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RESEARCH ARTICLE

EVALUATION ON THIN FILM ORGANIC FIELD EFFECT TRANSISTORS FOR SENSING APPLICATIONS

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ABSTRACT

A new technology for sensing LPG by combining the properties of GFET, Graphene and HBN is reported in this work. It is reported that the use of organic semiconductor material can decrease the cost of the sensor substantially. The limited carrier mobility of OFET is improved by the addition of Graphene and HBN. Pentacene is also used in the expectation of enhancing carrier transport capabilities. An added advantage is that the same sensor can be used for the selective detection of sulphur dioxide and n-butane.

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INTRODUCTION

The sensing of LPG gas is given prior importance to foresee the wide alert caused by its leakage. So we may go for the innovation of the same. The revolutionary impact made by the organic thin film technology has sophisticated the existing fabricating processes. to a large extend. The technology point towards the use of organic semi conducting compounds. In current manufacturing domains, the need for organic semi conductors which extend its hands to decrease cost effectively is increasing dramatically. So we select OFET with increased performance by the addition of Graphene (Tarun Chari, 2015) and HBN for the purpose of making gas sensors. The constrained performance of OFET due to the carrier channel mobility limited by the dielectric semiconductor interface is solved by the use of Hexogonal Boron Nitride; an insulating isomorph of Graphene.HBN is a highly optimal substrate and dielectric for Graphene, which has drawn significant intrust as an electronic channel material for FET.

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Graphene-based field effect transistors (GFETs) (Tarun Chari, 2015) are nowadays considered as a technology option for future high-speed radio-frequency (RF) circuits and systems. Performance metrics, such as high-intrinsic transit frequency f_T and transconductance gain g_m have shown very competitive performance when compared hands to decrease cost effectively is increasing dramatically. Along with Graphene the addition of Pentacene exhibits outstanding carrier transport capabilities for fabrication. An efficient and transparent FET is innovated here. Transparent device based ultra-thin graded Ag layer has much better field-effect mobility than other Organic Field Effect Transistor with thin metal electrodes or with metal oxide multilayer. Also, the difference of large work function at the interface of silver/pentacene will induce the tunnelling injection effect to dominate the injection property in the pentacene field effect transistor, which will improve the contact barrier of the organic/metal interface. Sulfur dioxide (Sanhita Majumdar *et al.,* 2016) which is toxic to plants, animals and human beings can also damage historical monuments and structures. It has been shown that semiconducting vanadium doped in dioxide can sense sulfur dioxide at a concentration low as 5 ppm, which is sufficient to detect leakage at the sources. The same electronic circuitry and the same sensor material can be used for the selective detection of sulfur dioxide as well as n-butane by either varying the dopant concentration or by modulating the operating temperature.it is very useful for development of sensor array and this system reduces the costs compared to noble metal catalysts, normally used in such purpose. This is highly helpful for technological explorations and commercialization.

