New sensors offer promise of bedside diagnosis

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Semiconductor devices based on high-electron-mobility transistors can be functionalized for specific applications.

There is strong interest in the development of handheld, programmable, single-chip sensors that are capable of wireless communication. Such sensors could revolutionize current clinical practice through real-time monitoring of patient health. For example, the sensor could be programmed in the doctor’s office for a specific medical condition and then given to patients for use at home. Encrypted sensing results would then be transmitted directly back to the doctor to monitor the effectiveness of prescribed medicines, providing patients with better and more immediate health care. Such devices may also reduce the number of unnecessary visits to the emergency room and the resulting cost to the national health system. Similar sensors would allow fast detection of toxins in the environment and greatly improve our ability to respond. Environmental safety monitoring would benefit from in-field deployable sensors.

Fluorescence-based molecular recognition is currently the most common method used to identify biomarkers. The response time of sensors varies from a few minutes to hours. These methods also require expensive equipment. Conversely, semiconductor-based sensors that produce an electronic signal have much faster response times. The electrical output signals from the sensor can be digitized and used for quantifying the concentration of the detected species. The resulting data can be transmitted wirelessly. Recently, aluminum gallium nitride/gallium nitride (AlGaN/GaN) high-electron-mobility transistors (HEMTs) have been employed as gas, chemical, biological, and medical sensors due to their excellent sensitivity to the ambient environment of the devices.\textsuperscript{1–3} AlGaN/GaN optical device technology is quite mature. AlGaN/GaN blue and UV light-emitting diodes and lasers have been manufactured for display and optical storage applications for almost a decade. AlGaN/GaN HEMT-based electronic devices are also widely used as power transistors for wireless telecommunication applications. The AlGaN/GaN material system has a wide energy bandgap (3.3eV for GaN and 6.4eV for AlN as compared to 1.12eV for silicon). This makes them capable of high-temperature operation, and their bond strength makes them extremely chemically stable. No known wet chemical solution can etch these materials under normal conditions.

At present, we have installed hydrogen gas sensors based on AlGaN/GaN materials at an automobile dealership in Orlando, FL, where they have been operational for almost two years, monitoring emissions from a fleet of hydrogen-fueled demonstration

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vehicles. The output from the sensors can be checked from remote locations and any alarm conditions sent to cell phones or personal digital assistants. At the University of Florida, we have used AlGaN/GaN HEMT sensors to detect DNA, kidney injury molecules, prostate cancer-specific antigens, breast cancer markers, botulinum toxins, hydrogen gas, carbon dioxide, oxygen gas, mercury ions, and to measure the pH of exhaled breath condensates. This shows the great versatility of these sensors.

The principle is based on detecting changes in source-drain current flowing through a two-dimensional electron gas (2DEG) at the AlGaN/GaN interface on exposure to the desired target. This 2DEG is formed as a result of polarization effects, inducing counter positive charges below the AlGaN surface. These positive charges are extremely sensitive to environmental conditions. By functionalizing the AlGaN/GaN HEMT surface with different metals or antibodies, only the specified gases, chemicals, or cancer markers will be detected. For example, in an HEMT sensor for prostate-specific antigen (PSA) detection, an antibody for the PSA is immobilized on the HEMT surface (see Figure 1).

There is also significant interest in developing noninvasive rapid diagnostic sensors for determining early signs of medical problems in humans. Exhaled breath and saliva are unique bodily fluids that can be used in this regard. While most applications will detect substances or diseases in the breath as a gas or aerosol, breath can also be analyzed in the liquid phase as exhaled breath condensate (EBC). The pH value of the EBC of a typical healthy person is between 7 and 8. However, pH can vary significantly depending on the health condition of each individual. The pH value for patients with acute asthma has been reported to be as low as 5.23. Recently, research at the University of Florida used zinc oxide nanorods integrated into an AlGaN/GaN HEMT to detect EBC glucose levels in the nanomolarity range. This offers the potential for these devices to be used in diabetic applications. We have also detected breast cancer by functionalizing the HEMT sensor with antibodies to c-erb-2, a breast cancer biomarker in human saliva. The versatility of these AlGaN/GaN HEMT detectors clearly suggests some obvious commercial opportunities. Our research continues to look into the mechanisms involved in functionalizing HEMT sensors in order to expand their potential applications.

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References
