Printed/Flexible/Stretchable Sensors: New Technologies EnableHigh Volume Applications

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Introduction

Printed/Flexible/Stretchable (P/F/S) Sensors have been around for many years. While Electronic induction of its first Force Sensing Resistor (touch) sensor in 1982. Tekscan (to be addressed later) introduced its version of a touch sensor soon thereafter. Based on the Roger Grace Associates (RGA) research, and as one can see from figure 1, a great number of the current commercial suppliers of P/F/S sensors provide touch sensors. Other types of sensors including humidity, temperature, electrochemical gas and image sensors are currently in small-scale production.

This article will address the motivation of developing P/F/S sensors and will provide information on some of the current offerings. Also to be addressed, and which I consider to be the most important and exciting aspect of P/F/S sensors, is the work currently being conducted worldwide in the Printable/Flexible/Stretchable (P/F/S) field. One of the most mature is the success of printed/flexible electronics and will be strongly influenced on the ability for a solution to include more additional functionality to make these sensors “smart” with the addition of low power signal conditioning ASICs with richly embedded algorithms microcontrollers, energy supply and communication functionality, including P/H-S antenna or IC wireless or networking chips will be critical for their widespread acceptance. I have called this approach “MEMS-based systems solutions”, see ref. 1, figure 2. As part of this MEMS concept, low-cost and robust packaging and interconnectivity will be key as well as the integration strategy of whether the solution has judiciously adopted functionalities that optimise their introduction into the solution, whether they be discrete devices attached to flexible substrates, P/F/S sensor or a mix. To quote the famous US architect John Louis Sullivan: “Form must follow function”.

Finally, RGA believes that the success of P/F/S sensors will rely heavily on the success of printed/flexible electronics (PFE). In our opinion, we believe this will be strongly influenced on the ability of high volume/low cost manufacture of these functionalities. A recent US Department of Defense award to San Jose California FlexTech Alliance of $75 million with matching grants more than doubling this amount, will address the creation of a PFE manufacturing facility in Silicon Valley California to address these manufacturing issues.

Markets and applications

Market research firm IDTechEx has reported that the market for fully printable sensors will be worth more than $6 Billion (US) of the $340 Billion US flexible worldwide electronics market by 2030. RGA believes that the growth will be driven by a market pull applications strategy and not by a technology push strategy. Significant applications will include a myriad of sports/health activity/medical monitoring wearable devices and which will exploit several inherent features of P/F/S sensors.

Why printed/flexible/stretchable?

Significant applications for P/F/S sensors will include a myriad of sports/health activity/medical monitoring wearable and disposable applications and which will exploit several inherent features of these sensors including:

• Small size/low profile
• Low manufacturing cost based on existing batch mode processing with the ability to be scaled to a ultra high volume roll-to-roll (R-2-R) manufacturing approach
• Enhanced performance over discrete 3D solutions because of their size and geometry
• Device-to-device uniformity
• Ability to conform to attaching surfaces
• Lower capital equipment (CAPEX) and elimination of expensive clean room environment requirements for manufacturing
• Ease for integration of other functionalities onto same or layered carriers

Several of these attributes are also shared by microelectromechanical systems (MEMS). However, MEMS typically are not flexible, cannot be manufactured in an R-2-R process, but rather in a batch mode approach, and require significant CAPEX investments, unless of course one uses a Silicon foundry for processing the Silicon wafers.

This article will address several of the currently available P/F/S sensors, their applications, manufacturing process and technologies in addition to the work currently being conducted in university and industrial research laboratories and institutes worldwide. All references will be in alphabetical order.

Current offerings

The following are brief reviews of several commercial organisations currently involved in P/F/S sensor development.

BREWER SCIENCE (temperature, humidity) (www.brewerscience.com)

A new entrant into the P/F/S sensor world, Brewer Science is leveraging its 30 years of specialty materials experience in the semiconductor space in the development of a fully integrated temperature and humidity sensor. Demonstrating the innovative nature of the company’s culture as the enabling element of PFE TH022A101 transducer, Brewer Science employs its proprietary electronics-grade, highly purified aqueous-based SWCNT ink. It is capable of providing real-time simultaneous measurement of the temperature and rapid fluctuations of humidity in a surrounding environment. Its ultrahigh-speed sensing capability positions it among the fastest sensors of its kind in the world. Within 10 milliseconds, the technology can sense humidity, which is fast enough to read the fluctuations in humidity as someone speaks.

