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Кафедра иностранных языков

ИНОСТРАННЫЙ ЯЗЫК

НАНОЭЛЕКТРОНИКА: ПРОМЫШЛЕННАЯ ЭЛЕКТРОНИКА

FOREIGN LANGUAGE NANOELECTRONICS: INDUSRIAL ELECTRONICS

Методические указания к самостоятельной работе для студентов магистратуры направления 11.04.04

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Данные методические указания предназначены для самостоятельной работы студентов магистратуры по дисциплине «Иностранный язык». Методические указания включают аутентичные тексты в соответствии с направлением подготовки. Тексты сопровождаются заданиями, целью которых является развитие умений чтения, перевода и поиска информации.

Методические указания предназначены для студентов магистратуры, обучающихся по специальности 11.04.04 «Электроника и наноэлектроника» направления подготовки «Промышленная электроника» и согласованы с программой по иностранному языку для студентов неязыковых вузов.

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ВВЕДЕНИЕ

Данные методические указания для самостоятельной работы по английскому языку предназначены для студентов магистров специальности 11.04.04 «Электроника и наноэлектроника», направления подготовки «Промышленная электроника». Методические указания составлены в соответствии с учебной программой по дисциплине «Иностранный язык» для формирования иноязычной профессиональной компетенции будущих специалистов.

Предложенные методические материалы предназначены для самостоятельной работы студентов и состоят из пяти разделов, содержащих информацию о наноэлектронике и применении нанотехнологий в различных сферах промышленной электроники. Каждый текст сопровождается комплексом послетекстовых заданий и упражнений, направленных на контроль понимания прочитанного материала, формирование умения ориентироваться в оригинальных текстах, отработку и закрепление изучаемого лексического материала, контроль навыков перевода.

Изучение предложенного материала имеет целью развитие и совершенствование навыков чтения и перевода оригинальной научной литературы по наноэлектронике и промышленной электронике, расширение словарного запаса, преодоление трудностей перевода и приобретение навыков устной и письменной коммуникации в сфере профессиональной деятельности.

UNIT 1 NANOELECTRONICS

TEXT 1.1 Nanotechnology in Electronics

1 Read the introductory text about nanoelectronic devices and translate it.

Nanoelectronics – Nanotechnology in Electronics

The term nanoelectronics refers to the use of nanotechnology in electronic components. These components are often only a few nanometers in size. However, the tinier electronic components become, the harder they are to manufacture.

Nanoelectronics covers a diverse set of devices and materials, with the common characteristic that they are so small that physical effects alter the materials' properties on a nanoscale – inter-atomic interactions and quantum mechanical properties play a significant role in the workings of these devices. At the nanoscale, new phenomena take precedence over those that hold sway in the macro-world. Quantum effects such as tunneling and atomistic disorder dominate the characteristics of these nanoscale devices.

The first transistors built in 1947 were over 1 centimeter in size; the smallest working transistor today is 7 nanometers long – over 1.4 million times smaller (1 cm equals 10 million nanometers). The result of these efforts are billion-transistor processors where, once industry embraces 7nm manufacturing techniques, 20 billion transistor-based circuits are integrated into a single chip.

Nanoelectronic Devices

Spintronics. Besides transistors, nanoelectronic devices play a role in data storage (memory). Here, spintronics – the study and exploitation in solid-state devices of electron spin and its associated magnetic moment, along with electric charge – is already an established technology. Spintronics also plays a role in new technologies that exploit quantum behaviour for computing.

Optoelectronics. Electronic devices that source, detect and control light – i.e. optoelectronic devices – come in many shapes and forms. Highly energy-efficient (less heat generation and power consumption) optical communications are increasingly important because they have the potential to solve one of the biggest problems of our information age: energy consumption.

In the field of nanotechnology, materials like nanofibers and carbon nanotubes have been used and especially graphene has shown exciting potential for optoelectronic devices.

Displays. Display technologies can be grouped into three broad technology areas: Organic LEDs, electronic paper and other devices intended to show still images, and field emission displays.

Source: https://www.nanowerk.com/nanoelectronics.php

2 Read and translate the following words and expressions from the text.

To manufacture, to cover a diverse set of devices and materials, to alter the materials' properties on a nanoscale, to take precedence over, inter-atomic interactions, quantum mechanical properties, tunneling, atomistic disorder, to dominate, to embrace technology, manufacturing techniques, transistor-based circuits, to integrate into a chip, solid-state devices, data storage, an established technology, energy consumption, field emission displays.

3 Answer the questions.

- What devices and materials refer to nanoelectronics?
- What are the main characteristics of nanoscale devices?
- How has the size of the transistor evolved over the years?
- What is spintronics and where is it applied?
- What function do optoelectronic devices perform?
- What areas are display technologies used in?

4 Follow-up task: presentation.

Choose one of the domains of nanoelectronic devices described in the text: transistors, spintronics, optoelectronics or display technologies. Search for the latest developments in the chosen area and prepare a brief 3-minute talk on the subject.

