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Research Highlight

Human spinal reflex like strain-controlled power devices based on piezotronic effect

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With the development of information technology, AI system and Internet of Things (IOT) technology, it is a long-term challenge to realize the automate actions of power devices in unexpected environmental changes. In recent years, many efforts had been reported to develop new intelligent power devices. Among them, III-V material alloys with semiconductor and piezotronic effect had been proved to be a very effective solution for power electronics application problems. Since the piezotronic effect has been proposed by Prof. Zhong Lin Wang [1,2], it is proved the important application potential in the field of design and application of semiconductor optoelectronic devices. By using the adjustment of piezoelectric potential at the interface of semiconductor-metal or heterojunction, we can use strain or deformation to adjust the performance of electronic devices, or prepare new types of pressure sensor. For example, the high resolution pressure distribution sensor arrays had been designed by adjusting the performance of organic light-emitting diode (OLED) or field-effect-transistor (FET) arrays [3–6]. These kinds of sensors need complex external circuits to read information, so it is difficult to achieve real-time feedback controlling.

Recently, Prof. Zhong Lin Wang and co-workers [7] reported a new device that can directly modulate the output power according to external strain at a rapid speed. The cantilever-structured AlGaN/AlN/GaN-based high electron mobility transistor (HEMT) had been used to control significant output power modulation. Different from the traditional tactile sensor, which needs complex signal processing system with low feedback speed, this system can get the real-time external stress information through the change of piezotronic charge, and then implement feedback output power at a fast speed. At the same time, people can also implement terminal control by complex circuits' modules. Two ways of power regulations run at the same time, similar to human spinal reflex and brain control system. So, the device has wide application potential in the field of auto driving or action control of intelligence robots.

As shown in Fig. 1a and b, the strain-controlled power device (SPD) inspired by human reflex consists of a the AlGaN/AlN/GaN-HEMT and a GaN-based cantilever architecture, which had been fabricated by a fully dry etching process using the inductively coupled plasma etching (ICP). The measured *I-V* characteristics of the source-drain and gate show that the SPD has good capability of gate-control. When the external stress is applied to the free end of the cantilever along the *c*-axis by the probe, the increase of tensile strain results in static piezoelectric charge generated at the interface, which can be converted into a corresponding change in the two-dimensional electron (2DEG) density formed and thus modulating electron transport. As shown in Fig. 1c and d, the I_{ds}-V_{ds} curves show up-shifts to some degrees according to the increasing of the strain (0–16 mN). Furthermore, the results of controllable capabilities of various V_{gs} (−5–1 V) under strains of 0–16 mN (Fig. 1e) show that the output power intensity rapidly increases as the external compressive strain increases, and the change of output power is also sensitive to the increase of gate voltage in SPD. The V_{gs} can significantly change the sensitivity of the output power to external strain. It means that SPD can be used as a device to directly adjust the power output under the stimulation of weak external mechanical force, and the power can still be adjusted through the gate voltage by external control circuit. The authors compared this dual control process with the human reflex system. The piezotronic effect regulation is similar with the human spinal reflex whose reflected nerve center is in the spinal cord and it can respond very quickly without interfering with the more complex modulated process of the high central nervous system (adjusting the power of SPD device through V_{gs}).

Furthermore, the authors explored the application of SPD in the field of artificial intelligence and designed a new acceleration control system, which uses acceleration to directly control the output power. By the measurement combing the system of semiconductor characterization tester and linear motor, the new acceleration control system shows an excellent sensitivity on the acceleration of reciprocating motion from 1 to 5 G (Fig. 1f). The results further proved the sensitivity of SPD to external weak stress stimulation and the possibility of its application in the field of artificial intelligence control.