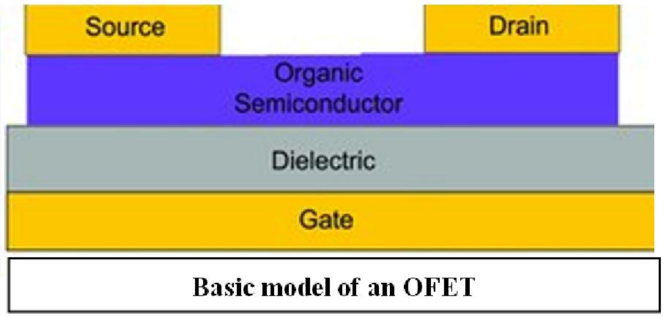

Fig.1. OFET Model

Experimental set up

The semiconductor layer is the most important part of an Organic Field Effect Transistor (OFET). In an OFET, the semiconductor layer utilizes organic molecules as the active layer. However, the performance of OFETs is limited by the carrier channel mobility of the dielectric-semiconductor interfaces. The threshold voltage, mobility, and hysteresis in the transfer characteristics affects the residual charge density in the dielectric layer. In order to produce a more flexible, lighter and less expensive material we use Graphene as the first layer in the semiconductor region. This single layer Graphene is fully capped with Hexagonal Boron Nitride (HBN) as the dielectric with a thickness greater than 5 nm. By using this we propose to model transistors of channel length (LG) upto 67nm. The expected mean-free-path, ballistic velocity, and effective mobility are 850 nm, 9.3×107 cm/s, and 13700 cm^2/Vs, respectively, These are the highest velocities and mobilities reported for GFETs. Graphene's electrical properties diminishes when it is in contact with external environment. So we use a full covering of Boron Nitride around the Graphene layer (Tarun Chari, 2015). This GFET is fabricated on a Silicon Dioxide substrate with a bottom gate approach. It has a dielectric thickness greater than 5 nm and is made of high-κ materials, such as HfO_2 or Al_2O_3. These are formed by Atomic Layer Deposition. It has a low field mobility, typically less than 1000–3000 cm^2/Vs There are changes in gate voltage due to trapped charge from the substrate and gate oxide. Source and drain formed by depositing metal over an area of the Graphene to form the contacts . It has a contact resistance that is typically 1 k-µm and no better than 200 -µm. Generally device current–voltage (I–V) characteristics for GFETs, particularly at short-channel lengths (LG), does not show strong saturating characteristics, due to these large contact resistances combined with the relatively poor electrostatics of the large oxide thickness (t_{ox}). By using hexagonal BN (HBN) for dielectric encapsulation of Graphene we may get low-field mobilities in excess of 1000000 cm^2/Vs which can be achieved at room temperature in these heterostructures. In this paper, we are going to present the first short-channel self-aligned GFETs (<100 nm) based on full HBN encapsulation of the Graphene sample fabricated by making edge contact to the Graphene; this is also the first time that this contact technology is used in a short-channel FET structures . Source and drain contacts are electrical contact to the edge of Graphene whivh gives low contact resistances, 100 and 200 -µm for electrons and holes.

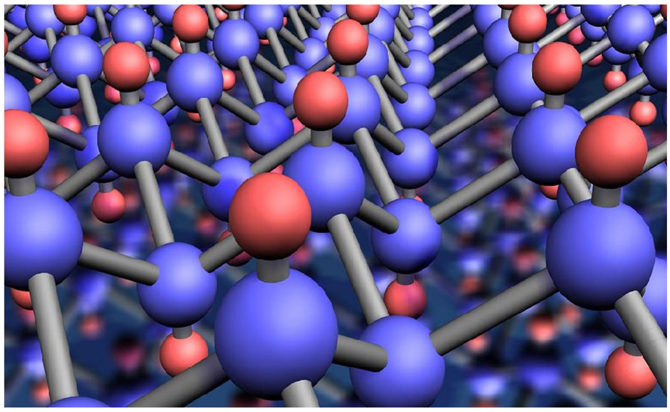

Fig. 2. Graphene Crystal

A van der Waals mechanical transfer technique is employed to assemble the encapsulated HBN/Graphene/HBN heterostructures (Cheng *et al.,* 2012). Firstly, HBN and Graphene crystals are exfoliated on 285-nm SiO2 on Si substrates. To verify the thickness of the crystals, the HBN is characterized by atomic force microscopy (AFM), by using a polymer handle, a thin HBN is selected to serve as the gate dielectric and then lifted from the SiO_2 surface. Monolayer Graphene is pick up by the HBN crystal. Then it is transferred onto a relatively thicker (>15 nm) HBN crystal which acts as the device substrate. Vacuum annealed at 350 °C for 15 min at <2×10−7 mbar is done on this assembled heterostructure to remove polymer residue left during the transfer process. A pristine, bubble-free heterostructure is obtained by characterization by AFM. An additional ungated, intrinsic Graphene region is present in most GFET structures. This region is a source of substantial additional contact resistance. By using a self-aligned process edge contacts are combined that effectively eliminates these spacer regions. Bottom gates are defined by e-beam lithography using a bilayer resist consisting of 200 nm of a copolymer below 100 nm of poly (methyl methacrylate) (PMMA). The gate metal is composed of 2 nm of Cr, 100 nm of Au and 20 nm of Pd. We anneal the device at 350 °C for 15 min at $<2\times10^{-7}$ mbar vacuum after the deposition of the gate metal to remove any PMMA residue. To make electrical contact with the Graphene edge, we evaporate 1.5-/10-nm Cr/Au. Low resistance connections to the devices are made by using the thick (100 nm) gold leads.