TEXT 1.2 Nanoelectronics in Different Spheres

1 Read and translate the text.

Nanoelectronics and its Applications

Wearable, flexible electronics

The age of wearable electronics is upon us as witnessed by the fast growing array of smart watches, fitness bands and other advanced, next-generation health monitoring devices such as electronic stick-on tattoos.

If current research is an indicator, wearable electronics will go far beyond just very small electronic devices or wearable, flexible computers. Not only will these devices be embedded in textile substrates but an electronics device or system could ultimately become the fabric itself. Electronic textiles (e-textiles) will allow the design and production of a new generation of garments with distributed sensors and electronic functions. Such e-textiles will have the revolutionary ability to sense, act, store, emit, and move – think biomedical monitoring functions or new man-machine interfaces – while ideally leveraging an existing low-cost textile manufacturing infrastructure.

Nanoelectronics in Energy

Solar cells and supercapacitors are examples of areas where nanoelectronics is playing a major role in energy generation and storage. Nanotechnologies provide essential improvement potentials for the development of both conventional energy sources (fossil and nuclear fuels) and renewable energy sources like geothermal energy, sun, wind, water, tides or biomass. Nano-coated, wear resistant drill probes, for example, allow the optimisation of lifespan and efficiency of systems for the development of oil and natural gas deposits or geothermal energy and thus the saving of costs.

Molecular Electronics

Distinct from nanoelectronics, where devices are scaled down to nanoscale levels, molecular electronics deals with electronic processes that occur in molecular structures such as those found in nature, from photosynthesis to signal transduction.

Molecular electronics aims at the fundamental understanding of charge transport through molecules and is motivated by the vision of molecular circuits to enable miniscule, powerful and energy efficient computers.

Source: https://www.nanowerk.com/nanoelectronics.php

2 Explain the meaning of the terms used in the text.

Wearable electronics, e-textiles, a solar cell, a supercapacitor, molecular electronics, signal transduction.

3 Follow-up task: watch the video.

To manage the large data streams of the future we need new strategies and solutions that are more energy-efficient, which means avoiding the build-up of heat and enabling a faster data rate. At the Helmholtz-Zentrum Dresden-Rossendorf research is focusing on one electron property in particular: the spin.

Watch the video ‘Nanoelectronics: Highly Efficient Structures for Tomorrow’s Information Technology’:
https://www.youtube.com/watch?v=E_HxLqlhzuI

Make a brief summary of the key developments of the research centre and spheres of nanoelectronics they work in.

UNIT 2 RESEARCH AND INNOVATION

TEXT 2.1 Innovative Nanocomposite Material

1 Read and translate the first part of the article covering the recent innovation in the sphere of nanocomposite materials.

An Innovative Nanocomposite Material May Revolutionize the Electronics Industry
(Part 1)

The new breed of electronic devices is all-digital and nanosized. However, to make these devices work, innovative materials solutions are required. New research from an international team headed by scientists at Russia's South Ural State University has identified a nanocomposite material comprised of magnesium oxide (MgO) and barium titanate (BaTiO3).

The new material can be used to design ever smaller, flatter and thinner electronic devices, and has the potential to revolutionize the electronics industry.

Specializing in the Future of Materials

The latest research breakthrough from South Ural State University (SUSU) in Russia builds on one of the institution's three strategic research focuses. Smart industry and ecology sit alongside world-class materials science output, which includes the potentially revolutionary new nanocomposite.

An international team of scientists from Belarus, India, and China cooperated with SUSU scientists led by their Senior Researcher at the Nanotechnology Research and Education Center, Aleksey Trukhanov.

The Innovative Nanocomposite Material

This pioneering development is a combination of cutting-edge nanotechnology, methods, and materials science research.

"A fundamentally significant result of this research is the development of new composite materials with improved dielectric characteristics," said Aleksey Trukhanov, Senior Researcher at the Nanotechnology Research and Education Center.

The nanocomposite material combines nanoparticles of magnesium oxide (MgO) with barium titanate (BaTiO3) in a so-called core-shell nanostructure. This means that the MgO nanoparticles are encapsulated in a shell of BaTiO3.

This is the first time that these materials have been successfully combined in a nanostructure. The scientists led by Trukhanov have also demonstrated a novel method for dispersing the nanocomposite into a polymer matrix.

The Properties of the New Nanocomposite Material

Nanocomposite materials are being studied worldwide due to their ability to combine desirable properties of different materials for functional applications.

The benefits of innovative nanocomposite materials are their ability to dramatically improve properties like: mechanical properties including strength, modulus and dimensional stability; electrical conductivity; decreased gas, water and hydrocarbon permeability; flame retardancy; thermal stability; chemical resistance; surface appearance; and optical clarity.

Trukhanov explains the importance of his team's nanocomposite materials research, "The results of our joint work will be used for controlling the electrical characteristics of functional polymeric materials of this class."

In the case of this latest nanocomposite material innovation, the nanoparticle core of MgO is dielectric – it insulates against electronic conductivity.

Meanwhile, the nanosized BaTiO3 shell – which encapsulates MgO nanoparticles in the new material – is ferroelectric. This means that it has spontaneous electric polarization, which is reversible upon applying an external electrical field.

