A new method for determination of the energy markers to control the hormonal state of the human body with quantum point-contact sensors

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Motivation

Breath analysis to study the content of hormones in the human body is an attractive task since in theory, breath contains complete information about the metabolic processes occurring in the human body. Mass spectrometry, gas chromatography–mass spectrometry, and various optical spectroscopy techniques are successfully used to detect substances in the breath. Yet, the high costs of the equipment and the need for highly skilled staff to operate and maintain it impede the large-scale implementation of these techniques in daily medical practice. From this point of view, it seems promising to use conductive sensors to analyze the breath. In this work, we propose a new method for analyzing melatonin, serotonin and cortisol levels in the human body using quantum point-contact sensors. This method is based on the fundamental properties of Yanson point contacts, which have previously shown their effectiveness for solving a wide range of problems.

Point contacts as a gas sensors

Two bulk electrodes, contacting each other over an extremely small area, constitute an electrical contact of a small dimension – a **point contact**. Such contacts have several specific properties, provided by their nature:

1.The extremely high surface-to-volume ratio of those contacts means that they are sensitive even to several molecules of the gas absorbed on their surface;
2.The specific potential distribution in the contacts means that only the constriction area is responsible for the conductivity changes (**fig.1**);
3.The thermal and non-equilibrium processes are separated in space for such objects.

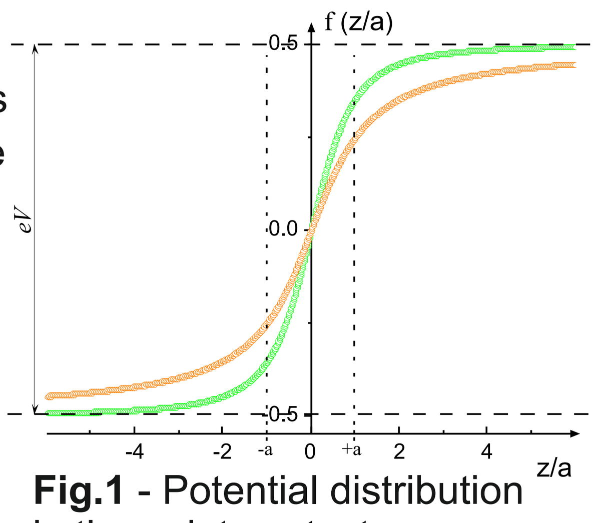

Fig.1 - Potential distribution in the point contact

Experimental

The complex surface of the gas sensor consists of a large amount of point contacts, that are made between layered **Cu-TCNQ** crystals (**Fig.2**). Such structure is obtained by combined electrochemical deposition of TCNQ from the saturated solution of acetonitrile to the foiled by copper textolite. Every square millimeter of the gas sensor contains more than **$5*10^5$** point contacts. This ensures the high level of the sensor output signal under the action of the gas media.

A response of a gas sensor to the action of the breath is recorded as the equidistant time series of the potential drop. Each response curve consists of the exposure and relaxation period (**Fig. 3**).

The measurement complex consists of the gas sensor, a sensor holder with the built-in temperature and humidity sensor (**Fig. 4 A**), a PCB that provides the ability to perform measures in a real-time regime (**Fig. 4 B**), and a PC with the specially developed software (**Fig. 4 C**).

