Printed Electronics

Takayuki Imai[1]

We have been manufacturing and selling membrane switches, as a herald of printed electronics, for approximately thirty years. This paper describes the trends of the membrane switches used in various markets and progressive printed electronics technologies such as advanced printing and surface mounting technologies.

1. Introduction—What is printed electronics?

A membrane wiring board consists of a thin polyester base film and screen-printed patterns of conductive inks, such as a silver ink, a carbon ink, and an insulation ink. A membrane switch consists of two membrane wiring boards facing each other and being isolated by an insulation film with holes called a spacer film. The contact electrode, a part of wiring patterns, on each board is located at the hole of the spacer and contacts with the other due to the deformation of the base film when the part is pushed. The part functions as an electrical contact of a switch. As the switches are produced in lots, the cost of the membrane switch is intrinsically low compared with combined discrete switches. Consequently, the most of switch arrays for keyboards for personal computers are membrane switches.

Printed electronics refers to a manufacturing technology of electronic circuits, sensors and devices by printing process. Recently, the development of active devices made by printing not only conductive inks and insulation inks but also semiconductor materials and/or lighting materials is being carried out. Some of national projects are under way in Europe, Korea, Taiwan and so on. In our country, Japan Advanced Printed Electronics Technology Research Association, abbreviated to JAPERA, has started operations in May, 2011. The target is to promptly commercialize printed electronics that allows producing flexible displays or flexible input devices while achieving energy-savings, resource-savings and high productivity.

Conventional manufacturing processes of electronic circuits or devices mainly include subtractive processes by photolithography, vacuum processes such as vacuum deposition and sputtering, and wet process such as etching and plating. Substituting a printing process consisting of full-additive, atmospheric pressure, and dry processes for the conventional processes will result in energy-saving, resource-saving, highly productive manufacturing processes. Printing methods include a screen printing, gravure printing, flexographic printing and ink-jet printing. Features of these methods are low equipment costs and low initial costs for masks or plates to achieve the products of new design. Moreover, a setup change to switch a manufacturing product to another is easy in printing process, compared with a wet process or vacuum process. Therefore, printed electronics is suitable for high-variety low-volume manufacturing, and it can bring an innovation in production of more and more diversifying electronic parts.

2. Fujikura's printed electronics products

Fujikura has started a production of membrane switches for keyboards for desktop computers by screen printing technology in the 1980's. Since then, the field of membrane switches has extended to interface panels for microwave ovens, keyboards for notebook computers and human-machine interface panels for audio and visual equipment such as digital still cameras and digital camcorders. We have achieved the world's first water-proof membrane switches for notebook keyboards. We have extended the uses of membrane wiring boards from contact switches to antennas to capacitance sensors to other applications. New uses also have expanded to many market fields such as personal computers, home appliances and automobiles. Some of the membrane wiring boards produced by Fujikura are introduced in this paper.

2.1 Membrane switch for digital appliance

We invented halogen-free flame-retardant resist coating ink in collaboration with Fujikura Kasei and achieved halogen-free, flame-retardant and polyester-based membrane wiring boards in 2003 for the first time in the world. Since then, the application range of membrane wiring boards has expanded to the fields of digital appliances besides computer keyboards, such as interface panels of digital still cameras and digital camcorders, sub-interface panels or LED indication panels of notebook computers and some applications in mobile phones and portable game machines.

1 Electronic Components R&D Center

The demand for high functionality and downsizing of the equipment has brought many difficult requirements for membrane wiring boards. We have developed small-diameter and high-durability through-hole interconnections for double sided membrane wiring boards, fine-pitch migration-proof connector terminals, high-durability printed sliding resistors and pressure-sensitive switches. Figure 1 shows an example of membrane wiring boards for digital appliances.

Regarding small-diameter and high-durability through-hole interconnections, we achieved a 0.25mm hole diameter, a 0.75mm land diameter and 10 times bending durability at the part of interconnection. They were achieved by precise hole punching process and low-cost hole filling process by screen printing. The through-hole structure is shown in Figure 2.

As described in 3.2, a surface mounting technology of various parts on membrane wiring boards have been established. High-accuracy printed resistors, embossing keys on polyester base film, board-to-board interconnections, light guiding with flexible films and membrane switch modules hybridized with mechanical parts have contributed to the extension of the market and to the enhancement of added value of membrane wiring boards.

2.2 *Capacitive touch sensor*

Capacitive touch sensors are widely used as input interfaces for notebook computers and audio and visual equipment. A capacitive touch sensor typically consists of multi-layered and highly precise X, Y matrix electrode patterns and wiring patterns connecting them. Fig. 3 As for a conventional technology, a capacitive touch sensor is made of a conventional rigid wiring board made by a subtractive process. We have succeeded in replacing it with a lower-cost and thinner membrane wiring board by utilizing a highly precise printing technology. We also achieved a precise multi-layer printed circuit by using a new conductive ink with a suitable rheology for high-resolution pattern printing and insulation ink with a suitable surface characteristics. In addition, we established extremely high interlayer positioning accuracy for multi-layered conductive patterns and precise capacitance control and measurement. These technologies enables capacitive touch sensors to reduce the size and cost by replacing subtractive rigid wiring boards with membrane wiring boards.

