TECHNICAL INSIGHTS

SENSOR

TECHNOLOGY ALERT

11th September 2015

1. INTEGRATED GRAPHENE SENSORS

Graphene, a monolayer of carbon atoms, can offer outstanding electronic and mechanical properties, thermal conductivity, and optical transparency that are beneficial for sensor applications. Furthermore, graphene has superior, very high carrier mobility.

Graphene can benefit diverse types of sensors such as chemical and gas (including electrochemical) sensors, magnetic or electric field sensors, optical sensors (including photodetectors, image sensors), strain sensors, and so on.

For example, graphene's large area, and the phenomenon in which molecules that are sensitive to certain gases can attach to the carbon atoms in graphene, can allow for combining graphene, strands of DNA, and fluorescent molecules for disease diagnosis. This technique could create a sensor capable of detecting the same DNA for a particular disease in a sample.

Since graphene is only one atom thick, membranes made of graphene sheets that contain nanoscale pores could allow for more efficient separation of gases. It would require less energy for gas separation compared to using thicker membranes. Sheets of graphene in the form of a foam that changes resistance in the presence of low levels of chemical vapors (such as ammonia) could be beneficial for explosives detection.

In addition, the ability to more efficiently create graphene-based sensors with integrated electronics can enable enhanced types of graphene sensors such as biosensors or pH sensors.

Researchers at the Harvard University (USA) have addressed the need to integrate the graphene layer with electrodes for fabricating a range of device components based on graphene materials, such as FETs (field-effect transistors), and electrical interconnects.

Moreover, in contrast to the multiple processing steps required in conventional complementary metal oxide- semiconductor (CMOS) microfabrication, the single-step process allows for the synthesis and integration of complex graphene devices, such as fabrication of flexible semitransparent graphene FET arrays, graphene biosensors, and pH sensor arrays.

The invention enables a single-step chemical vapor deposition (CVD) graphene synthesis process to build monolithically-integrated electronic devices with structures and regions of varying numbers of graphene layers to produce a range of elements, including graphene channels and graphite electrodes. The single-step synthesis technique, moreover, facilitates production of an entire device area, including interconnect lines, in a single step and the assembly of multiple components of FETs on flexible and transparent plastic films.

The technology addresses key challenges in the widespread adoption of graphene nanolayer devices and components, which have potential to transform the field of post-silicon electronics. The single-step synthesis of a large number of monolithic graphene structures as well as integration of graphene components with other circuit components comprised of carbon allows for creating a new class set of graphene-based components and circuits. For instance, multi-layer graphene structures synthesized via the technology can be transferred onto rigid or flexible substrates, including transparent plastic films.

The single-step synthesis process, furthermore, is conducive to the creation of sensors, such as a a monolithic graphene/graphite field-effect transistor array for real-time, multiplexed sensing of parameters such as voltage and pH, or, with the proper functionalization, sensing of biomolecules. For example, a FET biosensor that is a macromolecule protein sensor with antibody receptors linked to the sensor's graphene layer. The micro-scale sensor enables detection of minuscule amounts of specific proteins in a solution for medical, drug development, and safety inspection.

Details: Mick Sawka, Director of Business Development, Physical Sciences, Harvard University, Office of Technology Development, Richard A. and Susan F. Smith Campus Center, Suite 727E, 1350 Massachusetts Avenue, Cambridge, MA 02138. Phone: +617-496-3830. E-mail: mick_sawka@harvard.edu. URL: www.otd.harvard.edu.

2. OPTICAL SENSORS IMPROVE DETECTION OF SMOLDERING FIRES

Smoldering constitutes a slow, low-temperature, flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed-phase fuel. Smoldering represents a very fire hazard because it generally yields a higher conversion of a fuel to toxic compounds than flaming and it provides a pathway to flaming that can be initiated by heat sources that are too weak to directly generate a flame.

Smoldering fires are quite hazardous and include residential fires involving mattresses or upholstered furniture that are initiated by smoking material.

A smoke detector detects the visible or invisible smoke particles from combustion as an indicator of fire. Such devices primarily use optical photoelectric detection (in which a light source is aimed at a sensing chamber and smoke in the sensing chamber reflects light onto a light sensor to trigger an alarm), ionization (such devices contain a radioactive source, and smoke disrupts the flow of ions, reducing current flow and activating an alarm), or a combination of the two detection methods.

Ionization detectors can respond very slowly to the dense smoke associated with smoldering or low-temperature fires. Photoelectric detectors may react relatively quickly to visible smoke particles from smoldering fires.