ISORG (www.isorg.com)

An interesting development demonstrating the successful collaboration in the technology transfer process is with ISORG, established in 2009, and the research institute CEA-Leti. ISORG is developing a novel P/F/S imaging sensor which is capable of measuring visible and near infra-red light up to wavelengths of 900 nm, providing low light current/generation generated under low light conditions. Large dynamic range between illumination current and low and dark current of six decades and high linearity. In addition to the P/S sensor, they are developing a P/F backplane to connect the sensor to the signal processing electronics. This plastic imager is robust and has been designed for lightweight and portable applications. PET plastic foil of 32 x 38 cm is currently being used for plastic production, which will migrate to 60 x 60 cm format for full production resulting in thousands of sensors per sheet. Initial applications for the product include medical X-ray imagers and industrial applications for monitoring packages on shelves for inventory control analysis and large area biometrics for security applications. Longer term applications include smart watches and biometrics for computer security. The low-cost and large surface area capability permit whole hand versus fingerprint analysis. Also, the technology is capable of measuring the configuration of veins in the fingers and hand that will provide additional security versus that of a surface fingerprint that can be emulated by various approaches (see figure 3).

SPEC SENSORS (electrochemical gas) www.specsensors.com

Their current product line, in volume production since early 2014, includes sensors that measure CO as well as Ozone, H₂S, NO₂, NO and alcohol. Sensor construction includes a base layer of plastic, a printed conductive ink gas sensitive layer and a laminated plastic top layer and is currently provided in a 10 x 10 x 2.5 mm format and is reported to shrink to a 10 x 10 x 2.5 mm format by end of 2015. Current applications include residential and commercial indoor/outdoor home air quality monitoring of CO and NO₂ and consumer alcohol breath monitoring.
applications include medical devices, forming the conductive leads. Connectors at the other end of the sensor, silver extends from the sensing area to the circle on top of the pressure-sensitive ink. The active sensing area is defined by the silver to laminate the two layers of substrate. Adhesive is then used between each layer, a conductive material (silver) is constructed of two layers of polyimide. On the other hand, outsourced sensors inform the wearer of what, when, and how much they should ingest to prevent dehydration. Courtesy: INESC Microsystems and Nanotechnologies, Lisbon Portugal, (www.inesc-mn.pt) has developed a unique technology to enable the integration of magnetic field sensors and other spintronic devices micro-fabricated on flexible substrates that are able to bend and conform to the non-planar geometries. The fabrication process is based on polyimide (PI) materials due to their flexibility, thermal stability, chemical resistance, high mechanical modulus, and biocompatibility. Fabricated devices, shown in figure 5, show a strip of several probes already released and connected to each other by small struts that can be cut off to isolate a single structure, one individual probe and one device already assembled to a FPC adaptor board that buffers both impedance and magnetic signals to external electronics. Courtesy: INESC Microsystems and Nanotechnologies, Lisbon Portugal.

Future developments

Research conducted for the creation of this article showed that there was not an abundance of commercial organisations currently in production of P/F sensors. However, a great deal of research is currently being conducted at several research universities and institutes worldwide to increase the pool of knowledge for future sensor development. Some of the more interesting activities include (listed in alphabetical order): The Imec Holst Centre, The Netherlands, (www.holstcentre.com) has developed several P/F sensors including a solid-state ion selective electrode for the monitoring of pH, Cl, Na and K. Additionally, it is developing developing sensor labels built on ultra-thin (less than 150 μm) polyester foils that can measure humidity, temperature chemicals and gases and include NFC/RFID functionality.

TEKSCAN (www.tekscan.com)

Its FlexiForce force sensor can measure force between almost any two surfaces and is sufficiently robust to endure most environments. The supplier states that it has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin-film force sensors. The sensor provides the user the ability to detect the relative change in force or applied load, rate of change in force, or contact and/or touch. These sensors also allow the user to determine force thresholds and trigger an appropriate action.

The standard A201 sensor is constructed of two layers of substrate (polyester film). The high-temp model (HT201) is constructed of two layers of polyimide. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the force sensor. The active sensing area is defined by the silver circle on top of the pressure-sensitive ink. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. Applications include medical devices, control and diagnostic tools, robotics, sports and fitness, and consumer products. Their form factor and low power requirements make them ideal for portable devices and wearable devices.

