Screen printing is advantageous in terms of its process simplicity, low cost, variety of inks, and thick film and multilayer forming capabilities. Teikoku Tsushin Kogyo Co., Ltd. (Teikoku), a manufacturer of variable resistors and other electronic components, has recently become involved in producing custom-made electronic components using PET film substrates and screen printing. By combining the advantages of screen printing with various technologies, the company has developed a unique set of sensors that are not restricted by the framework of existing products. One example is their “XCS Series” of curved surface variable resistors, which were well received by the camera market for their ability to simplify camera structures when they were originally released several years ago.

**Film Integration Technology**

Since its founding in 1944, Teikoku has manufactured variable resistors, fixed resistors, preset resistors, sensors, switches, encoders, and other electronic components. Under their technological concept of “Film Integration Technology,” the company is currently taking a unique approach to manufacturing by integrating their die-mold production, molding, press, printing/coating decoration, film printing, material application, design, and other production technologies.

One typical example of this approach is their integrated control block (ICB), used in digital video cameras, digital cameras, LCD televisions, mobile phones, and other consumer electronics, as well as automobile electronics. Digital video cameras, for example, use ICB for auto focus, image control, image display and effect, menu setting, digital zoom control, mode, power, and recording control switches. In this case, combining a PET film base and the electronic components into a single unit allows the ICB to contribute to smaller, thinner, and lighter electronics. During the production of ICB and other such products, screen printing plays an important role in forming the resistors from carbon ink and the conductive circuits from silver paste. In other words, the company has rich experience in actually applying printed electronics, whereby they produce electronic components by printing conductive circuits and such on film substrates.

Digital Video Camera ICB Are Made of a PET Film Base Packaged With the Various Electronic Components

(1) Auto focus switch
(2) Image controller
(3) Image display/effects
(4) Menu settings
(5) Digital zoom controller
(6) Mode switch
(7) Power/Record controller
Naoki Hayashi, manager of the Sales Engineering Unit, Marketing & Sales Planning Department, explains the company’s use of screen printing by saying that today cutting-edge printed electronics developments tend to pursue the use of ultra-fine printing technology to form conductive interconnects of a few micrometers in width, whereas Teikoku aims to use the advantages of screen printing in a different direction. Screen printing is a simple, inexpensive process that can print various inks in thick films and multiple layers. In this light, the company’s approach is to combine these advantages with other existing technologies to create novel products. Today’s market demands flexible hybrid electronics (FHE) that fuse printed electronics with existing semiconductor and MEMS technologies, so the company is focused on this type of FHE. Likewise, the company is considering expanding further into the FHE field in the future.

In January, the company exhibited at the 46th NEPCON Japan exhibition for R&D and Manufacturing, where Mr. Hayashi led a team that focused on promoting their film integration technology. According to Mr. Hayashi, simply displaying general-purpose products would not attract attention, so they exhibited sensors that went beyond the framework of their existing products for greater impact. In a positive sense, their exhibition was a stab in the back to the company’s image. For example, their exhibition included “XCS Series” of curved surface variable resistors, the pinnacle of their flexible integration technologies; 0.5 mm thick X, Y, and Z axis triaxial tactile film sensors; capacitance fluid-level sensors that can be installed on the outside of a container; and a fully printed sheet for biocompatible electrodes. Although these examples are not made using the latest technologies, they add a slight twist to screen printing and other existing technologies, which are then combined to produce previously unseen functions.

**Flexible Curved Surface Variable Resistors**

The company has positioned its XCS Series of curved surface variable resistors as the flagship product for its film integration technology.

Standard variable resistors are composed of a conductive metal brush (slider) that sits above a resistor printed as a line or as a circle using carbon ink. The position of the slider over the resistor changes the resistivity and partial pressure between the terminals, which is used widely as a means of adjusting sound volume, for example. Typically, resistors are formed on a flat, rigid substrate, but XCS Series’ resistors are printed on a PET film, which is molded as a single unit to allow the slider to run over a curved surface.

Mr. Hayashi explains that the company has provided variable resistors using a PET film substrate for some time. Rigid substrates will sometimes form burrs or debris at the edges during production, so they originally adopted flexible substrates instead as a way of improving reliability. As a secondary benefit, they found that PET made for thinner, lighter components as a whole. However, the goal of utilizing the flexibility of PET itself was something that they did not arrive at easily.

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**Flexible Curved Surface Variable Resistors**

The unit consists of A and C terminals fixed at the ends of a circular resistor and a B contact that can be moved to the desired position. The resistivity between terminals A and C is constant, while moving B changes the resistivity between A and B and between B and C as a function of the position ratio. In this case, running a current between terminals A and B will result in a high resistivity in the left figure and a lower resistivity in the right figure. Here, the output increases when the slider is turned to the left.

In addition, when power is applied to terminals A and C, the voltage of the plus and minus power source at contact B have a partial pressure proportional to the resistivity, allowing the position of B to be known from the partial pressure between A and B and between B and C. The XCS Series uses this mechanism.

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**Basic Variable Resistor Mechanism.**

Moving the Slider Changes the Partial Pressure Ratio of the Resistance and Voltage Between the Terminals
Although the XCS Series is a successful example that uses the flexibility of film in a variable resistor that can conform to curved surfaces, it is the only example of this type of integrated component available on the market.

The XCS Series is used today to detect the angle of rotating mechanisms. Specifically, these resistors are placed on the lens unit of digital cameras and single lens reflex cameras as a means of sensing the position of the focus, zoom, and aperture adjustors. Mr. Hayashi says that after releasing the XCS Series several years ago, the company has continued to see growing demand for this unique technology, particularly from camera manufacturers.

