# Graphene in silicon photovoltaic cells

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Keywords: graphene, silicon technology, transparent electrode, photovoltaic technology, CVD.

Abstract Text

Graphene is an allotrope of carbon. Its structure is one-atom-thick planar sheets of carbon atoms that are densely packed in a honeycomb crystal lattice [1]. The richness of optical and electronic properties of graphene attracts enormous interest. Its true potential seems to be in photonics and optoelectronics, where the combination of its unique optical and electronic properties can be fully exploited. The optical absorption of graphene layers is proportional to the number of layers, each absorbing $A=1-T=\pi\alpha=2.3\%$ over the visible spectrum [2].The rise of graphene in photonics and optoelectronics is shown by several recent results, ranging from solar cells and light emitting devices, to touch screens, photodetectors and ultrafast lasers.

Current photovoltaic (PV) technology is dominated by Si cells, with an energy conversion coefficient $\eta$ up to 25% [3]. Such an inorganic PV consists in a current transparent conductor (TC) replacing one of the electrodes of a PIN photodiode. The standard material used so far for these electrodes is indium-tin-oxide, or ITO. But indium is expensive and relatively rare, so the search has been on for a suitable replacement. A possible substitute made from inexpensive and ubiquitous carbon is graphene. Being only constituted of carbon, it will become cheap and easily recyclable. But at the moment, the major difficulty consists in its fabrication and/or transfer.

Our project consists in synthetizing graphene by CVD (Chemical Vapor Deposition) on Cu and in transferring the obtained layer on silicon PV cells, and then in testing their energy conversion efficiency.

Graphene was produced in a hot wall tubular APCVD (Atmospheric Pressure CVD) reactor, 5 cm ID and 1m length, from methane diluted in hydrogen and argon. Copper foils (25 µm thick, 99,999% Alfa Aesar) of 2x2 cm$^2$ were used as the catalyst. The operating temperature was fixed at 1000°C. Scanning electron microscopy (SEM), optical microscopy and Raman spectroscopy measurements were carried out to investigate the quality and uniformity of graphene sheets. After synthesis, graphene was transferred classically by a PMMA-assisted wet transfer method directly on the PV cells. Figure 1 presents a characteristic example of APCVD results. As it can be seen on the optical image, the sample shows a good homogeneity on mm$^2$ scale. On the Raman spectrum obtained before transfer, the low ratio of D/G peaks indicates a low density of defect in the graphene layers. The ratio of 2D/G peaks is slightly lower than 1, which means that the number of graphene layers is between 2 and 4. For this application, a lower number of layers would have been much better and will be one of the keys to increase the PV cell performance.

The photovoltaic (PV) cells are constituted of $N^+P$ junctions implemented on silicon <100> P-substrate (fig.2 left). The solar light used to characterize them is a solar light LS1000 and has a maximal optical power of 22 000 lux. The I(V) measurements are performed by a Keithley 2612 (fig.2 right). The results obtained for one of the tested cell are presented as an example in fig.3. One can see a sensitivity increasing. Considering the very low surface of graphene transferred on the PV cell, these first results are encouraging.

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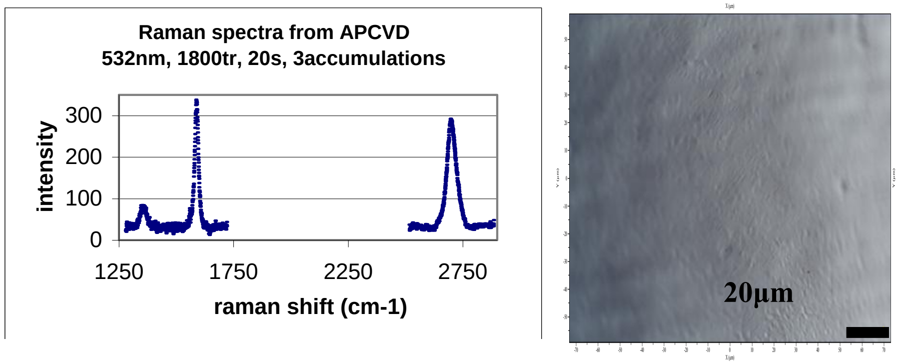


Figure 1: Raman spectrum and optical image of graphene synthesized on Cu foil

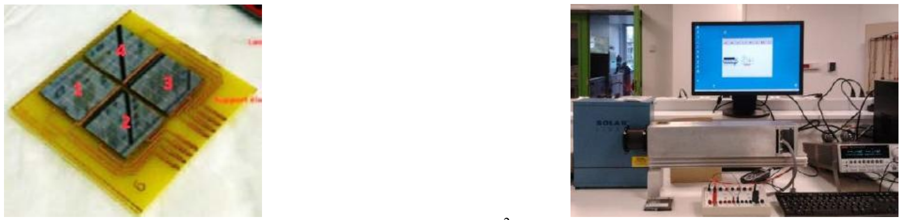

Figure 2.Left: 4 silicon photovoltaic(PV) cells of 3.24 cm$^2$, glued with a conducting paste on a test PCB. Right: Automated test bench for I(V) measurements of the PV cells, in obscurity or under lighting.

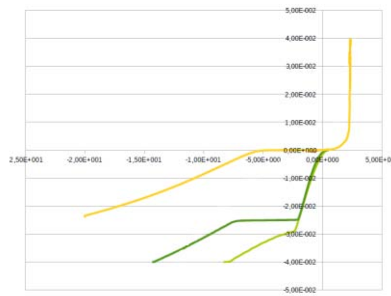

Figure 3. I(V) curves obtained. Yellow: PV cell in obscurity. Dark green: PV cell without graphene under lighting. Light green: PV cell with graphene under lighting.