Source: https://www.azonano.com/article.aspx?ArticleID=5563

2 Give the definition of the following terms from the text.

A nanocomposite material, electrical conductivity, water and hydrocarbon permeability, chemical resistance, flame retardancy, thermal stability, optical clarity, to insulate, dielectric, ferroelectric, an external electrical field.

3 Answer the questions.

- What innovation has the Russian University proposed?
- What is new about the innovative nanocomposite material developed by the research team?
- What are the properties of this new nanocomposite material?
- What are the major benefits of the new material?

4 Scan the text and find the English equivalents to the following words and expressions that refer to the sphere of general English.

Группа ученых во главе с…; кардинальным образом изменить отрасль; важное научное открытие, прорыв; передовые технологии; новый метод; преимущества; значительно улучшить, свойства, внешний вид (поверхности).

5 Follow-up task: information search.

What research into nanoelectronic technology is being conducted in Saint Petersburg Mining University?

Make the web search and find the information on the main research studies in nanotechnology carried out by the scientists and departments at Saint Petersburg Mining University. Prepare the list of key issues and a brief record of achievements in the research work. Try to use the academic expressions from exercise 4.

TEXT 2.2 Revolution in the Electronics Industry

1 Continue reading the article and translate it into Russian.

An Innovative Nanocomposite Material May Revolutionize the Electronics Industry (Part 2)

Innovative Nanocomposite Material Application

The combination of materials and their properties – dielectric MgO and ferroelectric BaTiO3 – can be used as a dielectric, insulating material in polymer capacitors.

Capacitors are the materials in electronic devices that control and modulate electrons' otherwise irregular flow, preventing electronic surges that cause short-circuiting and other electronic failures. They work by storing electronic energy.

Polymer (plastic-based) capacitors are used in electronic devices with integrated power. They are used as buffer, bypass and decoupling capacitors.

The need for integrated capacitors was brought on by the advent of digital electronic equipment, which led to the development of switching power supplies with higher frequencies and integrated DC/DC converters, along with lower supply voltages and higher supply currents.

Revolution in the Electronics Industry

Commenting on the relevance of his team's latest research, Trukhanov added: "Such research is now relevant, since the rapid development of micro- and nanoelectronics requires new approaches and the development of new materials to reduce the size of functional components."

The latest nanocomposite development presents a significant step forward in advanced polymer capacitor materials. When added to a polymer matrix at only 3% of the base polymer's weight, the innovative new nanocomposite increases discharge current density by 187%.

This minor addition of mass and weight to the polymer capacitor material – set against a significant performance improvement – means that future electronic devices can be designed with more power in mind without sacrificing weight or bulk.

Such a development will play an essential role in the future of electronic devices. They can now be designed to be even smaller, flatter and lighter than before, enabling increasingly diverse applications, for example, in wearable electronics, micro- and nanoelectronic devices, and biomedical devices.

Future Research Directions

Trukhanov and his team and colleagues will continue to work on advanced materials such as the latest innovation. Using nanotechnology, they will develop new materials and nanocomposites for a wide array of applications and features.

Trukhanov said, "At the moment, there are plans to continue research of functional composites with controlled properties. Currently, active research work is being carried out in the field of composite materials with magnetic fillers."

Source: https://www.azonano.com/article.aspx?ArticleID=5563

2 Translate the following terms from the text into Russian.

Polymer capacitors, to modulate, an irregular flow, to cause short-circuiting, electronic failures, electronic surges, a decoupling capacitor, the advent of digital electronic equipment, switching power supply, a DC converter, supply voltage, supply currents, relevant research, advanced materials, discharge current density, to play an essential role in…, wearable electronics, to carry out the research work in the field of…, a wide array of applications and features.

3 Answer the questions.

- How is the innovative nanocomposite material used?
- How can the new nanocomposite revolutionize the electronics industry?
- What are the researchers' next steps?
- What is the research team working on at the present moment?

4 Follow-up task: presentation.

What research into nanoelectronic technology is being conducted in Saint Petersburg Mining University?

In the previous part, you searched for the studies conducted at Saint Petersburg Mining University in the field of nanotechnology. Using this information and the record of achievements you have compiled, make a short presentation covering the main research areas.

Remember to use the vocabulary units and terms discussed in Unit 2 to make your speech sound academic.

Remember to structure your presentation according to the academic presentation rules, i.e. make an introduction, talk about the aims and relevance of the research, describe the applied methodology and research stages, and conclude your speech with future prospects of the research results.

UNIT 3 MEMRISTORS

TEXT 3.1 Nanoelectronic Components and Memristor Characteristics

1 Explain the meaning of the following terms in English.

A capacitor, an inductor, a resistor, a transistor-based processor, spiking activity.

2 Read and translate the text.

Memristors - Nanoelectronic Components

Memristors can be defined as a fourth class of electrical component, in addition to the capacitor, inductor and the resistor, which exhibit distinct characteristics at the nanoscale. Memristors, or memory resistors, are a kind of passive circuit element that enables an association between the time integrals of voltage and current across a two terminal element. The time-dependent component, which is unique in passive components, allows the history of the voltages applied to the device to be accessed via a series of minute read charges.

