PERSPECTIVE ARTICLE

Piezoelectric Alternative Energy Sources as a Part of the Global Energy Concerns – Future Prospects in the Science and Market

Mariya Aleksandrova*

Department of Microelectronics, Technical University of Sofia, Kliment Ohridski blvd., 8, Sofia 1000, Bulgaria

*Corresponding author: E-mail: m_aleksandrova@tu-sofia.bg; Tel.: (+359) 29653085

Web of Science Researcher ID: G-4803-2014
ORCID ID: 0000-0002-1345-2626

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Portable and smart electronic devices are powered by batteries whose life is limited. On the other hand, in recent years the idea of renewable energy and methods of its obtaining by environmentally friendly technologies gained popularity. The conversion of energy from various sources in the surrounding environment (energy harvesting) solves the problem of battery-less power supply and satisfies the modern concepts of "clean" energy. One of the mechanisms for electrical energy generation is the piezoelectric effect, which relies on mechanical activation (vibrations, pressure, force) and the corresponding devices are piezoelectric energy harvesters. This article has overviewed the global situation, efforts, and prospects of the development of piezoelectric materials and harvesting devices in terms of research interest, industrial implementation, sectors of application and market forecasts.

Introduction

Novel materials and technologies have been constantly developed during the last few years in the field of piezoelectric energy harvesting (PEH) elements and systems to enhance material properties, device architectures, the performance of the interfaces, and overall reliability. The reason is their importance for the implantable biomedical applications, where the natural processes in the human organism (heart beating, breathing, blood pressure change) are used to activate the piezoelectric elements and convert them into an independent power supply and at the same time into a sensor, detecting the intensity of the corresponding activity [**1**]. Sensor networks and IoT wearables are tightly related to this technology. Of course, the application of the PEH is not limited only to the biomedical sector. It is an advanced technology in the modern automotive industry, where a lot of vibrations appearing in the cars, or other vehicles from the transport sector, have to be absorbed to guarantee normal operation mode of the electrical and mechanical modules and why not convert this vibrational energy into electricity [**2**]. Thus, although the PEH is characterized by one of the lowest yields as compared to the other energy harvesting technologies (solar, thermal, RF), it has become irreplaceable in these specific cases. For this reason, great efforts will be made in the research laboratories soon to improve the PEHs features and enhance their competitiveness in the energy harvesting market. A lot of new applications that use PEH as a battery alternative are going to be closer to commercialization.

In this perspective data about the researchers' interest, commercial applications and market trends, related to different types of PEHs are showed and discussed.

Research interest related to PEH

One of the largest databases for scientific literature, more popular in Europe [**3**], shows that the keywords "piezoelectric energy harvesting" return 4 458 results published in the last 5 years. The trend is for continuously increasing interest in this field. Up to date (July 2020), there are 999 published papers devoted to PEH, which is near to the total number of such papers for 2019 (1 128), although we have just passed the mid-year time. Data are available for 15 papers pending publishing in 2021, which use the option "on-line first". This is an indication of the significance of this "hot topic". **Fig. 1** illustrates this trend and the distribution of papers like research papers type (3164), review papers (502) and book chapters (383) for the same period 2016-2020. 356 materials from the above-mentioned papers are open access. Some of the journals that are going to publish papers related to PEH in 2021 have impact factors 6.31, 6.47, and 31.56.

Another database that is more popular in USA **[4]** shows that there are a lot of conference papers for the last 5 years – 649, which are reported on prestigious international conferences all over the world.

At the same time, the popular articles published in magazines for non-specialists are relatively low numbers (less than 100 for the last year) which reduces the social dimension of the topic. The web-sites devoted to dissemination and communication with the general public

and increase social awareness about PEH are also small number. Titles like "Piezoelectric Power Generation in Automotive", in which the achievements in the field are explained more accessible to the reader and less technical, are rare [**5**].

