Ascorbate Detection Using Single Trap Phenomena in Two-Layer Si NW FETs

Yurii Kutovyi
Bioelectronics (ICS-8), Forschungszentrum Jülich, 52428 Jülich, Germany
y.kutovyi@fz-juelich.de

Ihor Zadorozhnyi
Bioelectronics (ICS-8), Forschungszentrum Jülich, 52428 Jülich, Germany
i.zadorozhnyi@fz-juelich.de

Natalia Naumova
Bioelectronics (ICS-8), Forschungszentrum Jülich, 52428 Jülich, Germany
naumova.kandaurova@gmail.com

Nazarii Boichuk
Bioelectronics (ICS-8), Forschungszentrum Jülich, 52428 Jülich, Germany
n.boichuk@fz-juelich.de

Mykhaylo Petrychuk
Taras Shevchenko National University of Kyiv
03127 Kyiv, Ukraine
m.petrychuk@gmail.com

Svetlana Vitusevich
Bioelectronics (ICS-8), Forschungszentrum Jülich, 52428 Jülich, Germany
s.vitusevich@fz-juelich.de

Abstract—Biosensing and detection of biological and chemical species are essential to many areas of life sciences, including the diagnoses of different diseases. We recently revealed that single-trap phenomena in nanowire field-effect transistors (NW FETs) are very sensitive to changes in the pH or ionic strength of solutions [1, 2]. In this study, we apply a new sensing approach based on single-trap phenomena for the detection of ascorbate biomolecules in electrolyte solutions using liquid-gated silicon (Si) two-layer (TL) NW FETs. It is extremely important to develop a highly sensitive tool for monitoring such antioxidant molecules like ascorbate, since they are one of the most powerful antioxidants and can be used as a measure of oxidative stress in chemical, biochemical, and biological systems.

Keywords—Nanowire biosensors, single trap, low-frequency noise, ascorbate molecules, oxidative stress.

I. INTRODUCTION
Si NW FETs are excellent candidates for biosensing from the viewpoint of the development of label-free, low-noise, high-speed and ultra-sensitive biosensors. Recently we have proposed a new sensing approach for biosensing based on single trap phenomena that can be observed in nanoscale devices like Si NW FETs. The key idea of the new sensing approach is to utilize a single trap as a sensor in order to enhance the sensitivity of FET-based biosensors. In this work we show that exploiting of a single-electron trapping-detrapping process in Si TL NW FETs allows for detection of ascorbate molecules with enhanced sensitivity.

II. RESULTS AND DISCUSSION
The schematic view of the fabricated nanostructures is presented in Fig. 1a). The TL nanowire consists of two p-type silicon layers with different dopant concentrations. The specific TL design of the nanowire is beneficial for single-trap phenomena, which are demonstrated by the random telegraph signal (RTS) noise [2]. Typical two-level fluctuations of drain current measured for 70-nm-wide and 400-nm-long Si TL NW FETs are presented in the inset of Fig. 2a. Such drain current fluctuations are the result of the carrier exchange process between a conductive channel and a single trap allocated in the gate oxide layer close to the Si/SiO₂ interface.

Until recently, RTS noise was largely considered to be an undesirable effect that affects transistor performance. However, in this study, we show that single-trap phenomena can have a positive role for biosensing applications. We demonstrate that different concentrations of ascorbate molecules (or L-ascorbic acid) in phosphate-buffered saline solutions can be detected with considerably higher sensitivity by monitoring changes in capture time as a characteristic of a single trap compared to traditional sensing approaches in which the drain current or threshold voltage of a transistor is used as a sensing parameter (see Fig. 1b).

Fig. 1. (a) Schematic view of a Si TL NW FET with a microfluidic channel (cross section along the nanowire); (b) Response of the sensor to different concentrations of ascorbate molecules (or L-ascorbic acid) in relation to the sensitivity calculated for both the standard approach (change in drain current) and the single-trap approach (change in capture time). Inset: typical time trace of drain current fluctuations, reflecting RTS noise in a Si TL NW FET.

Therefore, we show that RTS phenomena in two-layer Si NW FETs can be considered as a source of useful information with respect to analyte molecules detection. Our results open new prospects for fundamental studies and practical applications in biosensing with enhanced sensitivity.

References