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RECENT DEVELOPMENT IN TWO-DIMENSIONAL SOLAR CELL

Physics

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ABSTRACT

Sun is source of sustainable energy. Depletion of fossil fuel, increase in green house gas emission and threats to energy security pushes us to develop technology for greener and sustainable energy sources. The 2D materials are promising materials for next generation ultra thin solar cell. 2D solar cell are thin, flexible and uses much less material than conventional solar cell. The present paper reviews the recent development of 2D material solar cell.

INTRODUCTION

The revolutionary work of Geim and Novoselov et al. (2004) and colleagues showing the mechanical exfoliation of graphene with scotch tape method in 2004 gives the path to a new class of materials, the two-dimensional (2D) material.

The 2D material such as graphene (Novoselov et al., 2005) and transition metal dichalcogenides (TMDs)(Chhowalla et al. 2015) has been extensively studied and analyzed in recent year. The properties of these materials are very different from their bulk counter part on account of their reduced dimensions and symmetry. These new class of materials are inherently flexible, mechanically very strong and extremely thin. Their 2D structure allows them to possess unique properties. Electrons can flow at very high speed through them (Novoselov et al., 2004).

The remarkable properties of these material make them interesting for fundamental studies and future applications. Introduction of 2D material provides platform for new generation ultra-thin solar cell. The 2D solar cell panel will be thinner; more light weighted and provides power densities (watt per kilogram of material) higher than the current technology.

CHALLENGES IN CURRENT SOLAR CELL INDUSTRY

Most of research efforts for solar cell have been done to improve their efficiency and lowering manufacturing costs. Today mostly solar cells are made from bulk multicrystalline silicon semiconductors with efficiency about 15-20 percent. Moreover these cells does not absorb light efficiently, have heavy weight and high production costs. Improving the sunlight collection and absorption can optimize efficiency of the solar cell. To enhance the performance of solar cell many alternative materials have been investigated. Lot of research have been going on organic solar cells, Schottky junction solar cells, dye-sensitized solar cells, quantum dot-sensitized solar cells, other inorganic solar cells, and perovskite solar cells, polymer solar cells. 2-D materials are crystalline in nature and have high material quality.

GRAPHENE AND 2D MATERIAL BEYOND GRAPHENE

2D material is exfoliated from the materials in which the forces along two dimensions are much stronger than the forces along third dimension. The weak van der walls forces among different layer enable the exfoliation of these materials.

The first material exfoliated in this series is Graphene (Novoselov et al., 2004). Graphene is atomically thin layer of pure carbon (graphite) in which carbon atoms are arranged in hexagonal honeycomb lattice. Graphene's success opened the pave for exfoliation of stable, single and few-atom-thick layers of van der Wall materials, Since after the exfoliation of graphene, the properties of the graphene are extensively studied (Nato et al , 2009)

The fascinating properties of graphene such as an ultrahigh carrier mobility, large mechanical strength, a linear dispersion relation, long-range ballistic transport, quantum Hall effects at room temperature, high optical transmittance and tunable optical absorption properties makes the graphene as an outstanding material for future electronics, optics, and energy-harvesting devices. (Geim & Novoselov, 2007;Schwierz, 2010; Bonaccorso et al. 2010). Graphene's Fermi level is tunable by doping and changing bias (Shi et al., 2010). The high optical transmittance of graphene enables its use as electrode in PVs(photovoltaic devices).

Since after the exfoliation of graphene , monolayer of BN , hybrid graphene –BN, MoS2, MoSe2 and WS2 have been exfoliated. The techniques available for exfoliation are Mechanical exfoliation, Chemical exfoliation (CVD), Liquid phase exfoliation, Electrochemical exfoliation. A lot of research work has been done to study the optical, electronic and mechanical properties of 2D materials.(Butler et. al , 2013) TMD also hold potential as sunlight absorber and may enable ultra thin photovoltaic devices due to their semi conducting characteristics.