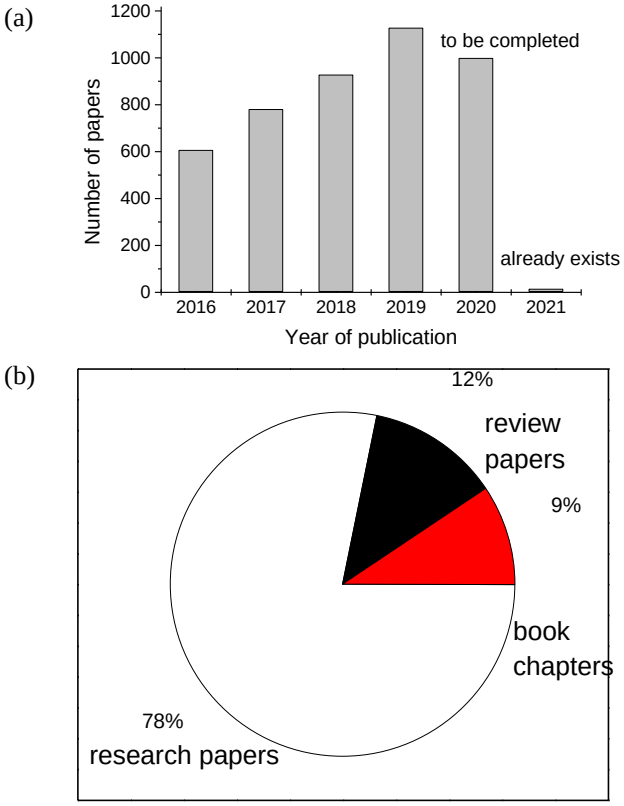

Fig. 1. Distribution of the papers with keywords PEH over the last 5 years, including also the future publishing activity in 2021: (a) distribution by year; (b) distribution by paper type.

Regarding the programs and funding schemes supporting research in the field of energy generation and storage (in general, including all approaches), European Energy Research Alliance has been established in Europe [**6**]. It currently outlines the prospects for the development of the alternative energy sources for society by 2050 as a measure to continue and expand the funding initiatives from the Horizon 2020 program period. Most of the programs from the new program period aim to increase the Technology Readiness Level (TRL) from 2-3 (proof of concept) to 5-6 (demonstration in relevant environment). Piezoelectric energy harvesting elements fall into the group of renewable energy for health care and transport. Tracking the progress in the development of this technology, it is expected capacity raise with 48% in the next 5 years by 2025. Approximately 19% of them are intended for the needs of biomedical engineering. PEHs are part of the strategic energy technology plan (SET-Plan), which will support and stimulate partnerships with industry deploy new, environmentally friendly and energy efficient fabrication technologies on a large scale [**7**].

Practical applications and market of PEHs

World-wide analysis has been made in different regions having potential to develop PEHs based on their manufacturing infrastructure and profit [**8**]. As leading regions in this term North America, Europe, China, Japan and India have been pointed out. As major industry sectors that will need and use PEH in their products have been recognized the aerospace, vehicle, consumer electronics, healthcare, military, roads, sensors, toys, etc.

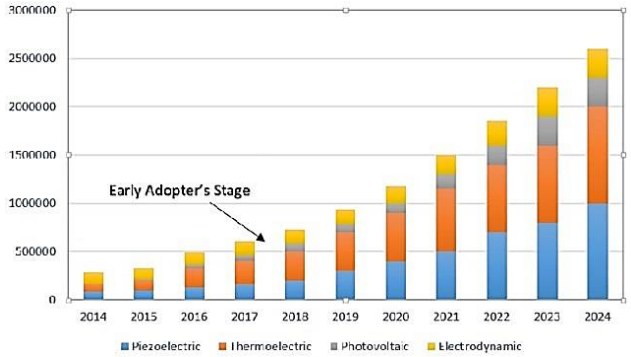

Fig. 2. Investments in USD in the sector energy harvesting, particularly piezoelectric one **[9].**

It is shown the forecast for the global market of energy harvesters for the next 5 years. It could be seen that PEH and thermoelectric harvesters are going to be more perspective in the near future, even more than the photovoltaics and electrodynamic type (**Fig. 2**). Among applications, the aerospace held one of the largest shares of the piezoelectric devices market during the last year, counting also PEH. The percentage distribution of usage by regions up to now and for the next 5 years is shown in **Fig. 3** (note: APAC includes China, Japan, South Korea and RoW includes Middle East, Africa and South America).

