

# Graphene as transparent conducting layer in Si-nanodot based p-i-n thin film solar cells

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Advanced concepts on photovoltaic device design include the introduction of nanostructured materials to exploit at best the absorption and conversion of the solar spectrum. An example is the case of silicon nanocrystals (Si-NC) that have been proposed as tunable band gap absorber in multi-junction all-silicon photovoltaic devices [1] (Fig.1).

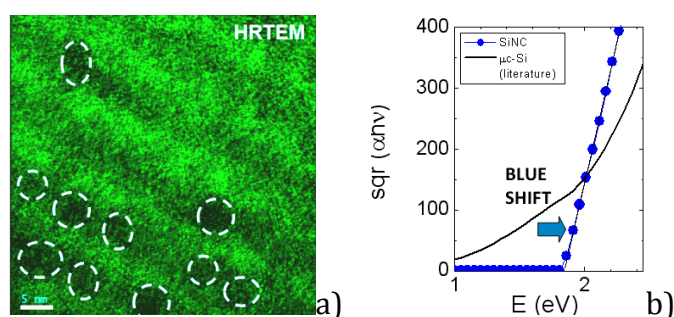


Figure 1: a) High resolution TEM cross section image of Si-NC in microcrystallized SiC matrix. b) optical absorption of Si-NC.

Silicon nanocrystals have indeed been fabricated and extensively characterized. However, a major inconvenience that prevents their direct introduction within a standard thin film structure is the process temperature, that may be as high as 1100°C. This implies that the transparent conducting layer (TCL) through which the solar radiation reaches the absorber must be resistant to such temperature.

For such application, graphene (G) is an ideal candidate. Graphene is inherently highly conductive, transparent, and stable upon thermal treatments. Moreover, its application in replacement of TCL metal oxides in photovoltaic and optoelectronic devices has already been demonstrated [2], [3]. However, the thermal stability of the device once graphene is introduced within an actual nanostructured photovoltaic device requiring high temperature processing has not yet been proven.

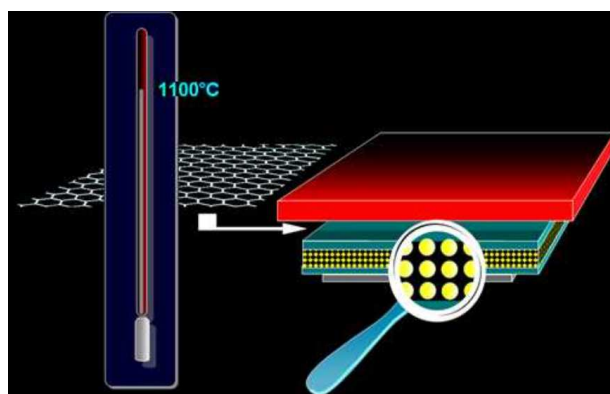


Figure 2: Sketch illustrating the role of the G-sheets within the device incorporating silicon nanocrystals as absorber layer.

In this contribution, we investigate on the use of graphene as temperature tolerant TCL in thin film devices that include silicon nanocrystals as tunable bandgap solar absorber.

The G-sheets are fabricated by means of Catalytic Chemical Vapor Deposition (CVD) on Cu foil or Cu films, and transferred on quartz substrates. The sheets are then capped by a-Si:H deposited using Plasma Enhanced Chemical Vapor Deposition (PECVD), and annealed at increasing temperature. The capping is then removed and the G-sheets characterized. We demonstrate that opportunely capped G-sheets maintain their original electrical and optical properties up to at least the process temperature required by Si-NC fabrication. For reference, the results are compared with ITO (Fig.3).. To support the conclusion, we report the results obtained on a test p-i-n device that incorporates high temperature annealed G-sheets as TCL.

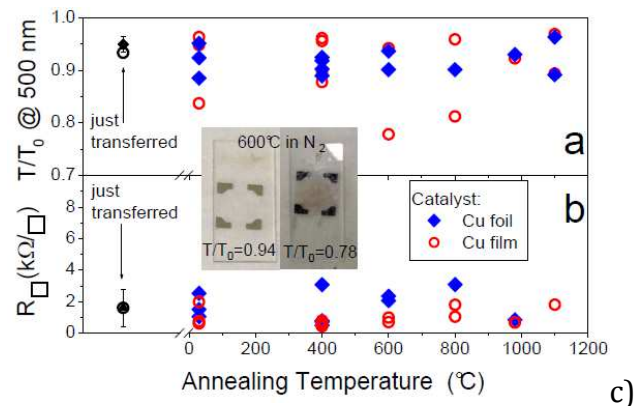


Figure 3: a) Optical transmittance, and b) sheet resistance, of G-sheets after annealing.

The results are tested with the introduction of graphene as temperature resistant TCL within a Si-NC based thin film device. A thin film photovoltaic device in superstrate configuration is fabricated, entirely based on silicon nanocrystals and embedding temperature-resistant graphene as TCL, thus enabling the needed electrical access to the p-type selective contact (Fig.2)

After transferring on quartz substrate, the optimized graphene sheets are used as a substrate for the p-i-n stack deposition. where the i- layer represents the precursor for Si-NC formation taking place by thermal precipitation of excess silicon in silicon rich carbide (SRC). To control the Si-NC diameter the alternated SiC/SRC multilayer structure is adopted.

We show that the technology is not straightforward, and that the adhesion of the nanostructured p-i-n stack to the underlying G-sheet needs to be opportunely engineered. By means of the vibrational spectra associated to stress measurements, we show that the crucial step is the temperature slot between the evolution of the hydrogen incorporated during the PECVD process, and the nanocrystallization of the material. A strategy is suggested to circumvent the occurrence.

In conclusion, we show that the use of graphene as TCL is compatible with the use of the high process temperature (1100°C) required by Si-NC formation, thus enabling the fabrication of a device that, with the currently available, low temperature technology of standard transparent conducting oxides, would not be feasible. However, some technological aspects still need to be clarified.

## References

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