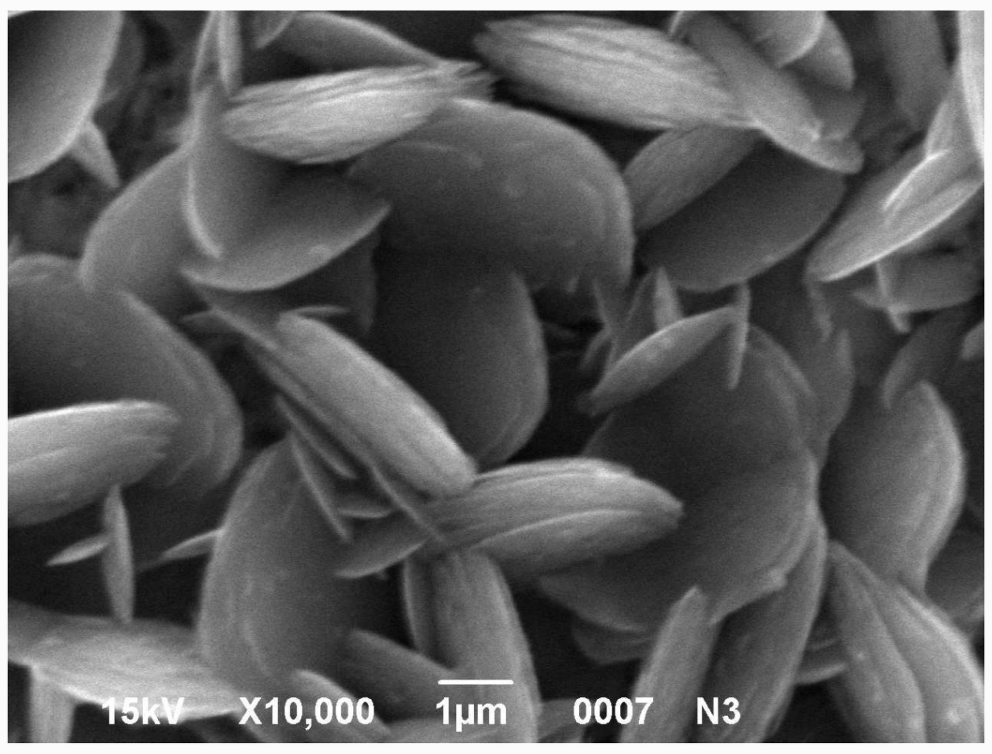

Fig.2 - General view of the surface of a point-contact sensing element based on the TCNQ compound.

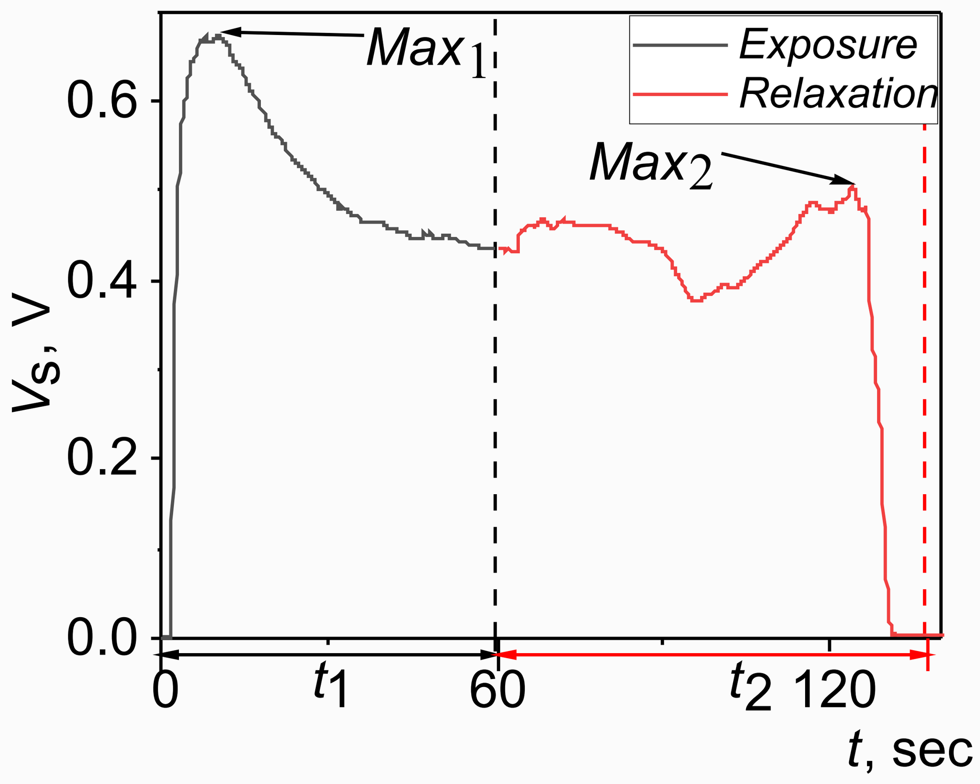

Fig.3 - Typical response curve of point contact sensor based on TCNQ compound under the action of breath of a healthy person.