2.3 *Human body detection*

Contact switch arrays and capacitance sensors with printed electrodes are utilized in detecting the existence or size of a human in the automotive, medical or nursing field. As an example, Figure 4 shows a human detection sensor utilized for a seat belt reminding system in an automobile. The sensor is installed in a passenger seat. The device detects the existence of a passenger when determining the pressure excerted by him/her sitting on the seat and brings it into continuity. The operation mechanism of the switch is the same as described for the membrane switch. Because some of the contacts are connected serially, the circuit turns ON only when two or more contacts are pushed. Optimized combination of these contacts enables the system to detect a person in any posture or weight and to minimize detection errors due to mixup between luggage and a person. Membrane wiring boards consist of a low-cost polyester base film is suitable for these kinds of applications, because a relatively large base film is necessary for human body detection.

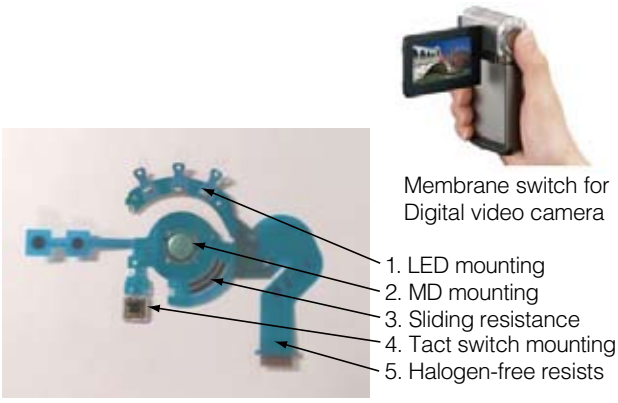
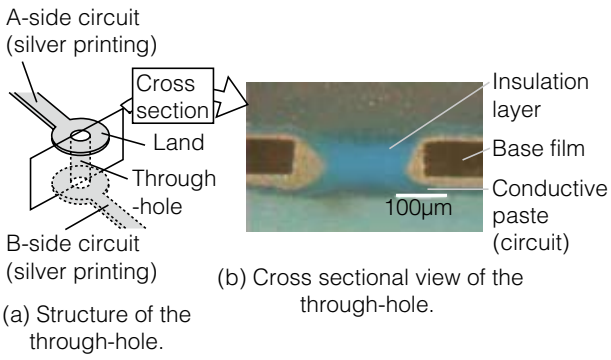


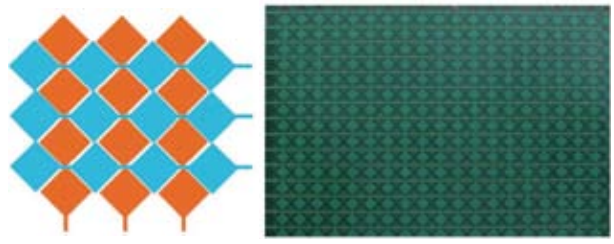
Fig. 1. An example of membarane switches for digital appliance.



(a) Structure of the through-hole.

(b) Cross sectional view of the through-hole.

Fig. 2. Structure of the through-hole.



(a) Electrode Pattern of Capacitive Touch Sensor

(b) Photograph of Capacitive Touch Sensor

Fig. 3. An example of capacitive touch sensors

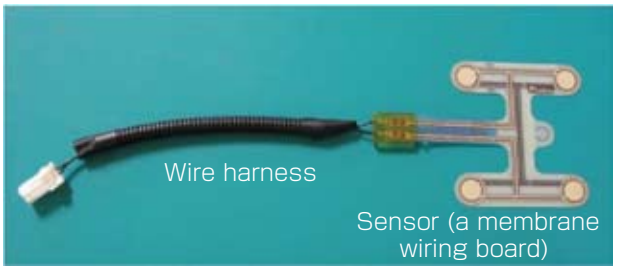


Fig. 4. Occupant detection sensor for seat-belt reminder system

In these applications, as shown in Figure 4, a membrane wiring board is often connected to a wire harness for transmitting signals from a sensor to signal processing system. One weak point of membrane wiring boards was the difficulty of connecting wires because the heat resistance of polyester base film is too low to solder the wire to it. It was also difficult to obtain long term durability with a normal mechanical crimping method because a ink-printed circuit is easy to deform or be damaged due to pressure from a crimping terminal. To solve the challenges, we have already established a pressure welding method and a water-proof housing structure, which is highly durable even under severe environments. The connection structure has presented no trouble for over 10 years for automotive use.

