological approaches allowing formation of Si nanocrystals in a dielectric matrix have already been developed, permitting to obtain the Si nanocrystals as small as 1 nm in diameter. It is also necessary to assure their high density in order to achieve a direct tunnelling of the photogenerated charge carriers between the nanocrystals. This still constitutes the bottleneck of many technological approaches. However, Si nanowires present a rather good conductivity in the longitudinal direction. In order to ensure the quantum confinement effect, the diameter of Si nanowires should be less than 5 nm. The mechanical instability at such small dimensions becomes rather severe. The further processing like encapsulation of Si nanowires into dielectric matrix may easily destroy the tiny structures. Some solutions exist and we will present the following one (collaboration between INL in France and IMR in Tohoku). It is based on the growth of epitaxial Si nanowires directly in anodic aluminum oxide template (AAO) with vertical nanopores. To obtain such structure, AAO is realized by anodization of Al films on Si substrate using sulfuric acid solution. Then Au nanopartilcles are embedded in each nanopore by using electroless deposition with a mixture of NaAuCl2 and HF. Finally Si nanowires were produced by using chemical vapour deposition at temperatures around 550°C with disilane. Such Si nanowire based substrates will be then used as a brick material for tandem solar cells.

[1] Thin Film Solar Cells, ed. J. Poortmans and V. Arkhipov (Wiley, 2006)

[2] G. Conibeer, "Third-generation photovoltaics." Materials Today, Vol. 10, No. 11, pp. 42-50, (2007).

[3] Hochbaum AI, Yang P., Semiconductor nanowires for energy conversion. Chem. Rev. 110(1):527–
46, 2010.

[4] E. C. Garnett, M. L. Brongersma, Y. Cui, and M. D. McGehee, Annu. Rev. Mater. Res. 2011. 41:269–95

[5] Wojtczuk S, Chiu P, Zhang X, Derkacs D, Harris C, Pulver D, Timmons M. InGaP/GaAs/InGaAs concentrators using Bi-facial epigrowth. 35th IEEE PVSC, Honolulu, HI, June 2010