In summary, a new design concept of bionic SPD based on piezotronic effect has been reported, which realized the direct

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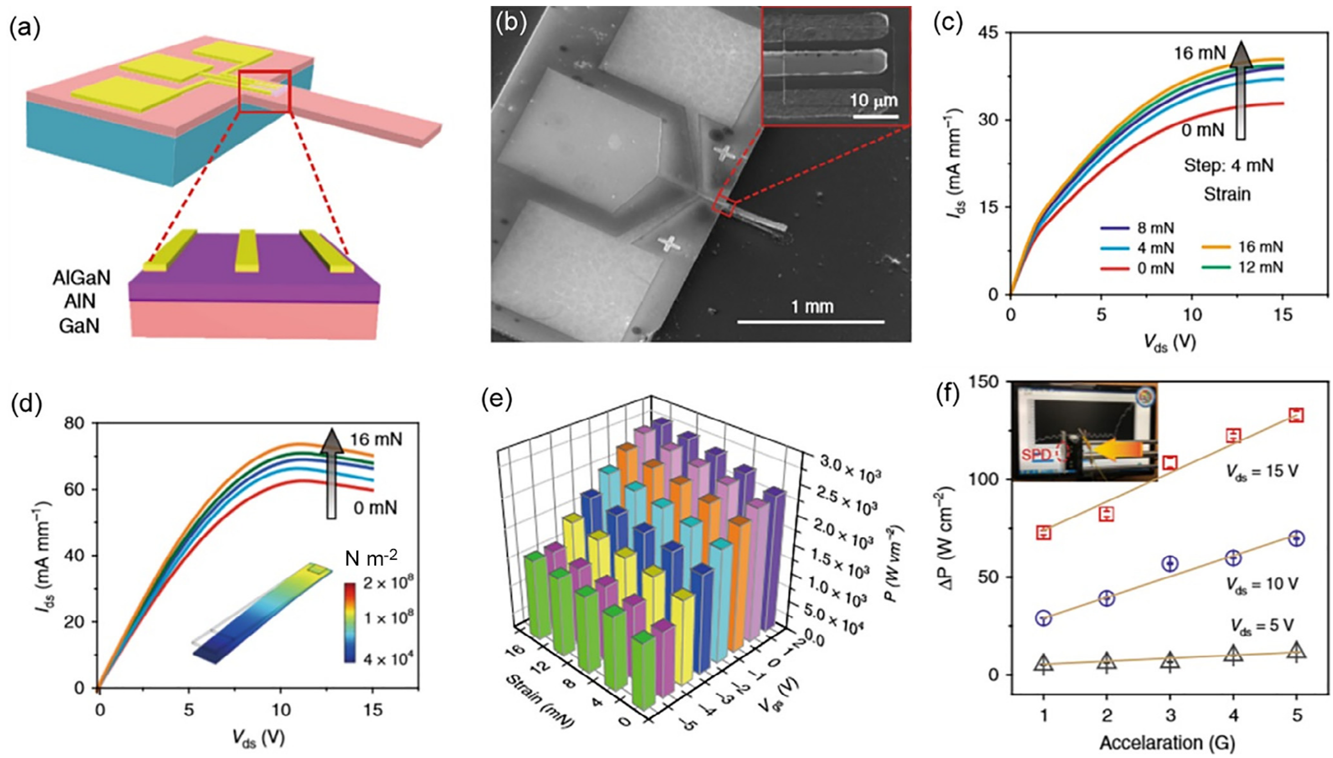

Fig. 1. Human spinal reflex like strain-controlled power devices based on piezotronic effect. (a) Schematic illustration of the device with the AlGaN/AlN/GaN heterostructures. (b) Scanning electron microscopy (SEM) image of the SPD. Output characteristics of the SPD under external strain from 0 to 16 mN, with the gate voltage V_{gs} of (c) −5 and (d) 1 V, respectively. The inset of (d) is the COMSOL multiphysics of strain distribution on the SPD under an external strain of 16 mN. (e) The results of controllable capabilities of various V_{gs} (−5–1 V) under strains of 0–16 mN show that the output current response to the external strain is also effectively modulated by the gate. (f) The performance of new acceleration control system based on the SPD. The changes in output power density with various acceleration. Reprinted with permission from Ref. [7], Copyright © 2020 Springer Nature.

control of output power density under the action of weak external mechanical stimulation (0–16 mN). This structure combines the advantages of AlGaN/AlN/GaN heterojunction HEMT and the piezoelectric effect of flexible GaN-based cantilevers. It can realize that the piezotronic effect power control similar to human spinal reflex and gate-control similar to human cerebral cortex reflex. A new acceleration control system based on SPD had been furthermore designed to prove that the device has potential application in many fields such as auto driving, intelligent robot action control and so on.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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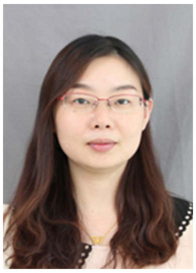

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