Attaching these resistors directly to the curve of the lens unit allows the photographer to directly know the precise angle of the lens as they turn it, thus enabling them to match the position to their visual sense. Until the XCS Series’ arrival, there were no variable resistors that could be applied to curved surfaces. As such, the angle was detected using a more complex, space-consuming mechanism. In contrast, the simple XCS Series configuration greatly reduces space usage and contributes to the improvement of lens performance.

The key to forming curved surface resistors was the carbon ink. Standard carbon ink is hard and will crack when bent, whereas softer carbon ink will wear down quickly when the lens is twisted and friction is generated between the ink and the metal brush, shortening the resistor’s life. As such, the company developed a high performance carbon ink that can withstand some degree of bending as well as withstand 100,000 revolutions worth of friction.

The current problem is finding applications beyond cameras, so the company is searching for other mechanisms that are similar to cameras. Given the basic configuration, the minimum curvature radius is typically 20 radians, but anything below this is not technologically difficult to achieve.

**0.5 mm Thick Triaxial Tactile Film Sensor**

The company’s triaxial tactile film sensor is used in a device composed of a rubber joy stick that sits over a printed electrode. In this case, the sensor is used to detect the strength and direction (X, Y, and Z) of the load applied to the joy stick. At only 0.5 mm thick, the sensor is still able to read the change in capacitance. The PET substrate is packaged with the various electronic components, which can be modularized for different applications. The sensor itself is being developed together with...
Meanwhile, the company also made modifications to how it packages electronic components on the PET film. Specifically, standard solder requires a temperature that is too hot for PET film, so they adopted low temperature solder. Mr. Hayashi explains that initially lead-free low temperature solder was developed to reduce damage to electronic components, so was not envisioned for use with PET film. As such, they had to make further modifications for low temperature soldering. For example, they had to optimize the anchorage of the solder paste because simply printing the low temperature solder paste does not produce a sufficient level of functionality.

A venture company having related technology. The sensor unit has the durability to detect more than 1 million times (4 N load), and has an operational temperature range of -40–85°C.

One application example is an analog pad as part of a 3D image display system produced for the company’s demonstrations. In this case, the joy stick is used to move a 3D character on the screen up, down, left, and right (X, Y directions), as well as to magnify the image (Z direction) by pressing down. Pressing down lightly moves the image slowly and pressing forcefully moves it quickly. Mr. Hayashi explains that there are plenty of other sensors with these functions, but what is unique in this case is the 0.5 mm thickness of the sensor and the fast response time. Moreover, because the sensor is made of film, the analog pad is less than 2 mm thick. This allows the sensor to miniaturize and lighten devices, where soldering allows the device to be modularized, thus improving the freedom of design and installation, as well as efficiently utilizing the sensor’s performance.

By combining the sensor with a touch screen display, one potential application is detecting the strength of the touch force used to modify text or images. Similarly, although robotic hand gripping force sensors or shoe sole sensors typically only detect force in the Z direction, combining this functionality with the X and Y axis might allow for completely new functionality.

The system consists of a triaxial tactile film sensor (left) and a controller in which the sensor is installed (right). By moving the joy stick in the middle up, down, left, and right, and by pressing down...
External Capacitance Fluid Level Sensor

Capacitance fluid level sensors that measure the surface level of a fluid typically require an electrode to be inserted into the container used to hold the fluid, which brings the electronics into contact with the fluid. In contrast, Mr. Hayashi explains that their capacitance fluid level sensor can be attached to the outside of the container instead, so is hygienic. Because the components are packaged on a flexible PET film, this sensor is also able to conform to the shape of the container.

In this case, the mechanism detects the fluid level from the change in capacitance of the air and the target fluid, and when the fluid surface reaches the height of the sensor sheet, the sensor lights up a low temperature solder packaged LED. The demonstration system consisted of three sensors attached to a container filled with water, where the topmost sensor played the role of a reference sensor. In this way, the mechanism prevents malfunctioning after initializing the fluid detection state, a problem for capacitance detection. For example, after the bottom sensor(s) detect the fluid level, if the power is turned off and on again, the sensor(s) will no longer be able to detect the change in capacitance and will not be able to determine that the fluid surface has reached their level. Using a reference sensor prevents such problems.

Moreover, they also adopted a circuit pattern (routing pattern) to prevent malfunctions caused by a change in capacitance as a result of some other part of the sensor being touched. A special piece of software allows the sensor to cancel out changes in capacitance to parts besides the sensor. These modifications reduce the risk of malfunction that occur when this type of sensor is installed on the outside of a container.

Screen Printed Sheets for Comfortable Biocompatible Electrodes

Recently, there has been rapid development of wearable sensing devices that are worn to detect bio-information, so one of the developmental problems is reducing the feeling of the device when attached to the body. In response, the company developed a screen printed sheet to fully cover biocompatible electrodes consisting of screen printed inks and interconnects. This newly developed sheet is made of a foamed material so that the finished product feels more comfortable to the touch. Mr. Hayashi comments that this was made possible by effectively using the ability of screen printing to print thick, layered materials.

The structure is composed of a silver paste electrode unit and signal line (conductive circuit) on a PET film, where the area around the signal line is covered in an electromagnetic shield and the unit as a whole covered in the foamed material. The shield layer blocks external noise to allow for stable detection of heart rates, for example. The unit is fully screen printed, so can be easily enlarged. The company has already produced two meter wide samples.