Until the first prototype was developed by HP Labs under Stanley William, memristance as a characteristic of a real material was virtually unknown. At length scales longer than the nanoscale, the memristance effect is overridden by other field and electronic effects – hence all the prototype memristors developed to date have used nanomaterials.

Presently HP, IBM, Samsung, HRL and several other research labs are investigating memristors made of titanium dioxide or niobium dioxide, and there are few other memristor materials still in the early stages of development.

Memristors enable the development of artificial neural networks which are able to model the activity of brain cells much more accurately than existing transistor-based processors.

Spiking Activity Enabled by Memristors

Computing hardware comprises a number of binary switches that can be either on or off. The human brain, on the other hand, is not binary

– each neuron exhibits brief spikes of activity and encodes data based on the timing and pattern of these spikes.

Because of this fundamental difference, modelling of neurons using computer hardware has to date been very difficult and limited. In the last few years, however, researchers have been working on a way of fabricating a chip that behaves more like a neuron, using a circuit made of capacitors and memristors. The signal spikes the chip generates tend to be more regular when compared to neurons, but future versions may be able to make these more variable.

In 2008, HP Labs announced the first memristor array fabricated from nanoscale titanium dioxide films. The key to fabricating these neuron-like devices is known as a Mott insulator. Mott insulators have an unusual electrical property – their structure should allow them to conduct electricity according to conventional band theory, but when measured they are found to be insulators at normal temperatures due to electron-electron interactions. Upon heating, these electronic interactions are overcome at a critical transition temperature, allowing them to conduct normally.

Niobium dioxide (NbO2) is one of the few materials which behaves like a Mott insulator – in the work done by HP Labs in 2012, the heat required to affect the transition into the conductive state was generated from the resistance of the material itself when a voltage is applied. When the voltage is removed, the subsequent cooling returns the material to its resistive state.

To obtain neuron-like spiking behaviour, a simplified neuron model based on proteins that allowed transmission of electrical signals was considered. The firing of a neuron causes sodium channels to open, allowing ions to rush into a nerve cell and modifying the relative charges inside and outside the membrane. In response to these changes, potassium channels open and allow ions to move out and restore the charge balance. The charge flow then stops, and various pumps begin restoring the former ion balance.

Source: https://www.azonano.com/article.aspx?ArticleID=3215

3 Scan the text and translate the following terms and word-combinations into English.

Проявлять отличительные характеристики; пассивный элемент схемы; компонент, зависящий от времени; на ранних стадиях разработки; искусственная нейронная сеть; изготовить чип; традиционная зонная теория; взаимодействие электронов; прикладывать напряжение.

4 Discuss these questions with a partner.

- How can a memristor be defined?
- Where and how was the first memristor developed?
- What is the function of memristors and what benefits do they provide for researchers?
- What is a Mott insulator and what properties does it possess?
- Why only a few materials can be used to fabricate this innovative device and how can it be explained?

5 Follow-up task: watch the video.

Watch R. Stanley William's 6-minute explanation about how the memristor device works:
https://www.youtube.com/watch?v=rvA5r4LtVnc&feature=emb_logo

Make a summary of his talk and present it in class.

TEXT 3.2 Memristor Types

1 Explain some of the important terms used in the text:

A voltage threshold, a circuit grid, an order of magnitude, polarization switching.

2 Read and translate the text.

Types of Memristors Discovered

The circuit developed by the HP researchers included two units, one representing sodium channels and the other potassium channels. Each unit included a capacitor parallel to a memristor. When arranged correctly, spikes of activity are produced on exceeding a given voltage threshold. This device was termed a neuristor.

The NbO2 neuristor is an effective proof-of-concept, but it has a number of limitations, including high power consumption and incompatibility with existing chip manufacturing techniques. HP Labs and other research groups are confident that it will be possible to find a material and architecture that solves these problems, allowing larger-scale research and early applications of memristors and neuristors in computing.

The other types of memristors discovered include the following:

In 2011, researchers from North Carolina State University announced the development of a biocompatible memristor array designed to be used as part of a brain-computer interface.

Titanium Oxide Memristor. This device developed by HP in 2008 includes a thin titanium dioxide film sandwiched between two thick electrodes, one Pt and the other Ti. The titanium dioxide film has two layers one with a slight depletion of oxygen atoms. These oxygen vacancies behave as charge carriers implying the depleted layer has a lower resistance than the non-depleted layer. The application of an electrical field results in drifting of oxygen vacancies, changing the boundary between low resistance and high resistance layers. The film resistance as a whole depends on how much charge has been transmitted in a particular direction which can be reversed when the direction of current is changed. The HP device is considered a nanoionic device because it enables rapid ion conduction at the nanoscale.

Polymeric Memristor. In 2012, researchers attempted to create neural synaptic memory circuits with organic ion-based memristors. The synapse circuit showed long-term potential for learning and inactivity-based forgetting. A light pattern was stored and recalled later using a circuit grid.