3. Printed electronics technology of Fujikura

3.1 Highly precise printing technology

Membrane wiring boards are produced by screen printing technologies as described above. We have established high resolution screen printing technologies of line 75μm and space 75μm (L/S=75μm/75μm). There have been problems of deformation and haze of the base filme caused by heat during curing ink. By utilizing a roll-to-roll screen printing line equiped with an original transferring system of films and an original drying and curing system of ink, we have achieved pattern formation on 12-μm-thick base film and highly accurate printed multi-layer circuit. Moreover, because haze generation on polyester film can be suppressed by using the original transferring system and the original drying and curing system, membrane wiring boards have been available for the application which requires high transparency of the base film, such as film antenna attached onto a window.

There have been some reports on trials to obtain higher resolution in screen printing and to substitute membrane wiring boards for subtractive flexible wiring boards. Extremely high resolution around L/S=30μm/30μm has already been reported as well trial production of organic thin film transistor arrays by combination of a screen printing method and a different printing method. While we are also making challenge toward the higher resolution by screen printing,

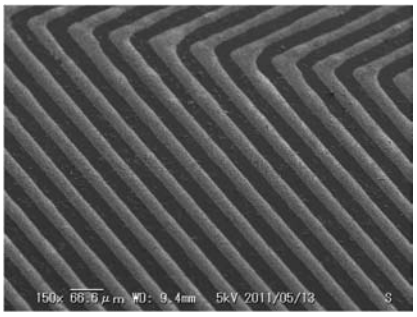
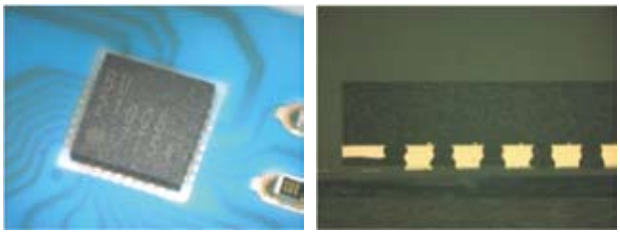


Fig. 5. Ultra-fine printed circuit (L/S=30μm/30μm)



(a) Appearance (b) Cross-section

Fig. 6. IC chip mounting.

we are challenging L/S=30μm/30μm or finer in another printing method, as shown in Figure 5. We are preparing for the demand in the printed electronics market which may glow drastically in near future.

3.2. Surface mounting technology on membrane wiring board

We have established a surface mounting technology of resistors, capacitors, LEDs and ICs with conductive adhesive ahead of our competitors, manufactured and sold printed circuit boards with surface-mouted components. Mounting process using conductive adhesive has strong points such as low impact on the environment and high durability against thermal stress because of the low modulus of the adhesive. On the other hand, it has weak points as follows.: Electrical shorts caused by adhesive bridges between lands easily occurs because the conductive adhesive is apt to run off and thus cannot be selectively applied to lands in contrast to solder. In addition, because of its lower adhesion compared with solder, mounted parts need to be reinforced or encapusulated by resin in an additional process. With surface mounting technology, Fujikura has commercialized membrane wiring boards using low-melting-point solder containing resin that we developed in collaboration with TAMURA Corporation ahead of all others in the industry. Optimizing the reflow conditions and other improvements resulted in reducing costs of the product compared with that using a conductive adhesive as well as ensuring the solder's high connection reliability and high adhesion. This technology enabled savings in mounting space and mounting of special shaped parts or parts with a narrower terminal pitch on membrane wiring boards, which had technical difficulties. An example of a mounted IC chip is shown in Figure 6. The application

range of membrane wiring boards has been expanding thanks to this technology.

3.3. Material technology

As described in 3.1, membrane wiring boards require higher resolution and higher circuit density than ever before. Narrower circuit widths, however, may cause higer circuit resistance. In order to solve the problem, we have developed a silver oxide conductive ink which can be reduced and sintered at a low temperature in collaboration with Fujikura Kasei and have succeeded in lowering circuit resistance by an order of magnitude. This ink has been used for film antennas for automobiles. The narrower the circuit gaps are, more easily ion migration phenomenon occurs. The phenomenon is one of the biggest issues in printed electronics, because silver atoms are subject to it. The other problem of silver is its high and unstable price. From these points of view, the development of substitutions for silver inks such as copper nano inks is actively done in the world. Fujikura also is making efforts to develop it in collaboration with material suppliers.

Improvement in printing productivity is one of the tasks for printed electronics. To achieve high speed printing practically, curing process of ink must become faster as well. We have developed a silver ink cured in an extremely short time by electron beams in collaboration with Goo Chemical and have succeeded in obtaining printed circuits available for actual use. This technology must be the key to the progress of printed electronics.

4. Conclusion

This paper introduces our current products and development efforts toward printed electronics. The printed electronics is expected to expand into a market of billion dollars by 2015. However, there still remain many technical issues, and the practical applications are still unclear. We are going to solve these issues through industry-academia collaboration or collaboration among different industries.