# Proceedings of the International Conference "Micro- and Nanoelectronics – 2023"

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IC Micro- and Nanoelectronics

**With the Extended Session**

QI 2023

Quantum Informatics

# *Book of*

# ABSTRACTS

**October 2 – 6, 2023**

**Moscow – Zvenigorod, Russia**

National Research Center “Kurchatov Institute”, Moscow, Russia
Valiev Institute of Physics and Technology
of the Russian Academy of Sciences

# Proceedings of the International Conference

# «MICRO- AND NANOELECTRONICS – 2023»
# ICMNE – 2023

## Book of Abstracts

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Сборник содержит тезисы докладов, представленных на Международной конференции «Микро- и наноэлектроника – 2023» (ICMNE-2023), включающей расширенную сессию «Квантовая информатика» (QI-2023). Тематика конференции охватывает большинство областей физики микро- и наноразмерных приборов, а также микро- и наноэлектронных технологий, и концентрируется на освещении последних достижений в этой сфере. Она продолжает серию всероссийских (с 1994 года) и международных конференций (с 2003 года).
*Ключевые слова:* нанотранзисторы, затворные стеки, квантовые компьютеры, МЭМС, магнитные материалы, оптоэлектроника.

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The Book of Abstracts contains the abstracts of the papers presented at the biannual International Conference “Micro- and Nanoelectronics – 2023” (ICMNE-2023) including the extended Session “Quantum Informatics” (QI-2023). The Conference topics cover the most of the areas dedicated to the physics of integrated micro- and nanoelectronic devices and related micro- and nanotechnologies. The Conference is focused on recent progress in those areas. It continues the series of the AllRussian Conferences (since 1994) and the International Conferences (since 2003).
*Keywords:* nanoscale transistors, gate stacks, quantum computers, MEMS, magnetic materials,optoelectronics.

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# Nitrogen-doped carbon nanotubes as a functional material for a piezoelectric nanogenerator

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In recent years, the development of new power sources for wearable devices has become increasingly important. The search for power sources led researchers to use the conversion of external mechanical energy into electrical energy. Sources of mechanical energy can be both human movements (breathing, walking, blinking) and noises created by passing cars, slamming doors, and so on. The use of the piezoelectric effect is well suited for energy conversion [1]. Well-known piezoelectrics, such as ZnO, $BaTiO_3$ and PZT, widely used as functional materials. However, the presence of some disadvantages of these materials has set the task of searching for new functional materials with a high piezoelectric strain coefficient and flexibility.

Recent studies have found that nitrogen-doped carbon nanotubes (N-CNTs) have anomalous piezoelectric properties [2]. The source of anomalous piezoelectricity in N-CNTs is bamboo-like bridges in the nanotube cavity. They are formed during the growth of N-CNTs when nitrogen atoms are incorporated into the hexagonal structure of a nanotube with the formation of pyrrole-like substitutional defects. The dipole moments are formed on these bridges as a result of the curvature of the graphene sheet and the entire nanotube is polarized. Together with excellent mechanical properties and high Young's modulus, nitrogen-doped carbon nanotubes are a promising material for creating energy-efficient piezoelectric nanogenerators (PENG). The aim of this study is to develop a piezoelectric nanogenerator based on N-CNTs.

The experimental samples were N-CNT arrays grown by plasma chemical vapor deposition method in ammonia and acetylene flows. The Mo, W, and Ta sublayers were used as the lower electrodes. The study of the piezoelectric properties of N-CNT arrays was carried out by the piezoelectric force microscopy method of an atomic force microscope (AFM). A commercial NSG10 probe with a conductive TiN coating was used as a AFM probe. Experimental studies have shown that N-CNT grown on the Mo sublayer had the highest piezoelectric strain coefficient $d_{33}$ with value 22.7 pm/V. For N-CNTs on the W and Ta sublayer the $d_{33}$ values were 18.5 pm/V and 7.8 pm/V, respectively. This dependence is directly related to the concentration of pyrrole-like nitrogen defects. Thus, the concentration of doping nitrogen measured by X-ray photoelectron spectroscopy was 10.1%, 7.6% and 2.85%, of which the concentration of pyrrole-like nitrogen was 2.85%, 1.94% and 1.37% for Mo, W and Ta sublayers, respectively.

The output voltage of the deformed N-CNT was also simulated in the COMSOL software package. The height of the N-CNT was 1 μm and the diameter was 80 nm. The simulation results showed that the magnitude of the generated potential in N-CNT is -0.316 V by an external force of 1 μN. This potential leads to the flow of current in the circuit near -31.6 A with a resistance of the measuring system of 10 MΩ. The obtained results correlate well with the obtained experimental results for the N-CNT with a height of 0.9 μm and a diameter of 82.5 nm. The value of the current generated during deformation N-CNT by an external force of 1.18 μN was 32 A, which corresponds to -0.32 V. The adequacy of the obtained model is shown. This makes it possible to further use it in the development of PENG based on N-CNTs with various geometric and mechanical parameters.

Thus, the dependence of the piezoelectric properties of N-CNTs on the concentration of pyrrole-like nitrogen has been established. The output parameters of a PENG based on a single N-CNT have been studied. In this case, it should be noted that the output current can be increased by increasing the number of N-CNTs in PENG. Thus, the prospects of using N-CNTs as a functional material for energy-efficient PENG are shown.

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1. Q. Xu, J. Wen, Y. Qin, “Development and outlook of high output piezoelectric nanogenerators”, Nano Energy, **86,** 106080, 2021.

2. M. V. Il’ina et al. “Study of Nitrogen-Doped Carbon Nanotubes for Creation of Piezoelectric Nanogenerator”, J. Low Power Electron. Appl., **13**, 2023.

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