While smoke detectors detect the smoke generated by flaming or smoldering fires, smoke is not always produced in a smoldering fire. Carbon monoxide (CO), which is invisible, odorless, tasteless yet highly poisonous, is produced from both smoldering and flaming combustion. Although production of CO from smoldering fires can be low, smoldering emits carbon monoxide or other toxic gases at a higher yield than flaming fires. Conventional smoke detectors are not able to detect carbon monoxide.

Nitrogen oxides (NOx) consist of nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O) and are formed when nitrogen (N_2) combines with oxygen (O_2). Nitrogen dioxide, a key component of smog, is produced by somewhat later in the course of a fire.

In a move that manifests opportunities for improved detection of key gases in a smoldering fire, researchers at the Fraunhofer Institute for Physical Measurement Techniques IPM in Germany have developed a cost-efficient yet highly sensitive fire gas sensor that can detect carbon monoxide and nitrogen dioxide to better identify a fire at an early stage. Instead of recognizing a fire by its smoke, the sensor identifies a fire by the level of carbon monoxide it emits.

The sensors are designed to provide reduced cost and maintenance or higher selectivity than conventional CO sensors. The devices ignore extraneous gases and only respond to carbon monoxide and nitrogen dioxide. Use of roll-to-roll processing can allow for producing such sensors very inexpensively, facilitating mass market devices. In mass production, the sensors are envisioned to cost around the same, or slightly more, than a conventional smoke detector.

The fire gas sensors use a specific dye for carbon monoxide and another dye for nitrogen dioxide. A tiny LED (light-emitting diode) shines blue light into a waveguide coated with a polymer containing the mixed dyes. The light travels to the other end of the waveguide where it meets a detector. When the air in a room is normal, the coating glows purple, which indicates it has absorbed only a small amount of blue light and allows most of the blue light reach the detector. When the air contains carbon monoxide, the dye glows yellow. The yellow dye absorbs more blue light, reducing the overall amount of light reaching the detector. An alarm is tripped below a given threshold value. A second waveguide, coated with another dye, is used to detect nitrogen oxide.

The fire gas sensors made by the researchers use the same components employed in smoke detectors, with the addition of the optical waveguides. The alarm threshold is determined by the electronics. The researchers have collaborated with an industrial partner to develop roll-to-roll processes capable of printing 15,000 measurement systems on a continuous roll.

Smoke detectors are ubiquitous and carbon monoxide sensors are now used in commercial and residential buildings CO detection. However, the new CO gas fire sensors, with an attractive price, high sensitivity and selectivity, and longevity, have opportunities for use to provide a higher level of safety in residential or commercial construction.

Details: Dr. Carolin Pannek, Researcher, Integrated Sensor Systems, Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstrasse 879110, Freiburg, Germany. Phone: +49-761-885-7731. E-mail: carolin.peter@ipm.Fraunhofer.de. URL: www.ipa.fraunhofer.de

3. ENERGY HARVESTING NODES DETERMINE CAMERA'S POSE AND LOCATION

Radio frequency identification (RFID) technology uses radio frequency (RF) wave communication to exchange information between a reader (or interrogator) and an electronic RFID tag (or transponder).

Passive RFID tags do not have a power source and require an external source (for example, reader) to power the tag and initiate signal transmission. Passive RFID tags are able to energize a sensor circuit when the reader is supplying power to the tag. Active RFID tags, include a battery and transmitter and are able to transmit signals to the reader.

Radio frequency electromagnetic energy has benefits for use in energy harvesting to power a diverse range of relatively low-power devices. Such benefits include the abundance of RF energy emanating from a plethora of radio transmitters, including mobile telephones, handheld radios, mobile base stations, and television and radio broadcast stations, and so on. The ability to harvest RF energy from ambient or dedicated sources, facilitates wireless charging of low-power devices. However, it is important to ensure that RF-based energy harvesting can work effectively in rural areas that may not have as many devices that emit the energy to be harvested, compared to metropolitan areas.

RFID-based energy harvesting has tended to be associated with relatively simple or low-power sensing applications such as sensors for monitoring an animal's core temperature. However, advancements now allow for RFID tags with energy harvesting that have opportunities to enable more comprehensive and effective wireless sensor networks comprised of relatively complex and power-hungry cameras that produce larger amounts of data.

In a development that boosts opportunities for energy harvesting (battery-free) camera networks, researchers at US-based Disney Research and the University of Washington have leveraged work at the University of Washington on WISP (wireless identification and sensing platform) battery-free RFID tags to demonstrate the ability of a network of energy-harvesting sensor nodes equipped with onboard cameras to automatically determine each camera's pose and location via optical cues. Such capability could help to enable large-scale wireless sensor networks that could operate without batteries or external power and need minimal maintenance.