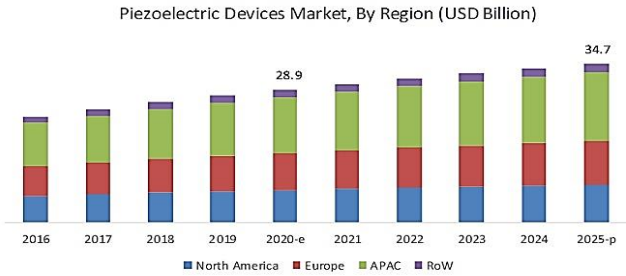

Fig. 3. Regional distribution of the implementation of PEHs in aerospace and defence industry in percent **[10].**

To gain development of the PEH's energy efficiency, new functional materials with enhanced properties have to be also synthesized and studied. The investments in this direction cannot be underestimated. According to the forecast, among the smart materials that are going to be improved in the future, the greatest extent of development is foreseen for the piezoelectric materials and after 5 years almost 20 billion USD will be invested in this sector **(Fig. 4)**.

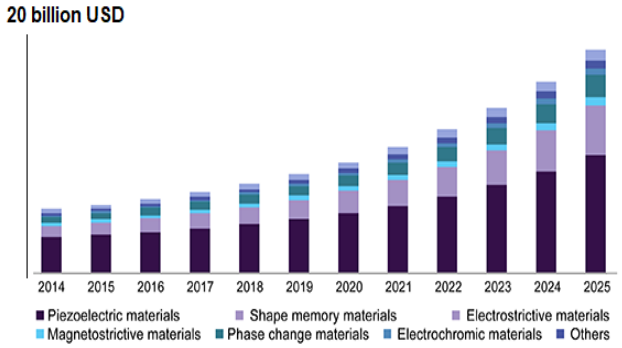

Fig. 4. Annual investment in the materials science development distributed among different smart materials **[11].**

It is reported that piezoelectric ceramics held the largest size of the market, during the last year and are expected to continue to hold this trend by 2025. They offer high output, can be used with low-voltage or high-voltage drive circuits and their properties can be easily tailored during growth to fit the demands of the specific applications.

While many of the research institutes concentrate their efforts on solar and fossil energy, the development and enhancement of novel smart materials with a particular interest in piezoelectrics are major targets of the world-leading research centers like Tyndall [**12**], which are tightly connected with industrial partners. Such centers' mission and goals are delivering economic impact through research excellence and work with industry and academia to transform research into products in the areas of electronics, communications, energy, health (**Fig. 5**). Currently, the institute and its over 200 industrial partners are interested in piezoelectric materials and applications, which is an indication for the near future scientific and manufacturing focus. As can be seen from **Fig. 5** the interest is not limited to energy harvesting only, but medical sensors, tactile sensors (electronic skin), resonators and actuators are also considered. Very interesting applications that will gain more popularity in future are the smart glove, drug delivery system, human interfacing and biomedical sensors, compatible with the CMOS technology.