Bioling (www.bioling.me)

A spin-out of work previously undertaken at UC San Diego (to be addressed later) to commercialise this work is Bioling. It has developed and licensed a flexible epidermal bio sensor system that can be used to determine the dehydration level of the wearer. The sensor suite consists of the P/F electrochemical sweat sensing device on a 7 x 40-mm PET substrate, along with several other externally sourced non-P/F sensors (which may include temperature and humidity at a minimum), and with some application algorithms provided by its “partner” customer. During intense exercise or other physical activities, the system will assist users in determining the quantity, intensity, and chemical composition of the fluids that the user will need to ingest to overcome the problems associated with de-hydration. Working with their integrator partner, this product is expected to reach the market in the second or third quarter of 2016, according to Bioling CTO Josh Windmiller.
Design and manufacturing infrastructure challenges

As the complexity of printed electronics circuits increase, design infrastructure becomes increasingly important to successful product development. The adoption of P/F/S sensors into the design engineer’s toolbox will be driven by several factors:

- Increased performance due to their smaller size and smaller mass
- Enhanced functionality based on their ability to mechanically conform to best accommodate the application requirement
- Cost

We believe that increased performance and the ability to mechanically conform to the application will be important. However, to achieve the major volumes expected from P/F/S sensors, cost will be the ultimate driver. For the time being with small, medium volume requirements, the low level capital equipment (CAPEX) requirements will nicely satisfy. However, to achieve the ultra low device cost required for large volume consumer applications, R2R processes using paper and/or plastic materials will need to be utilized. These equipment are in the process of being developed and are quite expensive. Again, P/F/S sensors will benefit from the infrastructure currently being developed by the PFE sector.

MaryAnn Maher Ph.D. Founder and CEO of SoftMEMS commented “Structured design methods and Computer Aided Design (CAD) tools available to manage complexity, verify functionality and simulate performance of printed electronics designs of those used in the semiconductor world of integrated circuits. However, many challenges remain in the area of materials characterisation, reliability and yield prediction as is the case with MEMS technology where a variety of new materials and manufacturing techniques are used and lack of standardisation makes modeling and statistical analysis challenging.

The expected success of the previously stated FlexTech Alliance recent award for “Design of Flexible and Stretchable Electronic Devices” in the achieving of the Trillion Sensors Opportunity in the sensors industry driven by unique materials and manufacturing processes supported by intellectual property (e.g. Brewer Science as mentioned above) and by intelligent system integration strategies.

Want to learn more?

Roger Grace will present papers on the topic of printed/flexible/stretchable sensors at the Trillion Sensors Summit (www.sensorsummit.org) which will take place in Orlando, Florida on December 9-10, 2015 and at the Sensors Expo (www.sensorexpo.com) which will take place on June 21-23, 2016 in San Jose, California. He will also present this topic in a webinar sponsored by the MEMS and Sensors Industry Group (www.memsindustryguru.org) on December 4, 2016.

Conclusions

Although printed flexible/stretchable sensors have been available for over three decades, their recent infrastructure by design engineers is beginning to move at an accelerated rate driven by the growth of wearables. It is expected that they will play a significant and important role in the achieving of the Trillion Sensor Initiative that Dr. Jarusz Bryzek has been evangelising for the past several years and for which a roadmap is being developed with the conjunction with the several international conferences and ongoing successful integration approaches undertaken on this topic (ref 6). With the expected migration of many P/F/S sensors from their current batch mode process to that of R2R, their manufacturing costs are expected to decrease dramatically and as such will enable their introduction into many high volume/price sensitive consumer applications. Much of the impetus of developing P/F/S sensors is an outgrowth of research and development undertaken the PFE electronics industry over the past several years (ref. 7). Roger Grace Associates considers that with the success of development of P/F/S sensors, and especially with the recent significant funding of the FlexTech Alliance FHI M5, we are at the beginning of a new wave of opportunity in the sensors industry as driven by the growth printed electronics for IoT and wearable/disposable applications. I expect this will attract new players into the market whose portfolios are driven by unique materials and manufacturing processes supported by intellectual property (e.g. Brewer Science as mentioned above) and by intelligent system integration strategies.

References: