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Chemical vapor growth of nitrogen doped carbon nanotube and graphene materials for application in organic photovoltaic devices.

Bepete, George

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Abstract

Application of carbon nanomaterials like fullerene, carbon nanotubes, and graphene in solar cells using solution processable methods presents a great potential to reduce the cost of producing electricity from solar energy. However, carbon nanotubes and graphene materials are predominantly metallic and this limits their function in organic photovoltaic devices (OPVs) where semiconducting behavior is required. Doping of carbon nanomaterials is a well-known method for making them semiconducting. Doping of carbon nanomaterials with nitrogen and boron can tune their properties to suit the requirements for use in photovoltaic applications as n-type and p-type semiconducting materials, respectively. Indeed, the use of nitrogen doped and boron doped carbon nanotubes in organic solar cells together with fullerene acceptors can improve the current density of the OPV devices.

Nitrogen doping of carbon nanotubes can be achieved by using nitrogen-containing precursor materials during chemical vapor deposition. However the doping of carbon nanotubes with nitrogen does not automatically make them n-type materials; they remain metallic unless a large amount of quaternary type nitrogen is incorporated in the carbon nanotubes. In this work we have developed a method to control the type of nitrogen that is incorporated in CNTs by using an appropriate synthesis temperature and use of oxygen-containing carbon precursors during the chemical deposition of carbon nanotubes. Quaternary N was incorporated in a CVD process when high temperatures and a high concentration of O in the precursor materials were used. We also showed that the type and amount of N can be changed from pyrrolic and pyridinic-N-oxide to pyridinic N and quaternary N by annealing N doped carbon nanotubes at temperatures above 400°C. At temperatures above 800°C most of the nitrogen is converted to quaternary nitrogen.

N-CNT thin films were used in OPVs so as to modify the ITO electrode and transform it into a 3D electrode. The resulting effect was an improved short circuit current density in the devices containing an N-CNT thin film that was placed on top of the ITO electrode. A reduction in efficiency losses in OPVs at increasing light intensity was observed in the N-CNT ITO modified electrode OPVs. This is a remarkable finding when considering that one of the main problems hindering commercialization of OPVs is the loss of efficiency at high light intensities. We related these effects to the efficient charge collection by the modified

ITO electrode. Incorporation of N-CNTs in the bulk heterojunction layer of the OPV device resulted in poor performance when compared to an OPV device made without N-CNTs. This effect is caused by shorting of the OPVs. We used a method of incorporating N-CNTs whilst minimizing shorting and this showed potential for better performance.

A study on the attempted doping of graphene with B to make it a p-type material showed that in the presence of a nitrogen carrier gas, BN instead of B was incorporated in graphene. This remarkable finding enabled us to grow a p-type graphene with a possible a band gap opening. This was corroborated by XPS and Raman spectroscopy studies of the material. This BN doped graphene material showed potential as a possible replacement of PEDOT:PSS as a hole transport material in OPVs. The BN doped graphene material can match the performance of PEDOT:PSS when the level of BN doping in graphene is increased.