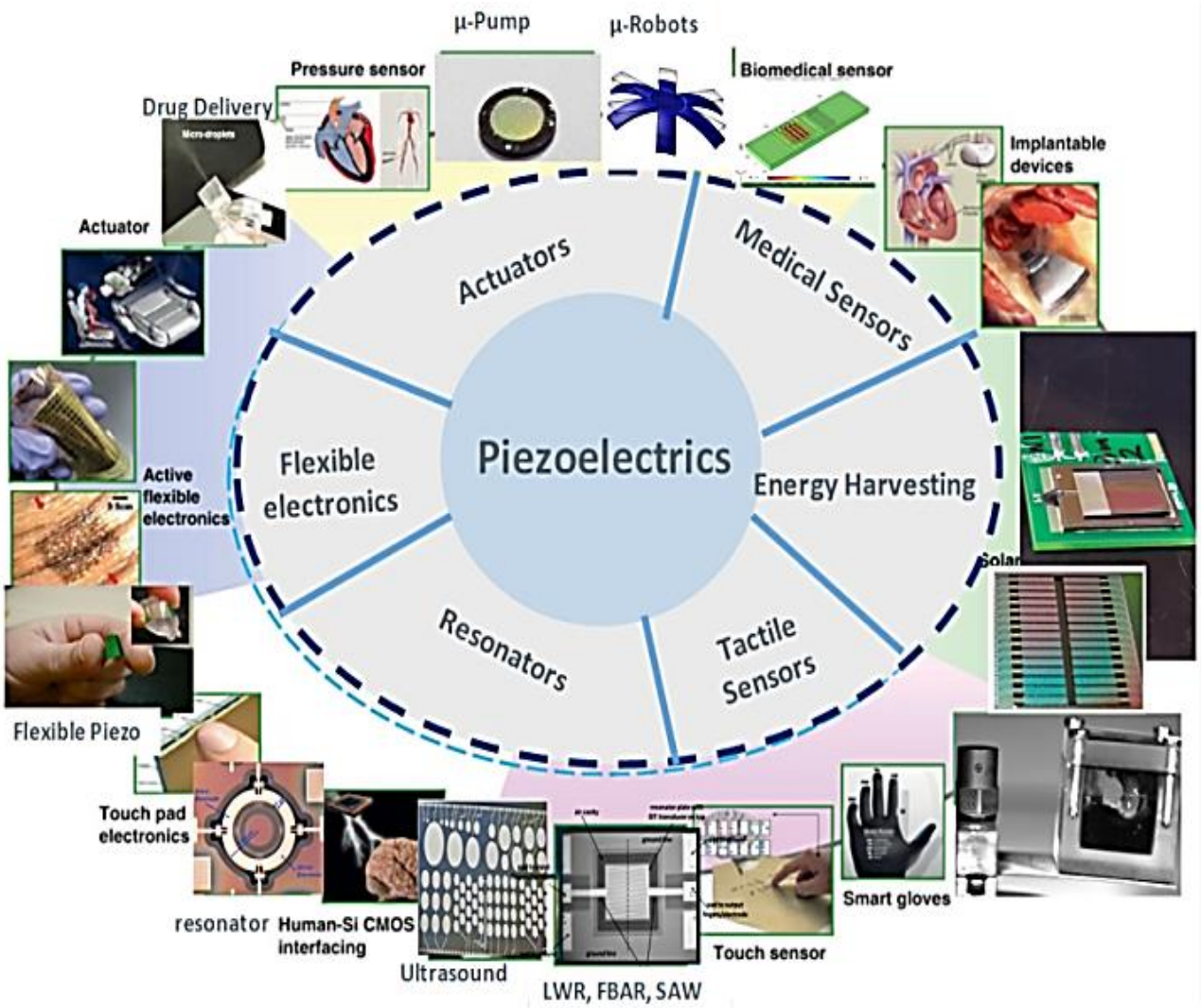

Fig. 5. Research perspectives of Tyndall and its academic and industrial partners **[13].**

Conclusion

Numerous manufacturers have received funding and support from government bodies and universities for the development of innovative and advanced products. New piezoceramic materials will be developed for high-power applications, as the low-power applications are well covered by the current state-of-the-art. Considerable demand from the medical industry is expected to drive the market. There is a lack of awareness among end users that may restrict the commercial scope of the product, which in turn is likely to hamper the market growth over the forecast period. However, the huge potential of the piezoelectric devices to work solely or in a hybrid configuration to increase the energy conversion efficiency will be the dominant force that will make the researchers and manufacturers of PEH key players on the scientific scene. The future prospective is for development of the wearable and implantable components as the next-generation portable devices. Among them, it is expected that the fiber-based self-powered systems will be dominant technology for the wearable devices' fabrication. Some problems are still unsolved and great efforts are required to overcome the technological challenges. Specific applications need properties like adaptability, durability, shape and size that have to be customized and in some cases – personalized. Therefore, this is going to be the next hot topic.