Ferroelectric Memristor. The ferroelectric memristor is based on a thin ferroelectric barrier placed between two metallic electrodes. The ferroelectric material polarization is switched by applying a negative or positive voltage across the junction leading to large resistance variations over two orders of magnitude. The polarization switching is not abrupt but gradual. The ferroelectric memristor has two key benefits: firstly, it is possible to tune ferroelectric domain dynamics so that memristor response can be engineered and, secondly, the variations in resistance are due to electronic phenomena rendering the device more reliable.

Source: https://www.azonano.com/article.aspx?ArticleID=3215

3 Scan the text again and translate the following terms into English.

Пороговое напряжение, опытно-экспериментальная установка, несовместимость с…, широкомасштабное исследование, биологически совместимый, матрица / интегральная схема, носитель заряда, запоминающая схема, порядок величины, переполяризация.

4 Discuss these questions with a partner.

- What is a neuristor and what limitations does it have?
- Where is a biocompatible memristor used?
- What is titanium oxide memristor and why is it called nanoionic?
- What is a potential sphere of application of the polymeric memristor?
- What is a ferroelectric memristor and what advantages does it offer?

5 Follow-up task: information search.

Make a web search about current applications of memristors and their future potential.

You can use the websites of leading world universities covering their news on conducted research, e.g. MIT News: https://news.mit.edu/2020/thousands-artificial-brain-synapses-single-chip-0608

Shanghai Ranking Consultancy has ranked universities all over the world in the field of nanotechnology. Nanyang Technological University ranks first. There are four universities from the United States, three from China, Two from Singapore, and one from South Korea among the top 10 universities.

Read more: http://www.shanghairanking.com/Shanghairanking-Subject-Rankings/nanoscience-nanotechnology.html

Write a short summary covering memristors application and the latest achievements in the field.

UNIT 4 GRAPHENE IN NANOELECTRONICS

TEXT 4.1 Graphene: Description and Properties

1 Translate the following terms into Russian.

A honeycomb, a fullerene, velocity, carrier concentration, rest mass, in-plane deformation.

2 Read and translate the text.

Graphene Description

Graphene is the name for an atom-thick honeycomb sheet of carbon atoms. It is the building block for other graphitic materials (since a typical carbon atom has a diameter of about 0.33 nanometers, there are about 3 million layers of graphene in 1 mm of graphite).

Units of graphene are known as nanographene; these are tailored to specific functions and as such their fabrication process is more complicated than that of generic graphene. Nanographene is made by selectively removing hydrogen atoms from organic molecules of carbon and hydrogen, a process called dehydrogenation.

Harder than diamond yet more elastic than rubber; tougher than steel yet lighter than aluminium. Graphene is the strongest known material.

Graphene discovery

Carbon comes in many different forms (so-called allotropes), from the graphite found in pencils to the world's most expensive diamonds. In 1980, we knew of only three basic forms of carbon, namely diamond, graphite, and amorphous carbon. Then, fullerenes and carbon nanotubes were discovered and, in 2004, graphene joined the club.

Before graphene was first demonstrated by Andre Geim and Konstantin Novoselov, two physicists from the University of Manchester, in 2004 (for which they received the Nobel Prize in 2010) scientists argued that strictly 2D crystalline materials were thermodynamically unstable and could not exist.

Graphene properties

Electronic properties. One of the reasons nanotechnology researchers working towards molecular electronics are so excited about graphene is its electronic properties – it is one of the best electrical conductors on Earth. The unique atomic arrangement of the carbon atoms in graphene allows its electrons to easily travel at extremely high velocity without the significant chance of scattering, saving precious energy typically lost in other conductors.

Scientists have found that graphene remains capable of conducting electricity even at the limit of nominally zero carrier concentration because the electrons don't seem to slow down or localize. The electrons moving around carbon atoms interact with the periodic potential of graphene's honeycomb lattice, which gives rise to new quasiparticles that have lost their mass, or rest mass (so-called massless Dirac fermions). That means that graphene never stops conducting. It was also found that they travel far faster than electrons in other semiconductors.

Mechanical properties. The impressive intrinsic mechanical properties of graphene, its stiffness, strength and toughness, are one of the reasons that make graphene stand out both as an individual material and as a reinforcing agent in composites. They are caused by the stability of the sp^2 bonds that form the hexagonal lattice and oppose a variety of in-plane deformations.

Source: https://www.nanowerk.com/what_is_graphene.php

3 Answer the following questions.

- What is graphene? What materials can it be compared to?
- What forms can carbon take?
- What was known about 2D crystalline materials before the discovery of graphene?
- What are the main properties of graphene?
- How can the properties affect graphene application?

4 Follow-up task: watch the video.

Graphene is a form of carbon that could bring us bulletproof armor and space elevators, improve medicine, and make the internet run faster. For the past 15 years, consumers have been hearing about this wonder material and all the ways it could change everything.

