Graphene Sensor for Future Local Economic Development: A Review

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Abstract. Graphene, a family of carbon has been known as a superior material of both conducting and transparent. Therefore, graphene is very promising material for many applications on microelectronics and nanotechnology. The structural, thermal, optical and electrical properties of the graphene were also potential to be applied on sensor. Graphene is the most recognized nanoparticle for fabrication of biomedical sensors due to its stimulating qualities such as excellence aqueous process ability, functional surface properties, surface-enhanced Raman scattering, cell growth ability, and good biocompatibility. Due to the high specific surface area of graphene, it was very excellent material for gas sensor application. The outstanding properties of graphene were also led to increasing the demand of graphene every year which is dominated by China (70%), India (14%), and Canada (2%). Moreover, current marketplace of graphene was also dominated for academic research, super capacitor, ITO, and sensor. Every year, the market of graphene sensor is continuously increasing. This trend reveals graphene-based sensors very promising commodity for future technology. The present study highlights the state of art review and potential future local economic development of graphene for use as sensors.

1. Introduction
Malaysia economy growth is one of the importance issues that got the attention by Malaysian government. Due to that concern, it has been include in Eleventh Malaysia Plan (11MP) for realization of five-year development plan towards realizing the goal of Vision 2020 [1][2]. The planning of the 11th Plan is based on the National Development Strategy of Malaysia (MyNDS) which focuses around the development of capital-based economy and people-based economy with the implementation of high impact projects [3]. For realization of high impact project, advance material is one of importance mechanism to promote local economic growth [4]. Graphene is a new advance materials designed for targeted properties that can support the government initiatives by improving the products development in manufacturing sectors [5][6].

Moreover, the broadest using in a human life since it has found a big advantage facilitate and ease people to do anything rapid and automated is sensor. In the recent years, challenging problems all over the world among clinical, environmental, and food lead to be solved with the innovative and efficient...
technology [7][8]. Sensor comes out with its analytical system detecting or measuring a physical property and recording, indicating or otherwise responding to it. Any environmental phenomena, light, heat, motion, pressure, moisture could be the specific input which then yielding output in a signal that is converted to readout and displayed data at location of the sensor or transmitted electronically through a network for further processing [9]. Prior to recent research, electrodes lead the important part to consent monitoring as the hole part which receive and analyze the sensed data [10].

Sensor is one of the ‘killer’ product and technology that have high demand now and in future that can bring high impact on economy advancement since it is important in daily lives [11]. With the rise of the Internet of Things and automated processes on sensor system, gain more interest in this area [12]. Although the large-scale production of sensor has been commercialized, many issues need to be addressed to advance their industrial applications [13]. One of the importance issues is including the material used for enhanced the ability of the sensor to be used in many applications including in the harsh environment [14] [15]. Graphene based material is highly recommended on becoming sensor material because of its excellent properties [16]. Now graphene come out as dominated of research interest and there are a lot of research graphene-based sensor product that have potential to reach the market [17].

2. Graphene-based sensor

Graphene has been performing as popular choice due to its unique properties possessing excellent electrical and crystal qualities. In a simple word, graphene known as a single layer of carbon atom in a planar sheet apply as structural element of graphite, carbon nanotube (CNT), and fullerene [18]. In comparison, graphene exhibits larger surface are (2630 m²g⁻¹) than graphite (10 m²g⁻¹) and CNT (1315 m²g⁻¹) [19][20]. The large surface area of 2D materials offers large range of reactive sites, which lead these materials as an efficient in sensing. This primary property particularly suited for gas sensor application which indicate to sensitivity of electrical properties against changes around [21] [22]. A small shifting of signal concentration initiated by gas contact, gradually lead to changes in electrical conductivity. Hence, graphene is also possessed in good electrical conductivity due to its highly sensitive in planar surface.

Some high performances of graphene contain of high electrical conductivity approximately (~1.0 .10⁸ S/m), high melting point (4510 K), high thermal conductivity (2000-4000 Wm⁻¹K⁻¹), highest current density (~1.6 .10⁹ A/cm²), and also high electron mobility (200,000 cm² V⁻¹ s⁻¹) at electron density ~2.10¹ⁱ cm⁻² [23]–[26]. A research reported that these properties performed fewer electrical noise and crystal defects which contribute to its application in electrochemical sensor of hazardous substances like hydrazine, biomolecules like uric acid, and selective detection of adenine dinucleotide [27]. These are appropriate materials for electrochemical sensors than the conventional one which required to the presence of electrical charge in stable state. Graphene showed zero band gap which then ease the electron transfer and carrier mobility stated in a very high level due to its large planar surface to volume ratio in sensor mechanism. In additional, further high electrical conductivity and high optical transparency of graphene makes it a potential candidate for expanding an electrode with transparent conductor which can have tremendous prospective applications in touchscreens sensor and the absence of nuclear magnetic moments. As known in visible region that graphene respectively reflects < 0.1%, for approximately 10 layers graphene raising showed ~2%. Hence, over the visible spectrum, number of layers to be proportional to the optical absorption of graphene with the number absorption of A = 1 = πα = 2.3% [28] [29].