This work was supported by the Intel Science and Technology Center for Pervasive Computing, a gift from Disney Corp., a Google Faculty Research Award and a National Science Foundation grant (CNS-1305072).

University of Washington researchers have created WISPs that possess innovative capabilities such as onboard computation, sensing, and image capture for enabling richer sensing capability. The WISPs operate at sufficiently low power to be able to scavenge the energy required for operation from radio waves. The WISPCams have used an innovative charge-storage scheme designed to match the needs of an image sensor. The arrangement optimizes the balance between capacitance and leakage to enhance the power harvester's sensitivity and efficiency. The latest work--supported by the Intel Science and Technology Center for Pervasive Computing, Disney Corp., a Google Faculty Research Award and a

National Science Foundation grant (CNS-1305072)--shows that such WISPs with onboard cameras are able to use optical cues to determine their location and the direction in which they are pointed. Deployment of autonomous sensor nodes becomes easier, and their sensor data becomes more meaningful as a result of the ability of each node to determine its location.

When the WISPCams know their positions, the networks of such cameras can be queried to gather higher-level information, such as sensor data from all of the nodes in a certain area. Further versions of the RFID-based sensing technology have potential to facilitate low-cost, maintenance-free Internet of Things (IoT) applications, due to the lack of needs for cumbersome wiring or periodic replacement of batteries. For instance, wide-scale networks of such sensors could be utilized to monitor the health of key infrastructure such as bridges, or for industrial equipment or security monitoring.

The researchers addressed key networking issues: design of the sensors in order to determine their position and pose, reducing the amount of data required to be transmitted over the network, and enhanced management of the small amount of power captured by the RF antennas.

The Perspective-n-Point (PnP) image processing technique was used to determine location and pose. In this technique, an image of an object is captured and compare with a second image in which the object is illuminated by four LEDs in know configuration. This technique enabled the cameras to estimate their position to within a few centimeters. The experimental setup used four WISPCams and a separate WISP with LEDs (light-emitting diodes); however, the LEDs could be incorporated into each WISPCam.

The innovative circuitry and firmware provided the initial processing required for localization to be conducted onboard each sensor, as opposed to having to send all the images to a central computer, which would be labor-intensive in very large-scale camera sensor networks and could create excess demands on low-power devices.

Details: Joshua R. Smith, Ph.D., Associate Professor, Department of Computer Science and Engineering, University of Washington, 185 Stevens Way, Box 352350, Seattle, WA 98195. Phone: 206-685-2094. E-mail: jrs@uw.edu. URL: https://sensor.cs.washington.edu

4. OPPORTUNITIES FOR MESH COMMUNICATIONS IN ELECTRIC POWER

A wireless mesh network consists of radio nodes in which each node relays data in the network. All of the nodes cooperate in the distribution of network data. Mesh networks, comprised of self-configuring or self-organizing nodes, offer key advantages, including greater reliability, redundancy, versatility, flexibility, and resiliency. Even if one node is no longer operable, the remaining nodes are able to communicate with each other. Mesh networks are able to relay messages from one radio to another until the final destination is reached. Moreover, mesh supports non line-of-sight communications and is capable of communication through hills or other obstructions. Mesh communications especially have applications, and can provide key benefits in dense urban or suburban areas.

Mesh communications is subject to certain limitations or challenges, such as latency (the speed at which the data can be to be sent), bandwidth (the amount of data that can be transmitted), or coverage area. Furthermore, Mesh communications, especially in the 900 MHz frequency band, is susceptible to interference; and, especially in mission-critical applications, there can be security concerns

In the electric power industry, mesh data communications has been primarily used in advanced metering infrastructure or smart metering, especially in dense urban or suburban areas or in areas with obstructions. In smart metering, mesh radios tend to be used to send data from the smart meter to a collection point; or to send data over a WAN (wide area network).

However, mesh data communications is finding use and opportunities in varied distribution automation applications in the electric power industry. Such applications include conservation voltage reduction and volt/VAR (volt-ampere-reactive) optimization to help reduce voltage to conserve energy and save money; distribution feeder line monitoring and control; fault location isolation service restoration (FLISR; which provides automated service restoration to non-faulty sections after a permanent fault and reconfiguration of the line to safeguard against overload); distributed energy resources (which allows for small power generation sources and storage and advanced renewable energy throughout the system) ; networked control of smart street lights; and transformer monitoring.