Watch the video *Why graphene hasn't taken over the world...yet:* https://www.youtube.com/watch?v=IesIsKMjB4Y

Make the summary of the key ideas discussed in the video. Give your own opinion about the possibility of using the full potential of graphene in the near future.

TEXT 4.2 Graphene Uses and Applications

1 Read the text and be ready to discuss it.

Graphene Uses and Applications

Energy storage and solar cells

Graphene-based nanomaterials have many promising applications in energy-related areas. Just some recent examples: graphene improves both energy capacity and charge rate in rechargeable batteries; activated graphene makes superior supercapacitors for energy storage; graphene electrodes may lead to a promising approach for making solar cells that are inexpensive, lightweight and flexible; and multifunctional graphene mats are promising substrates for catalytic systems.

Researchers also have discovered a critical and unexpected relationship between the graphene's chemical/structural defectiveness as a host material for electrodes and its ability to suppress the growth of dendrites – branch-like filament deposits on the electrodes that can penetrate the barrier between the two halves of the battery and potentially cause electrical shorts, overheating and fires.

These examples highlight the four major energy-related areas where graphene will have an impact: solar cells, supercapacitors, graphene batteries, and catalysis for fuel cells.

Due to their excellent electron-transport properties and extremely high carrier mobility, graphene and other direct bandgap monolayer materials such as transition-metal dichalcogenides (TMDCs) and black phosphorus show great potential to be used for low-cost, flexible, and highly efficient photovoltaic devices. They are the most promising materials for advanced solar cells.

Transistors and memory

Some of the most promising applications of graphene are in electronics (as transistors and interconnects), detectors (as sensor elements) and thermal management (as lateral heat spreaders). The first graphene field-effect transistors (FETs) – with both bottom and top gates – have already been demonstrated. At the same time, for any transistor to be useful for analog communication or digital applications, the level of the electronic low-frequency noise has to be decreased to an acceptable level.

Transistors on the basis of graphene are considered to be potential successors for some silicon components currently in use. Due to the fact that an electron can move faster through graphene than through silicon, the material shows potential to enable terahertz computing.

In the ultimate nanoscale transistor – dubbed a ballistic transistor – the electrons avoid collisions, i.e. there is a virtually unimpeded flow of current. Ballistic conduction would enable incredibly fast switching devices. Graphene has the potential to enable ballistic transistors at room temperature.

While graphene has the potential to revolutionize electronics and replace the currently used silicon materials, it does have an Achilles heel: pristine graphene is semi-metallic and lacks the necessary band gap to serve as a transistor. Therefore, it is necessary to engineer band gaps in graphene.

Experiments have demonstrated the benefits of graphene as a platform for flash memory which show the potential to exceed the performance of current flash memory technology by utilizing the intrinsic properties of graphene.

Flexible, stretchable and foldable electronics

Flexible electronics relies on bendable substrates and truly foldable electronics requires a foldable substrate with a very stable conductor that can withstand folding (i.e. an edge in the substrate at the point of the fold, which develops creases, and the deformation remains even after unfolding).

That means that, in addition to a foldable substrate like paper, the conductor that is deposited on this substrate also needs to be foldable. To that end, researchers have demonstrated a fabrication process for foldable graphene circuits based on paper substrates.

Graphene’s remarkable conductivity, strength and elasticity has also made it a promising choice for stretchable electronics – a technology that aims to produce circuits on flexible plastic substrates for applications like bendable solar cells or robotic-like artificial skin.

Scientists have devised a chemical vapor deposition (CVD) method for turning graphene sheets into porous three-dimensional foams with extremely high conductivity. By permeating this foam with a siloxane-based polymer, the researchers have produced a composite that can be twisted, stretched and bent without harming its electrical or mechanical properties.

Source: https://www.nanowerk.com/what_is_graphene.php

2 Answer the questions.

- How can graphene-based nanomaterials be used for energy storage?
- What properties make graphene unique and promising for energy storage?
- What advantages does graphene have compared to silicon?
- What is a ballistic transistor?
- What is graphene’s Achilles heel?
- How can stretchable electronics be defined?
- What possibilities does graphene create for flexible electronics?

3 Follow-up task: further reading.

Skim through the article written by Latin American scientists - ‘Tunable and sizeable band gaps in strained SiC3/hBN vdW heterostructures: A potential replacement for graphene in future nanoelectronics’: *https://doi.org/10.1016/j.commatsci.2020.110233*

It considers the possible substitute of graphene in nanoelectronics in the future. Prepare a short talk covering the researchers’ arguments, possible benefits and drawbacks of the alternative they offer. Give your opinion on the feasibility of using graphene. Remember to structure your talk according to rules for academic presentations.

4 Take a quiz about graphene. There are 14 questions to test your graphene IQ.

Graphene Quiz

Question 1: What is graphene?

- The name for a honeycomb sheet of carbon atoms
- The name for a nanoscale cube of random atoms
- The name for an invisible plastic membrane
- The scientific name for the graphite in a 6B pencil

Question 2: Graphene consists...