By sonication assisted simultaneous precipitation method, Vanadia (V_2O_5) (Sanhita Majumdar *et al.,* 2016) doped tin dioxide (SnO_2) nanocrystallites were synthesized, keeping in view their application for LPG (n-butane) gas sensor.). We make use of this property in Organic Field Effect Transistor without using any expensive nobel metal catalyst. In presence of 60-65% ambient humidity 0.50 wt % V_2O_5 doped SnO_2 exhibits the best sensitivity against butane at 4500^0C operating temperature. By sonication assisted simultaneous precipitation technique, the nanocrystalline SnO_2 based powders containing 0-1 wt % V_2O_5 can be prepared in this technique. After adding aqueous acidic vanadium pentoxide solution, $SnCl_2.2H_2O$ solution [0.0033 (M)] having a pH of 1.0 was sonicated (Ultrasonic processor, 25 KHz, 250 W, model-PR 1000, OSCAR Ultrasonics India). During sonication NH_4OH solution was added drop wise to the above solution. Finally the precipitates were centrifuged, after the sonication was continued for ~2 h (the pH of the mixture was kept at 9). Then it is washed with distilled water and acetone in a sequence and finally dried in a vacuum oven to obtain the dry powders.

Calcination is done on this dried powders at 600^0C for 2 hours. Thus we are planning to obtain a layer of V_2O_5 above the pentacene layer (Shun-Wei *et al.,* 2014). For the purpose of enhancement of the properties of the above structure we make use of Silver Pentacene (Shun-Wei *et al.,* 2014). The outstanding carrier transport capabilities of Pentacene make it a prominent candidate for the active semiconducting layer in organic thin film transistors. This compound which crystallizes in a layered structure has herringbone arrangement within each layer. Pentacene which appears in several polymorphic structures, differ basically by their c-axis lengths, meaning that the angle at which the molecules adsorb relative to the substrate changes from phase to phase. Stacking nature of the molecules make a reason for the interaction of the π-electron systems between adjacent molecules. It has been argued, that a smaller angle between the molecular axis and the surface normal results in a larger orbital overlap that is expected to provide better carrier transport properties. Therefore, to clarify and control the growth conditions for the different phases make for a good consideration.

A solution for the problem of energy mismatching between the metal electrode and organic channel, an efficient bottom-contact Pentacene FET is fabricated at room-temperature with Ag/self-assembled monolayers (Cheng *et al.*, 2012) electrodes that effectively change the work function from 4.2 to 5.8 eV. These results reveal that the injection efficiency is highly correlated to the metal/organic interfacial property. A highly transparency and high performance Pentacene FET based on ultra-thin graded Ag electrodes with top-contact structure is developed here. Better electrical characteristics than thick Au or Ag S–D electrodes is exhibited. By using the optimized thickness of 15 nm Ag and 35 nm capping layer of N,N^0-di(1-naphthyl)-N,N^0- diphenylbenzidine (NPB), it produces an efficient Pentacene FET with a threshold voltage of 6.0 V, on–off drain current ratio of 8.4 10^5, field-effect mobility of 1.71 cm^2/V s, and totally device transmission of 75% in visible light. Along with, electrical characteristics and conductive atomic-force microscopy (AFM) were used to address the injection property at the interface of Ag/pentacene and Au/pentacene.

Conclusion

By combining the properties of GFET, Graphene and HBN, an efficient and reliable sensor can be made for the detection of LPG. Such a sensor will be much cheaper than those currently available in the market. The introduction of Graphene, Pentacene and HBN significantly enhances the mobility of the OFET. Even though we don't go for the experimental verification of detection of sulphur dioxide and n-butane by the same structure, it certainly will be capable of doing so based on various analysis and simulations that have been performed.

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