Furthermore, in the electric power industry, mesh communications is finding opportunities for enhanced communication of data from power line monitoring sensors for monitoring parameters such as voltage or current in the distribution system, and also as opportunities for transmission line monitoring. Mesh communications can facilitate more cost-effective and reliable communication of power line monitoring data to a gateway, collector or access point. Mesh communications can, moreover, enable more adaptable, efficient, and resilient communication of important data regarding the condition or health of power lines, while providing enhanced fault tolerance and ability to endure node failures.

Details: Peter Adrian, Principal Analyst/Research Manager, TechVision, Frost & Sullivan, 331 E. Evelyn Avenue, Suite 100, Mountain View, CA 94041. Phone: 408-972-1865/650-475-4523. E-mail: peter.adrian@frost.com. URL: www.frost.com

5. RECENT PATENTS IN THE FIELD OF PRINTED SENSORS

Printed sensors and electronics, fabricated on flexible substrates such as plastic or metal foils, are attracting significant interest due to opportunities for low-cost fabrication and the potential to obtain multi-functional electronics over a large area. Printing techniques enable flexible and bendable sensors and electronics and large-area sensor arrays by allowing cost-efficient, streamlined processing of varied electronic materials at temperatures compatible with plastic (or organic) substrates, with reduced wastage. Printed techniques allow development of sensors, electronics and systems on non-planar surfaces, which is elusive to achieve using conventional wafer-based fabrication approaches. Printed sensors or electronics in flexible substrates could enable, for example, conformable, sensitive systems such as electronic skins capable of being wrapped around a robot’s body or prosthetic hand. The flexible substrates of printed sensors allow for light-weight sensors with a customized form factor and the creation of new designs.

Techniques for printing sensors and electronics include screen printing, inkjet printing, gravure printing, flexographic printing, roll-to-roll (R2R) printing, nano-imprinting.

Promising applications for printed sensors include disposable biosensors for diagnostics; wearable devices, such as pressure sensors, biometric sensors, image sensors, chemical sensors, head-mounted displays, smart textiles); smart packaging (protection of packaged food, tamper protection); defense and security.

An analysis of key patents indicates interest in printed circuit boards with an embedded sensors, printing touch screens sensors or touch sensors for touch screen displays, printing gas sensors, as well as printing stretchable strain sensors. R&D in the area of printed sensors spans the Unite States, Europe, and Asia,

For example, Patent WO/2015/126306, assigned to Innoscentia AB, pertains to a printed gas sensor comprised of a metalloporphyrin dye; a method of preparing a gas sensing composition for detection of food status, and a digital expiry date device system. The latter includes a packaging material, a transponder on the inner surface of the packaging material, another transponder on the outer surface of the packaging material, and a sensor electrically connected to the first transponder for detecting food status.

Patent GB2509870, assigned to Unipixel Displays Inc., pertains to a technique for manufacturing a capacitive touch sensor circuit using a roll-to-roll process for printing a conductive microscopic pattern on, for example, a flexible dielectric substrate. Mutual capacitance touch sensor circuits are used in various types of touch screen displays, other displays employed in computing, and in stationary or portable electronic devices.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
METHOD FOR PRODUCING A PRINTED CIRCUIT BOARD WITH AN EMBEDDED SENSOR CHIP, AND PRINTED CIRCUIT BOARD	03.09.2015; WO/2015/127486	AT&S AUSTRIA TECHNOLOGIE & SYSTEMTECHNIK AKTIENGESELLSCHAFT	WEIDINGER, Gerald	A method for producing a printed circuit board (10) with at least one embedded sensor chip (3), in which at least one sensor face (5) and connectors (4) are arranged on a face of the chip, comprising the following steps: a) providing an adhesive film (1), b) printing a conductor structure (2) made of a conductive paste onto a surface of the adhesive film, c) placing the at least one sensor chip (3) with the face having the at least one sensor face (5) and the connectors (4) onto the conductor structure (2) made of a conductive paste in a registered manner, d) curing the conductive paste, e) applying an insulation layer (6) with a conductor layer (7) lying thereabove onto the surface having the chip (3) of the structure created in the preceding steps, f) laminating the structure created in the preceding steps, g) structuring the conductor layer (7) and forming vias (9) from the conductor layer to the printed conductors (7b, 7c) of the conductor structure on the surface of the adhesive film and h) removing the adhesive film (1)