- entirely of carbon
- of 80% carbon and 20% silicon
- of 80% carbon, 10% silicon and 10% unidentified yet
- of none of the above

Question 3: When and where was graphene first isolated in the lab?

- 1998 in Tokyo
- 2004 in Manchester
- 2007 in Houston
- 2010 in Stockholm

Question 4: When graphene was first isolated in the lab, what technology did the researchers use?

- Atomic Force Microscopy (AFM)
- Scotch tape
- Hammer and chisel
- Ultrasensitive planing and milling machine

Question 5: Graphene shot into the public awareness because...

- In 2010, ground-breaking experiments with graphene were awarded the Nobel Prize in Physics
- In 2013, it became the first approved nanomaterial additive in baby milk formula
- In 2015, a complete graphene coating made the Eiffel Tower corrosion-proof
- In 2016, a UK freighter spilled tons of graphene flakes in Boston Harbor

Question 6: Which of its properties makes graphene such an amazing material?

- Electron mobility
- Mechanical strength
- Thermal conductivity
- All of the above

Question 7: Which of these carbon allotropes can be formed by graphene?

- Carbon nanotube
- Fullerene (buckyball)
- Graphite
- All of the above

Question 8: Which country contributes to over two thirds of the 31,000 graphene patents filed by 2018?

- China
- Japan
- UK
- USA

Question 9: Graphene is a...

- Zero-dimensional (0D) material
- One-dimensional (1D) material
- Two-dimensional (2D) material
- Three-dimensional (3D) material

Question 10: A 1 mm thick graphite sheet contains about how many graphene monolayers?

- Approximately 10
- Exactly 179
- Roughly 150,000
- Approximately 3 million

Question 11: Graphene...

- is more than 100 times stronger than steel
- is about as stiff as diamond

- has the highest electron mobility of all electronic materials
- All of the above

Question 12: Thanks to graphene's high surface area, how much of it would you need to cover a football (i.e. soccer) field?

- 5.5 grams
- 784 grams
- 12.4 kg
- There isn't enough graphene yet to do that

Question 13: What is the smallest atom that can pass through a sheet of defect-free, single-layer graphene?

- Cerium
- Oxygen
- Most atoms can pass
- Not even the smallest atoms (helium, hydrogen) can pass

Question 14: The commercial production of graphene...

- Hasn't begun yet
- Is in various trial stages in several countries
- Is already done by more than 100 companies worldwide
- Has been prohibited by most governments

Source: https://www.nanowerk.com/nanotechnology/graphene-quiz.php

UNIT 5 NANOELECTRONICS ROADMAP

TEXT 5.1 Nanoelectronics in Europe

1 Read and translate the text about future plans for nanoelectronics in Europe.

Nanoelectronics Roadmap for Europe

Roadmaps are **highly beneficial** for all high tech sectors, like nanoelectronics, to improve links between academic and industrial research, to drive investments, to provide inputs for future research programmes and to coordinate efforts **to overcome** the main technology **challenges**.

For more than 20 years, the International Technology Roadmap for Semiconductors (ITRS) has guided the industry to follow Moore's Law, with a constant reduction in device costs and **an exponential growth** of the semiconductor market. The main role of ITRS has been in providing research guidance for the many actors of the semiconductor ecosystem, in synchronizing the technology development and the timely availability of manufacturing equipment and methods and in providing focus on **critical bottlenecks**.

However, the "technology push" that has been at the base of ITRS has shown in recent years its limits: device size and speed are no longer the only parameters of importance, and system-driven technologies have been considered by the new IRDS Roadmap (International Roadmap for Devices and Systems), focusing on computing systems.

On the other hand, the integration of new functionalities, required by new applications, needs the incorporation of special metrics for technologies that do not necessarily scale according to "Moore's Law", expanding the focus from chips to different kinds of systems. This trend is **especially relevant** for the European semiconductor industry that has focused on segments of greater relevance for the European industry applications, like Automotive, Industrial and Medical. Therefore, an appropriate kind of roadmap is needed for Europe which focuses on nanoelectronics with respect to the European abilities and strengths.

The NEREID roadmap for European Nanoelectronics (NEREID stands for NanoElectronics Roadmap for Europe: Identification and Dissemination) covers both application and technology sectors. This comprises applications in the field of Energy, Automotive, Medical/Life Science, Security, Mobile Convergence and Digital Manufacturing as well as technologies like Advanced Logic and Connectivity, Functional Diversification (Smart Sensors, Smart Energy and Energy for Autonomous Systems), Beyond- CMOS, Heterogeneous Integration and System Design and Equipment, Materials and Manufacturing Science.

The important assets of NEREID are the following:

• the projection of the evolution of many Figures of Merit (FoMs) vs time for covering the most promising technologies including novel functionalities;

• the understanding of the dependencies between **short/ medium term** (e.g. More Moore and More than Moore) and long/very long term (e.g. Beyond CMOS) activities;

• the strong interaction between application and technology experts, coming from leading research players in industry and academia, especially with the organization of many workshops;

• the combination of a top-down approach, which is application driven, and a bottom-up one, based on planned technology evolution to **prompt** new **ideas** for **disruptive** products and applications.