Both graphene large surface area and high electrical conductivity act as the fundamental properties affecting another dynamic property. Larger active site is offered due to its large surface which potentially helps the loading of desired biomaterials, yielding an interaction between analyte biomolecule and graphene as the electrode [30]. As known that graphene is biocompatible material performing well interaction between both undamaged biomolecule after attachment [31] [32], [33]. Furthermore, π-π interaction on graphene allowed to be functionalized desirably through some linker which contact to the surface of graphene. Some researchers reported that graphene was linked by π-π
3. Graphene market

Graphene is considered as nanostructure material within the family of carbon [38]. A group of graphene materials including pristine graphene sheets, few layer graphene flakes, graphene oxide, reduce graphene oxide, Graphene Nanoplatelets (GNP) and others offer a scope of extraordinary, versatile, tunable properties that can be innovatively utilized in many fields such as defense [39], transportation [40], petrochemical [41], energy [42], electronic component [42] and many more. Until now, there are rapidly increase in research area of graphene start from the achievement of Nobel Prize winners, Andre Geim and Konstantin Novoselov with their research of using ‘scotch tape’ for high conductive graphene formation [43]. Up until now, 2020, more than 1,810,000 results found in scientific paper ‘google scholar’ by keyword ‘graphene’. From scientific knowledge of graphene material superiority in research paper, the graphene starts to spread it greatness for many technologies and opportunities. IDTechEx research had make a prediction that the total market for graphene and Graphene-based products could be worth 400 million USD by 2024 globally as shown in figure 1.

![Figure 1: IDTechEx. Graphene Markets, Technologies and Opportunities 2014-2024 [44].](image)

In the applied field of graphene, among its wide range of applications, graphene has been mostly used in super capacitor and energy storage like batteries. It is due to its large surface area and high strength to weight ratio effective to provide low charging time [45]. Large number of applications is also can be found in areas like RFID, sensors, functional inks, high – strength composition in flexible electronics and catalysis due to its unique properties which include a distinctive nanopore structure, high mechanical strength and high electrical and thermal conductivity [46]. All graphene application including graphene-based sensors application shown the steadily increase throughout the year [44]. The high production of economically scalable graphene and high ability to adapt the graphene material into the requirements commercialization industrial application is the key of success for highly gain on graphene-based product [47].
The company that is produced graphene, and graphene-based sensor such as Graphenea, Applied Nanotech Inc, 2-DTech, Graphene Frontier, play important role on graphene industrial around the world. Their products cover a high quality of graphene thin film, sensor based on graphene, which is has large potential in area of nanomaterials, nanoelectronics, nanosensors, and nanoeconomy as well. Further analyzed related to the global graphene market based on geographical regions that are contributing significantly towards the growth of the market, Asia Pacific is projected to exhibit a fastest growth in the global graphene market over the forecast period. The reserves for graphene in the region, especially in China, is one of the major factors contributing towards the market growth of graphene in Asia Pacific. North America embraces a dominant position in the global graphene market. This is due to rapid growth of automobile and electronics sector in the North America. Otherwise, the growing of energy sector has proven the major driver in the growth of the graphene market in North America. Currently, demand of graphene is dominated by China (70%), India (14%), and Canada (2%).

Locally, the development of graphene-based sensors was also led graphene to be a main focus of technology industries. Graphene-based sensor can be mass produced by local people or local researcher by commercializing from laboratory scale into industrial scale since the fabrication of graphene-based sensor is not difficult. These can absolutely bring economic benefit and increase local people income. Figure 2 shows a portable bacteria sensor using graphene as a sensing layer. The sensor is very compact, portable, user friendly, and easy to maintenance. This device is very promising for industrial purpose since it has a simple design and manufacturing.

![Portable bacteria sensor based on graphene](image)

**Figure 2:** Portable bacteria sensor based on graphene.

4. Conclusion

Graphene is superior material which is very potential for many sensor applications. Graphene usage in sensor industries would attribute towards creation of new sensor product that can be exported so we do not have to rely on commodities. The number of potential applications using graphene sensors can be increased by converting more of the graphene-based sensors into sensing systems. In order to enhance the graphene sensor products, the government needs to facilitate more company in using graphene.

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