Development of Graphene Based Flow Sensor

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Abstract:
This paper shows the research on a flow sensor based on graphene. Presented Results show the linear relation between voltage induced on graphene layer and flow velocity. The measurement shows that signal level is relatively low, and it is highly correlated with the time of the sample being submerged in water. A significant temperature dependency has been shown which indicates on necessity to develop a compensation system for the sensor. On the other hand, induced voltage is related to ion concentration of the liquid, so the sensor must be recalibrated for every working environment. The most important thing that turned out during research is that although the voltage signal itself is highly inconsistent, the difference between its value in steady state and for flowing liquid is always visible and correlated to the flow value – this property can be used in further deployment. Huge advantage of the sensor is also its scalability which opens so far unknown possibilities of applications.

Keywords: *graphene, flow, sensor, voltage*

1. Introduction

Graphene is characterized by a wide range of incredible properties, both electrical and mechanical, which makes it a very promising material in many branches. It is an excellent current [1] and heat [2] conductor and regarding its untypical dispersive relation [3] it provides electron flow with 1/300 speed of light! Despite a very small thickness its extension strength is more than hundred times higher than for construction steel or Kevlar [4].

Probably the biggest and most remarkable achievement of Poland in that matter is elaborating an innovative manufacturing technology. In 2011 a team led by professor Włodzimierz Strupiński from Instytut Technologii Materiałów Elektronicznych (Institute for Electronic Materials Technology) invented a method of producing thin graphene layers on SiC [5], which was given a patent the very same year. Presented results are the effect of the research made in *FlowGraf* project. Its final purpose is to design, build and deploy a flow sensor based on graphene. An underlying research focused on examining the influence of various factors on the voltage induced in the graphene sample among which the main one was the velocity of the flowing liquid and the others were the quantities which can disturb the consistency of the voltage level: in this case temperature and concentration of sodium chloride.

Currently known methods of flow measurement (e.g. ultrasonic, electromagnetic, Coriolis, vortex etc.) does not provide proper measurement of liquid flow for low speeds.

Research showed that the graphene sensor can be used in the measurement of low flow rate.

2. Possibility of Using Graphene as a Part of Flow Sensor

A flow sensor based on graphene has to meet several requirements, i.a.:
a) induced voltage is related to the flow velocity,
b) changes of voltage level are consistent and mathematically describable in a relatively simple manner,
c) signal dynamics is high enough – sensor is reasonably sensitive and can work in a wide range of flow velocities,
d) signal to noise ratio is low enough.

Proper measurements, needed to check how the sensor meets the requirements mentioned above, have

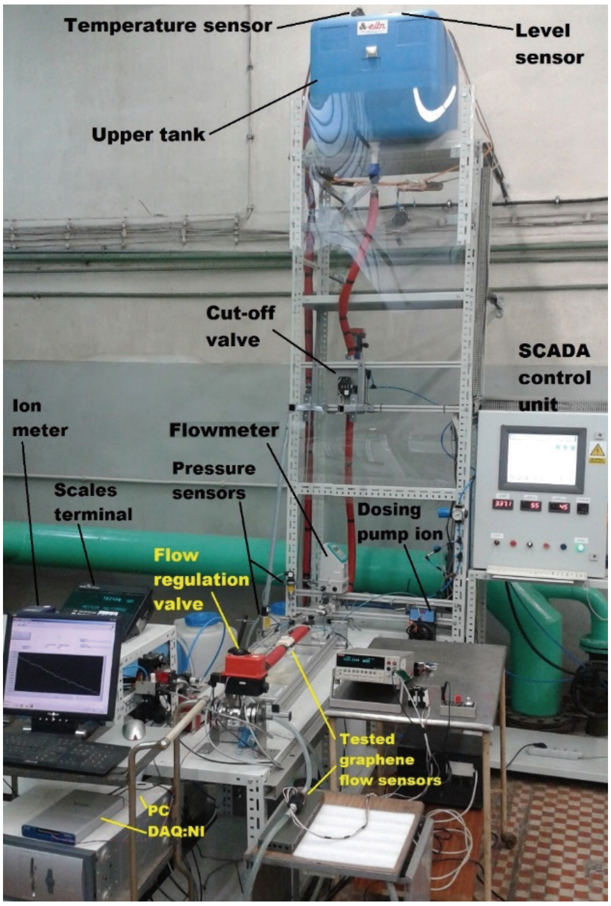

Fig.1. Laboratory stand for graphene sensor measurements

been proceeded in Przemysłowy Instytut Automatyki i Pomiarów (Industrial Research Institute for Automation and Measurement) in Warsaw, on a laboratory stand set specifically for that purpose (Fig. 1).