In the context of the present events and the COVID-19 pandemic, it seems that the functionality offered by the PEHs will be transformed into sensing ability for virus detection through advanced surface acoustic wave (SAW) devices. This is going to be step forward that helps the health specialists in the crisis to perform precise and at the same time sufficiently fast testing in an innovative way. The development of these energy autonomous biomedical devices will have important effect on the healthcare industry. A great number of studies are expected to help establishing the full implementation of the PEH powered and sensing biomedical systems.

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Conflicts of interest

There are no conflicts to declare.

Keywords

Piezoelectric energy harvesting, smart materials, energy efficiency, alternative energy sources.

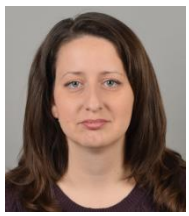
Supporting information

There is no supporting information.

References

1. Li, Z.; Zheng, Q.; Wang, Z. L.; Li, Z.; *Research*, **2020**, *2020*, 8710686.
2. Al-Yafeai, D.; Darabseh, T.; Mourad, A.-H. I.; *Energies*, **2020**, *13*, 2336.
3. https://www.sciencedirect.com/search?qs=piezoelectric%20energy%20harvesting (accessed on 31 July 2020).
4. https://ieeexplore.ieee.org/search/searchresult.jsp?newsearch= true&queryText=Piezoelectric%20energy%20harvesting (accessed on 31 July 2020).
5. https://www.altenergymag.com/article/2017/12/1-article-for-2018-piezoelectric-power-generation-in-automotive-tires/27642/ (accessed on 1 August 2020).
6. https://www.eera-set.eu/
7. European commission - Energy roadmap 2050, https://europeanpowergeneration.eu/files/Energy_Roadmap_2050pdf.pdf
8. Booming Growth in Piezoelectric Energy Harvesting Market 2019-2025 with Leading Players like Advanced Cerametrics, Boeing, Honeywell, ITT, Microstrain, Inc., Smart Material Corp. Press release from: CMFE Insights, 2019. https://www.openpr.com/news/1877744/booming-growth-in-piezoelectric-energy-harvesting-market (accessed on 1 August 2020).
9. Harrop, P.; Das, R.; *IDTechEx*, **2011**.
10. Piezoelectric Devices Market by Material (Piezoelectric Ceramics, Crystals, Polymers), Product (Piezoelectric Actuators, Transducers, Motors), Application (Aerospace & Defense, Industrial, Consumer), and Region - Global Forecast to 2025, **2020**, Report Code: SE 3950.
11. Smart Materials Market Size, Share & Trends Analysis Report By Product (Piezoelectric, Shape Memory Alloys, Electrostrictive, Magnetostrictive, Electrochromic), By Application, By Region, And Segment Forecasts, 2018 – 2025, **2018**, Report ID: GVR-2-68038-036-1.
12. https://www.tyndall.ie
13. https://www.tyndall.ie/piezo-mems (accessed on 1 August 2020).

Author biography



Mariya Aleksandrova received her MSc degree in electronics and the Ph.D. degree in the technology of electronic manufacturing from the TU-Sofia, in 2007 and 2010, respectively. Since 2015, she is an Associate Professor with the Department of Microlec¬tronics, TU-Sofia. She is an author or co-author of 6 books and more than 80 papers in international journals and conference proceedings. Her current research interests include microelectronic technologies, MEMS, piezoelectric energy harvesting, flexible electronics.

Graphical abstract

Distribution of the papers, including keyword "piezoelectric energy harvesting" over the last 5 years, including also the future publishing activity in 2021 shows increasing interest. The achieved output electrical power and miniaturization level allow fabrication of commersial self-powered devices.