INNOVATIVE ENERGY TECHNOSPHERE.
ENERGY RECOVERY FROM ENVIRONMENT.

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The article analyzes the modern energy technosphere that is one of the key high-tech socially-orientated area of creation a comfortable, safe and cost effective environment. The tendencies and prospects of development of flexible hybrid nano-energetics based on energy recovery from the environment and the human body are considered.

ГИБКАЯ ГИБРИДНАЯ НАНОЭНЕРГЕТИКА

Использование в качестве источников энергии как внешних природных и техногенных воздействий, так и воздействий человеческого организма актуально и востребовано в широком спектре устройств, в том числе в автономной носимой и биоимплантируемой электронике. Развитие подобных интеллектуальных систем индивидуального жизнеобеспечения и комфорта определяет потребность в миниатюрных гибких (а во многих случаях – и эластичных) устройствах гибридной наноэнергетики.

Термин "наноэнергетика" прочно вошел в современный научный лексikon и подчеркивает тот факт, что речь идет об устройствах, в основе работы которых положены наноразмерные эффекты и при создании которых широко используются наноматериалы и нанотехнологии. В то же время особенности работы, общность технологической и материаловедческой базы, а также сопоставимость достигнутых параметров наногенераторов обеспечивают синергетический эффект гибридным устройствам на их основе.

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Данное востребованное направление отвечает социально-техническим требованиям благодаря ориентации на "зеленые" технологии на основе инновационных наноструктурированных экологически дружественных материалов, которые минимизируют вредные отходы производства и безопасны после окончания жизненного цикла изделий.

Возможность преобразования в электричество энергии солнечного излучения, а также механических, акустических и электромагнитных воздействий, на основе инновационных наноструктурных решений многофункциональных устройств стала действенным стимулом развития наноэнергетики. Хотя ведущая роль в развитии гибкой гибридной наноэнергетики пока принадлежит фото-

Рapid intellectualization of technical systems that provide the modern human environment [1], is impossible without adequate harmonized energy solutions [2]. Today's global energy potential is a set of natural resources and actively developing alternative renewable resources (Fig.1) [3]. Studies of the dynamics of the structure of energy consumption until 2040, made by the International Energy Agency and the Energy Research Institute of Russian Academy of Sciences, predict a steady growth (up to 15%) of alternative energetics while maintaining the dominant role of natural resources [4].

The development of alternative energetics for intelligent biotechnosphere [5] includes already today (along with global renewable energy systems) devices that recovery energy of natural and anthropogenic sources of the environment (Fig.2). The purpose of this article is the analysis of the current state of flexible hybrid nano-energetics as one of the key socially oriented knowledge-intensive areas for creation of a comfortable, safe and cost effective environment [6].

FLEXIBLE HYBRID NANO-ENERGETICS
The use of both external natural and anthropogenic impacts and influences of human body as sources of energy is important and in demand in a wide range of devices, including wearable and autonomous bioimplantable electronics. The development of such intelligent systems of personal life sustenance and comfort determines need in
This demanded field meets socio-technical requirements because of its focus on “green” technologies based on innovative nanostructured environmentally friendly materials that minimize hazardous wastage and are safe after end-of-life of products.

The possibility of conversion to electricity of solar radiation energy as well as mechanical, acoustic and electromagnetic impacts, based on innovative nanostructured solutions of multifunctional devices has become an effective stimulus for the development of nano-energetics. Although photovoltaics is playing a leading role in the development of flexible hybrid nano-energetics [7, 8], in 2006, the first piezoelectric and triboelectric generators were presented [9], and in 2012 – the first tribo-nanogenerator [10]. Piezoelectric and triboelectric effects, which are the base for the appropriate devices, on the nano-structural level allows to convert the mechanical and acoustic effects of both external sources and the human body.

In a thermal generators, which directly convert thermal energy into electrical energy on the basis of Seebeck effect [11], the transition to the nano-structural level
unlocks the ability to use thermal radiation of both objects of the environment and human body [12].

The modern human environment (especially the environment of big cities) is saturated by electromagnetic radiation of industrial and domestic origin. That is why one of the modern trends in energetics is their recuperation and transformation, which are represented today by devices such as rectenna [13].

The use of flexible nanogenerators requires adequate devices for accumulation and storage of charge, among which the lithium–ion batteries and supercapacitors are the leaders [14].

Quite high (achieved in a relatively short period of time) parameter values for each type of energy recuperators (table) and technological unification of the modern developments contribute to the integration of devices of flexible hybrid nano-energetics into intelligent systems at all levels, from the individual to distributed global objects.

Environmentally safe non-volatile devices of flexible hybrid nano-energetic are in demand at all levels of the formation of economically viable intellectual environment. The commercial attractiveness of such devices increases due to high degree of demand in specific areas. So, the quality of life of people suffering from a number of diseases is directly determined by the use of wearable or implantable biomedical devices. It is obvious that not only the degree of functional comfort, but in many cases the possibility of application of these devices is determined by their nonvolatility. Such area of development of flexible hybrid nano-energetic as efficient use of energy processes occurring in the human body is largely consistent with

<table>
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<th>Рекуператоры энергии</th>
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<th>Удельная мощность, mВт/см²</th>
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<tr>
<td>Солнечные элементы</td>
<td>25–28</td>
<td>100,0</td>
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<td>Пьезонаногенераторы</td>
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<td>5–10</td>
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<td>Ректенны</td>
<td>40–70</td>
<td>0,5</td>
<td>Зависимость от мощности излучателя и расстояния</td>
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The establishment and development of flexible hybrid nano-energetics is the result of technological advances in the beginning of the XXI century. Although mass commercialization of its innovative features being formed, flexible hybrid nano-energetics, empowering individual personalized integration is already an integral part of the modern intellectual society [15, 16].

Saint-Petersburg Electrotechnical University "LETI", in the year of its 130th anniversary, in the framework of the generalization of the results of a number of research works in the field of energy recovery from the airwaves, the environment and the human body, have published a review of the current state of flexible hybrid nano-energetics (Fig.3). This edition is prepared by Department of micro- and nano-electronics and Center of micro-technology and diagnostics. His emergence is largely determined by the fact that miniature recuperators of energy from the environment as sources of autonomous power supply of modern electronic and information biomedical systems are one of the priority areas of joint scientific educational activities of the staff.
of the structural subdivisions of the university.

The publication reviews the current situation and future engineering solutions for subminiature devices for generation and storage of electricity, including flexible solar cells, piezo-, tribo- and thermo-nanogenerators, energy recovery from the radio (rectenna), lithium-ion batteries, supercapacitors and hybrid integrated energy-supply devices based on them. Special attention is given to the material basis and technological solutions of flexible, elastic and conformal structures providing easy integration into various objects, as well as the possibility of using high performance (including printing) technologies to achieve energy and economic efficiency of the energy recovery systems of new generation based on nanomaterials and nanotechnology. Commercially available components and devices, as well as innovative developments in the field of flexible hybrid nano-energy systems are considered.

CONCLUSION

New intelligent human habitat is in the process of its formation. Flexible hybrid nano-energetics as one of the modern areas of development of innovation technosphere, undoubtedly, is a significant part of intellectual, friendly and comfortable environment that provides a high quality of life and extends the physiological and functional abilities of a person.
направлений развития инновационной энерготехносферы, безусловно, является значимой составной частью не только интеллектуальной, но и дружественной комфортной среды, обеспечивающей высокое качество жизни и расширяющей физиологические и функциональные возможности человека.

**Литература**