The stand presented above enabled to control the flow velocity using proportional valve and to stop the flow on either inlet or outlet of the tube using on-off valves and to examine the behavior of the sensor (mounted as shown in Fig. 2)

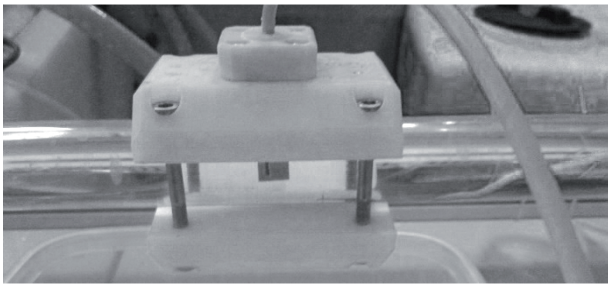

Fig. 2. Mounting of graphene sensor in the tube

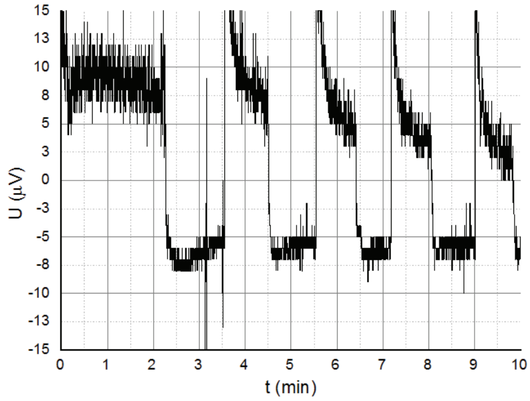

Fig 3. Transient of voltage for different flow velocities

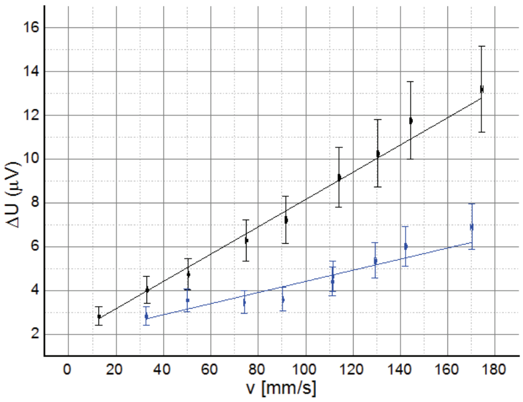

Fig. 4. Relation between voltage and liquid velocity

First thing that needed to be determined was the relation between flow velocity and voltage signal. It has been examined using (once) deionized water. During the research an attempt was made to simulate the differential system – using a proportional valve a certain flow value was set, the measurement was made and the same approach was repeated for a steady state, when the water flow was stopped. An exemplary transient of voltage was shown in Fig. 3.

As we can see, the signal level is higher for flowing liquid than in steady state. Another thing to note is that a signal for non-zero flow becomes stable after certain amount of time which is probably associated with inertial effects – charging and discharging of a capacitance of our sample or fluctuations of flow velocity. Liquid velocity was estimated basing on the indications of flow sensor – basing on that we obtained the relation between induced voltage and velocity for two series of measurements (Fig. 4).

Voltage level is higher for 1st series (black) than for the 2nd one (blue) which is related to constant drop of voltage in time. It shows again a phenomenon of discharging the graphene layer and every relation determined one after another with a sample constantly submerged in liquid will be lower than the previous one. Results presented above, as well as others obtained during our work, were inconsistent as far as voltage level is concerned, but the sensitivity is always of the same order of magnitude – about 10 nV/ mm/s and there is always a visible and measurable difference between the signal level for flowing liquid and steady state which can be useful in further research (look: conclusion).

3. Influence of Liquid Characteristics on Electrical Signal Generation

3.1. Influence of Temperature

In order to determine how temperature influences the voltage of graphene sample, liquid was heated up to a certain temperature and flew through a sample for a constant flow rate. Research has been made for temperature within 20–47 °C range every 3–4 °C and voltage has been measures after achieving a desired temperature which resulted in a voltage-temperature relation (Fig. 5).

Voltage difference increases with temperature which can be explained by growth of charges mobility which results in higher potential differences in a graphene layer. Order of magnitude for temperature sensitivity can be estimated as $\delta_T = 100$ nV/°C. Changes of voltage influenced by temperature aren't at all negligible – change of temperature by 1 °C causes similar change of voltage as change of flow velocity by 10 mm/s. This show that in a final flow sensor construction it is required to use temperature compensating systems (eg. thermistors) or taking it into account in a software algorithm for assigning flow velocity to certain voltage values.