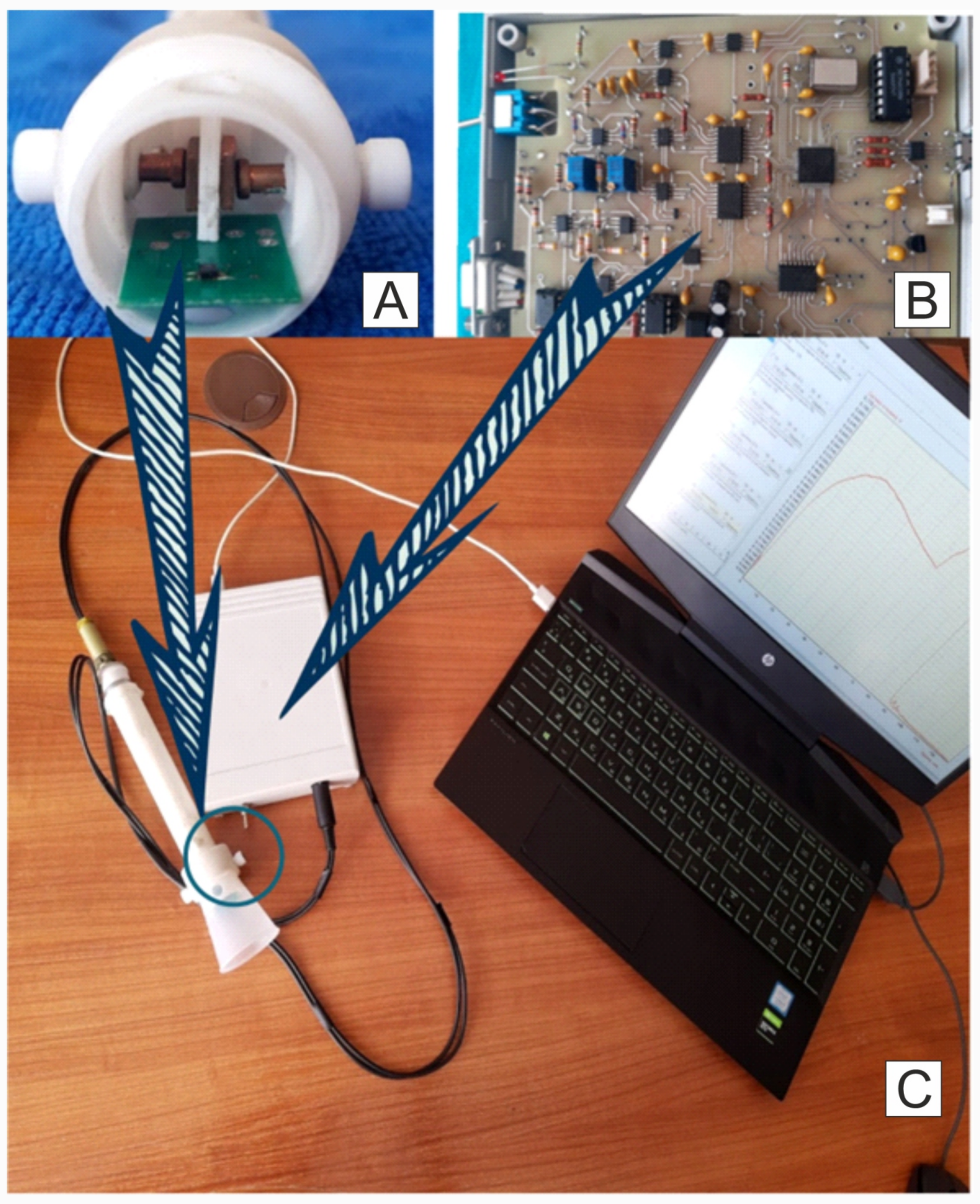

Fig. 4 - Appearance of the measuring complex

Results

The process of realization of the new express method for hormone detection can be divided into several phases. At first, in the control group of 20 patients, there were determined hormone concentrations and sensor response curves to the action of breath for each patient. Then for this group of patients, the temporal dependence of the correlation coefficient for the studied substance (melatonin) and the sensor signal was found.