PRINTED GAS SENSOR AND DIGITAL EXPIRY DATE THEREOF	27.08.2015 ; WO/2015/126306	INNOSCENTIA AB	OLSSON, Martin, Andreas	The invention discloses a printed gas sensor comprising a metalloporphyrin dye, having a first and second mode, and a nanoporous carrier material comprising a plurality of particles with a size less than 5μιτι, said plurality of particles having a plurality of pores with a pore size in the range 5-50nm, wherein said metalloporphyrin dye is bound to said nanoporous carrier material. The invention further discloses a method of preparing a gas sensing composition for detection of food status as well as a digital expiry date device system. The digital expiry date device system comprises a packaging material having an inner surface and an outer surface; a first transponder disposed on said inner surface and a second transponder disposed on said outer surface; a sensor portion electrically connected to said first transponder for detecting food status and communicate said status to said second transponder, wherein said sensor portion comprises a metalloporphyrin dye to configure said sensor portion for an impedance change upon binding of a gaseous analyte to said metalloporphyrin dye; and a printed numerical array.
PRINTED CIRCUIT BOARD WITH EMBEDDED SENSOR	13.08.2015; WO/2015/120439	BATTELLE MEMORIAL INSTITUTE	SCHIMMOELLER, Andrew, M.	A sensing device includes a printed circuit board (PCB) having a conductive trace. A micro-controller is attached to the conductive trace and data transmission means is connected to the micro-controller. A sensor is embedded within the PCB and is connected to the micro-controller via the conductive trace. The sensor is configured to sense at least one physiological parameter in a patient.
PRINTED STRETCHABLE STRAIN SENSOR	21.05.2015; WO/2015/073944	PRESIDENT AND FELLOWS OF HARVARD COLLEGE	LEWIS, Jennifer	A printed stretchable strain sensor comprises a seamless elastomeric body and a strain-sensitive conductive structure embedded in the seamless elastomeric body. The strain-sensitive conductive structure comprises one or more conductive filaments arranged in a continuous pattern. A method of printing a stretchable strain sensor comprises depositing one or more conductive filaments in a predetermined continuous pattern into or onto a support matrix. After the depositing, the support matrix is cured to embed a strain-sensitive conductive structure in a seamless elastomeric body.
Method for producing touch screen sensor in gravure micro transfer printing way	04.03.2015; CN104391614	SHENZHEN UNIRETE TECHNOLOGY CO., LTD.	ZHAO YUE	The invention discloses a method for producing a touch screen sensor in a gravure micro transfer printing way. The method comprises the steps of designing and producing a gravure, loading and pre-positioning a transfer printing roller, loading and positioning the gravure, aligning the gravure and a transfer printing substrate, filling grooves of the gravure and collecting ink, a micro transfer printing, to be specific: adjusting the clearance and pressure between the transfer printing roller and the gravure and between the transfer printing roller and the transfer printing substrate after the starting point position of the transfer printing roller on the gravure and the transfer printing substrate is adjusted; under the action of adhesion force of the transfer printing roller, adhering a transfer printing material in the groove of the gravure, and starting a heating system; transfer-printing the transfer printing material on the roller to an end point while the viscosity of the transfer printing material is reduced after the roller reaches a starting point of the substrate, injecting cooling water into the roller, cooling the roller, discharging the cooling water after the roller is cooled to certain temperature, and carrying out the next transfer printing; forming the touch screen sensor structure. By adopting the method, the production of all touch

				screen sensors in different sizes and with different substrates can be satisfied, the precision is high, the efficiency is high, and the environmental pollution is avoided.
Printed Gas Sensor	23.10.2014; US20140311905	Massachusetts Institute of Technology	Nicole M. Iverson	A printed gas sensor is disclosed. The sensor may include a partially porous substrate, an electrode layer, an electrolyte layer, and an encapsulation layer. The electrode layer comprises one or more electrodes that are formed on one side of the porous substrate. The electrolyte layer is in electrolytic contact with the one or more electrodes. The encapsulation layer encapsulates the electrode layer and electrolyte layer thereby forming an integrated structure with the partially porous substrate.
Method of manufacturing a capacative touch sensor circuit using a roll-to-roll process to print a conductive microscopic pattern	18.06.2014; GB2509870	UNIPIXEL DISPLAYS INC	PETCAVICH ROBERT J	Mutual capacitance touch sensor circuits are used in manufacturing displays, including touch screen displays, such as LED, LCD, plasma, 3D, and other displays used in computing as well as stationary and portable electronic devices. A flexographic printing process may be used, for example, in a roll to roll handling system to print geometric patterns on a substrate, for example, a flexible dielectric substrate. These patterns may then be coated with a conductive material by, for example, an electroless plating process.

Exhibit 1 lists some of the patents related to printed sensors.

Picture Credit: Frost & Sullivan, WIPO

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