Source: NanoElectronics roadmap for Europe: From nanodevices and innovative materials to system integration. Solid State Electronics 155 (2019) 7–19: https://doi.org/10.1016/j.sse.2019.03.014

2 Answer the following questions.

- What are the roadmaps and why are they used for technology sectors?
- What effect has the International Technology Roadmap for Semiconductors had on the industry for the last decades?
- What factors influenced the start of the NEREID project?
- What are the main aims of the NEREID roadmap?

3 Match the words in bold from the text with their synonyms.

1. very useful
2. to solve problems
3. a rapid increase
4. important problems
5. pressing, up-to-date
6. lasting a short or medium period of time
7. to put forward ideas
8. new, changing the traditional way of doing smth.

4 Follow-up task: presentation.

Make a 5-minute talk about the roadmaps or some similar projects on nanoelectronics that exist in Russia. Include the information about the contribution of your university in the local nanoelectronic roadmap.

Remember to structure your presentation according to the academic presentation rules.

TEXT 5.2 Nanoelectronics Roadmap: Technology Sectors

1 The text below contain some common abbreviations used in microelectronics field. Search for their meaning and translate them into Russian.

IC, IoT systems, FET, MOSFET, FinFET.

2 Read and translate the text.

Advanced Logic and Memories

The historical trend in micro-/nanoelectronics over the last 40 years has been to increase both speed and density by scaling down the size of electronic devices, together with reduced energy dissipation per binary transition, and to develop many novel functionalities for future electronic systems. We are facing today dramatic challenges for More Moore and More than Moore applications: substantial increase of energy consumption and heating which can jeopardize future IC (integrated circuits) integration and performance, reduced performance due to limitation in traditional high conductivity metal / low k dielectric interconnects, limit of optical lithography, heterogeneous integration of new functionalities for future nano systems, etc.

Therefore, many breakthroughs, disruptive technologies, novel materials, and innovative devices are needed in the next two decades.

In the More Moore domain there is strong interest in Europe for specific activities dealing with very low power systems, leading to possible disruptive applications for instance for future IoT systems, or for application driven performance, e.g. high temperature operation for the automotive industry, and also for embedded memories.

The following core technologies are the most promising for many future applications in order to overcome the number of challenges we are facing for future ICs, in particular:

- High performance
- Low/very low static and dynamic power consumption
- Device scaling
- Low variability
- Affordable cost

Considering these challenges, the following nanodevices and technologies have been considered as very relevant for future Nanoscale FETs:

• FD (Fully Depleted) SOI (Silicon-On-Insulator) MOSFET: for low power applications and low variability.

• FinFET (or Trigate FET): for high performance and/or low power applications.

• Nanowire FET: for high performance and low power applications and ultimate integration.

• CNTFET/Carbon NanoTube FET: for very fast and possibly ultimately scaled transistors for logic applications, with self-assembly based fabrication.

• NCFET/Negative Capacitance FET: for very low power applications using steep subthreshold slope.

• Non-charge-based Resistive Memories or alternative charge-based Memories: to replace charge-based memories using PCRAM (Phase Change RAM), RRAM (Resistive RAM using a nanofilament), MRAM (Magnetic RAM, especially STT/Spin Transfer Torque MRAM), or FeRAM or FeFET (using the polarization of a ferroelectric material).

• Sequential 3D integration: for increasing device integration (transistors, memories, sensors, etc.) and performance using 3D stacking.

The roadmap also covers the future modelling and characterization tools needed for developing these future devices and technologies. A major challenge we are facing is the energy consumption of future devices and systems.

Source: NanoElectronics roadmap for Europe: From nanodevices and innovative materials to system integration. Solid State Electronics 155 (2019) 7–19: https://doi.org/10.1016/j.sse.2019.03.014

3 Give the Russian equivalents to the following terms from the text.

Energy dissipation, low k dielectric interconnects, low power systems, embedded memories, silicon-on-insulator, transistor scaling, subthreshold slope, nanofilament, 3D stacking.

4 Follow-up task: information search and summary.

You read the excerpt from the European nanoelectronics roadmap about the Moore applications and the More Moore domain in nanoelectronics.

Choose one of the most promising nanodevices mentioned in the text, search for the relevant information about it and write a short summary presenting the key ideas.

Make sure to use the academic phrases you studied in this unit.

KEYS TO THE QUIZ
(Unit 4)

Question 1: The name for a honeycomb sheet of carbon atoms.

Question 2: Entirely of carbon.

Question 3: 2004 in Manchester.

Question 4: Scotch tape.

Question 5: In 2010, ground-breaking experiments with graphene were awarded the Nobel Prize in Physics.

Question 6: All of the above.

Question 7: All of the above.

Question 8: China.

Question 9: Two-dimensional (2D) material.

Question 10: Approximately 3 million.

Question 11: All of the above.

Question 12: 5.5 grams.

Question 13: Not even the smallest atoms (helium, hydrogen) can pass.

Question 14: Is already done by more than 100 companies worldwide.

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