We calculated the Pearson correlation coefficient **r** between the voltage drop **V** at a given time section and the hormone concentration **C** (**fig. 5**)

The values of average voltage drop from the founded time section with the highest correlation between voltage drop and corresponding hormone concentration were used to define the position of the points in the graph of response voltage as a function of concentration (**Fig. 6**). Then we used the linear approximation and drew a straight line from the points obtained by the least-squares method.

The obtained line equation served as characteristic to evaluate a hormone concentration in the human body by a breath analysis

$$r = \frac{cov_{vc}}{\sigma_v \sigma_c} = \frac{\sum_{j=1}^{n}(V_j-\overline{V})(C_j-\overline{C})}{\sqrt{\sum_{j=1}^{n}(V_j-\overline{V})^2 \sum_{j=1}^{n}(C_j-\overline{C})^2}},$$

$$\overline{V} = \frac{1}{n}\sum_{j=1}^{n} V_j, \overline{C} = \frac{1}{n}\sum_{j=1}^{n} C_j.$$

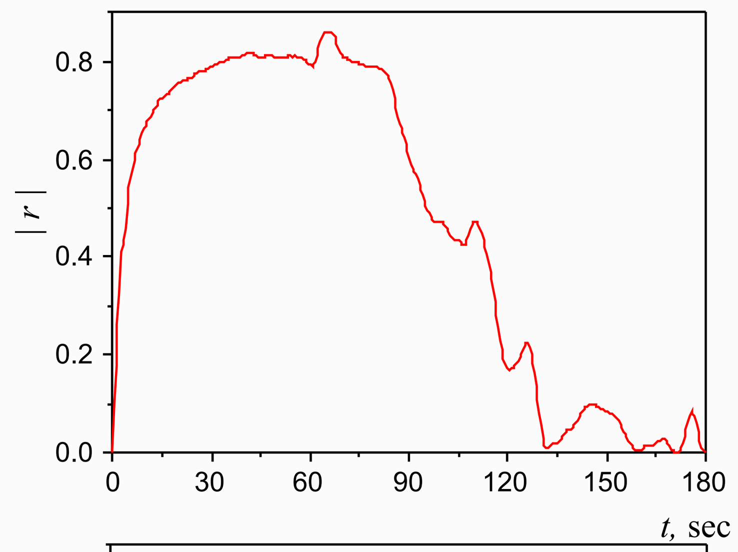

Fig. 5 - Visualization of the dependence of Pearson correlation coefficient between the Voltage drop and the melatonin concentration on response time.

It can be clearly seen that the maximum correlation is observed on the temporal section **63.5-67.5 s**

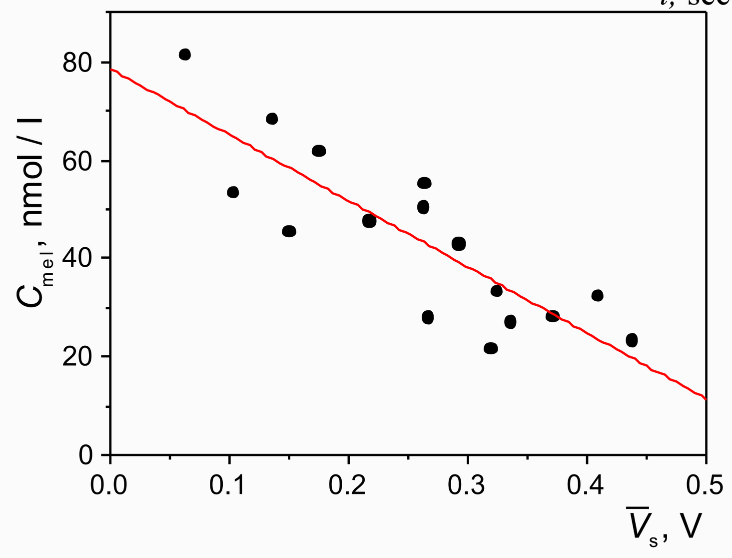

Fig. 6 - Dependence of the analytical concentration of melatonin on the average response voltage in the area of maximum correlation. Points are data of medical analyses; straight line is the result of the linear approximation.

$$C_{mel}[nmol/l] = 78{,}5 - 134 * \overline{V}$$

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