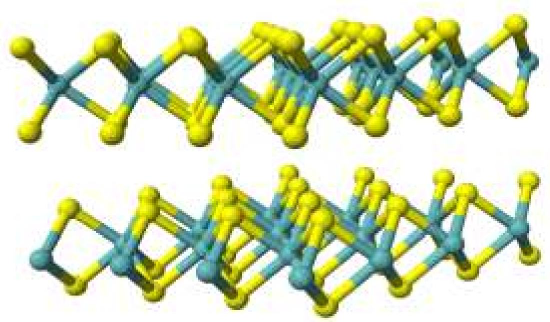

Figure-1: Layered structure of MoS2, with Mo in green and S in yellow

Sources: https://en.wikipedia.org/wiki/2D_Materials#Applications
2D SOLAR CELL

The graphene displays an extraordinary absorbance of 2.3% in the visible with thickness of only 3.3 Å. Such an absorbance is equivalent to that of ~10 nm thick Si and GaAs (Bernardi et al. 2013). This makes it an attractive material for solar energy conversion. But graphene is metal. It has zero band gap. Hence it is not suitable for photovoltaic generation. But it can be used in combination with other materials (Li et al. , 2010; Wang, 2008, Han et al, 2012; Shanmugum, 2014, Wang et al. 2015). Due to its metallic character as displayed by its high mobility and electrical conductivity, the graphene/n-type semiconductor heterojunction can be considered as an efficient Schottky junction. Schottky barrier solar cell are easy to fabricate, have low cost and simple design. In 2010, Li et al. first reported such a Schottky junction solar cell with a power conversion efficiency (PCE) up to 1.5% .The performance of such solar cells can be further improved by replacing the planer Si substrate with silicon nanowires (SiNW) (Fan et al., 2011). They demonstrated that graphene/SiNW solar cell had enhanced light trapping and enables faster carrier transport with PCEs up to 2.86%. Doping of graphene noticeably improves the performance of solar cell by reducing series resistance and enhancing build in potential. Wang et al (2015) demonstrated that he (Chemical Vapor Deposition) CVD grown single layer graphene/ InP solar cells exhibited the conversion efficiency of 3.3%, and increased up to 5.6% after the Fermi level tuning of graphene by chemical doping and electric field modulation. Shi et al. (2013) demonstated that a colloidal antireflection coating onto a monolayer graphene-Si solar cell enhanced the cell efficiency to 14.5% under standard illumination (air mass 1.5, 100 mW/cm2) with a stable antireflection effect over long time (figure- 2).

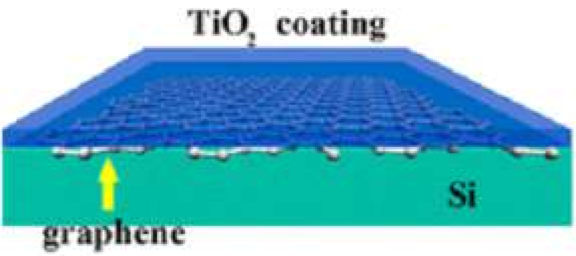

Figure 2: Solar cell model of Shi et al (2013)

More recently, Yang et al. (2014) demonstrated a new structure of graphene/Si Schottky junction solar cells by introducing a GO (graphene oxide) interlayer to engineer the graphene/Si interface. They found that the GO interlayer could effectively increase the Voc and meanwhile suppress the interface recombination of the solar cells. An optimized PCE of 6.18% was achieved for the graphene/GO/Si solar cells with undoped monolayer graphene as top electrodes.

2D atomic crystals are crystalline in nature. They can be produced at low cost and in large area. More recently other 2D materials, such as MoS_2 (Li et al., 2015) and WSe_2 (Cheng , 2014) are explored for solar energy generation. These materials have a band gap hence semiconductor in nature. Bulk MoS_2 and WSe_2 are indirect band gap semiconductors whereas their monolayer exhibits a direct band gap. Moreover the electronic properties of these 2D can be tuned, which enables the applications of these material in electronic devices. . MoS_2 has an indirect band gap of 1.3 eV in bulk structures but a direct band gap of 1.8 eV in the monolayer form. The tunable electronic properties of MoS_2 enable electron tunnelling and negative differential resistance for use in low-power electronics. Tsai et al (2014) showed that monolayer MoS_2 Hetrojunction solar cell have PCE 5.23%

A monolayer WSe_2 lateral junction diode has been demonstrated by Andreas Pospischil et. al (2014) . Their finding suggests that the diode exhibits ampipolar transfer characteristics. They reported an efficiency ~.5% for photovoltaic energy conversion. Bernardi et al. (2013) suggested the feasibility of bilayer solar cell by coupling semiconductor TMD monolayer with graphene . Similar solar cells obtained by stacking two different TMD monolayer were also suggested. They studied the viability and predict the performance of 1nm thick solar cell based on bilayers of MoS_2 /graphene or two stacked TMD monolayer. (MoS_2 /WS_2) . They demonstrate that both the interfaces can realize PV operation, respectively by forming a Schottky barrier and Type –II hetrojunction. Their work shows that single TMD monolayer with sub-nanometre thickness can absorb as munch as 15-50 nm thick GaAs and Si , and generate electrical current as high as 4.5 mA/cm2. The suggested solar cell can reach 1% power conversion effieciency in just 1 nm thickness, thus packing a power density of up to 2.5 MW/Kg.

CONCLUSION

The great achievements in application of 2D material in solar cells opens the new avenue in realizing the new generation ultra thin, efficient and mechanically strong solar cells. But still there is lot of scope for further improvement by optimizing the 2D material synthesis, film transfer, surface functionalization and doping processes. The quantum of research activities in above field definitely enables the highly efficient solar cell commercially very soon.

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