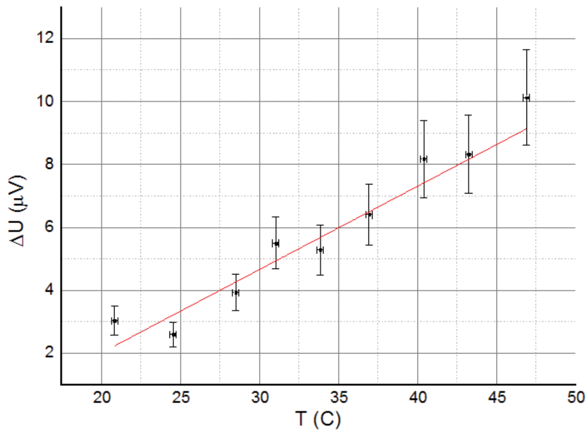

Fig. 5. Voltage-temperature relation for differential voltage

3.2. Influence of Sodium Chloride Concentration

Flow sensor is expected to work also for water solutions of various compounds. Thus, we examined how the concentration influences voltage level. In this research, different sample has been used so the results aren't quite comparable to the ones presented before, but can give us some knowledge about the scale of the phenomenon. We used sodium chloride solution within a range of concentration between 0 and 3% every 0,3% for measurements. Results are shown in Fig. 6.

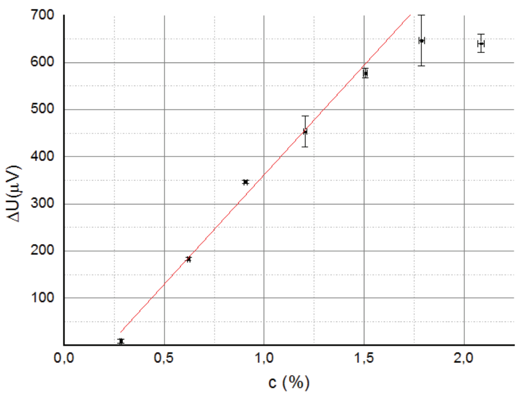

Fig. 6. Relation between voltage and sodium chloride concentration

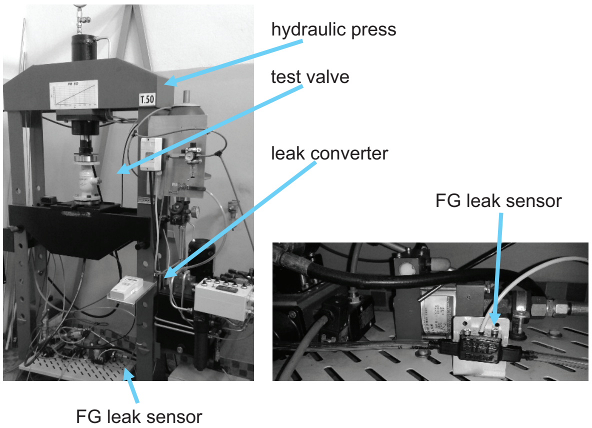

Fig. 7. Measuring station for the graphene leak sensors testing

Again we obtained constant sensitivity of order 100 μV/%NaCl. We can try comparing it to other results by scaling. For this sample voltage is of order 0,1 –1 mV, before it was 0,01 mV so 1–2 orders of magnitude higher. We can therefore estimate that for the sample examined before the sensitivity would be of order 1–10 μV/%NaCl. It is a very significant value compared to the previously estimated sensitivity values for velocity and temperature which shows that sensor acts in a different way for every liquid regarding its concentration.

4. Conclusion and Further Research Directions

It turned out that voltage changes in graphene sensor caused by liquid flow are inconsistent. On the other side there is always a significant change of voltage level which can indicate whether there is a flow of liquid or there isn't or if the flow increased or decreased because the direction of change always stays the same. This feature has already been used in *Industrial Research Institute for Automation and Measurement* – graphene sensor is used in one of laboratory stands as leak detector.

Further work is planned on the commercial application of sensor leaks. Recipients of a leak detector can be manufacture of valves such as APATOR Powogaz S.A., Broen S.A., Gazomet Sp. z o.o., Norson, MPWiK Wrocław etc.

Huge advantage of presented sensor is its size – flow- meters already present on market are very big which automatically excludes many applications. It is easily scalable and supported by relevant research it could be used in micro scale – for instance in human circulatory system to detect and prevent blood congestions.

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