RECENT PROGRESS OF WIRELSS TRANMISSION SYSTEMS USING PRINTED PLASTIC MEMS SWITCHES AND ORGANIC TRANSISTORS

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Abstract: We have successfully developed the sheet-type wireless power transmission system, which is based on printed organic transistors and printed MEMS switches. This is the new approach to feed power to electronic devices by placing them on a sheet or pad, with no wires or chargers needed. The 1-mm-thick flexible sheet weighs 50 g. It contains an 8 × 8 cell array comprising both position-sensing and power transmission units. The position of an object is sensed by electromagnetic coupling, using an organic active transistor matrix. Power is fed to it inductively, by an array of copper coils driven by a printed plastic MEMS-switching matrix. Since all the components are manufactured on plastic films, the system is thin, lightweight, and mechanically flexible. It is easy to place the wireless power transmission sheet on walls, ceilings or in imaginative locations, opening up new ways to interact with electronic products.

Key words: wireless power transmission, printed organic transistors, plastic MEMS switches

1. INTRODUCTION

Ubiquitous electronics or ambient intelligence is attracting attention because of its potential to open up a new class of applications. We demonstrated the first implementation of a large-area wireless power transmission system. The system realizes a low-cost sheet-type wireless power source of about 30 W. This is the first step toward building infrastructure for ubiquitous electronics where multiple electronic objects are scattered over desks, floors, walls, and ceilings and need to be powered. These objects may be mobile or located in the dark and therefore solar cells cannot be used to power them. On the other hand, the periodic replacement of the primary batteries could be tedious since there may be too many objects. The proposed wireless power transmission sheet may directly drive electronic objects and/or charge a rechargeable battery in the objects without a connector, thereby providing an easy-to-use and reliable power source.

The sheet-type large-area wireless power transmission system (Fig. 1) has been manufactured using organic transistors and MEMS switches. Although some existing systems have already used wireless power transmission, it has been difficult to transmit high-power to anywhere one likes over wire area. For example, weak power can be fed to IC cards relatively large area, while a fairly large power can be fed to electric tooth brushes at the exact mount position. The present method makes it possible to transmit high power to anywhere over large-area by "spatial subdivision". In this way, the system selectively feeds power as high as 30 W to electronic objects placed upon it.

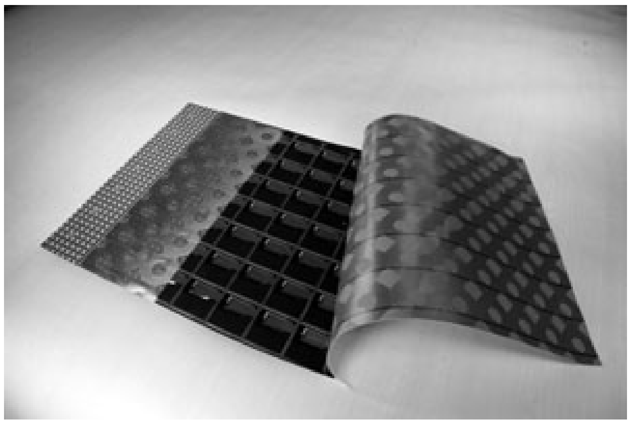

Fig. 1: An image of the manufactured sheet embedded on the floor.

Organic semiconductor technology relies on carbon-based material. Organic semiconductor devices cannot reach the high-speed performance of their silicon counterpart, but their fabrication cost is much lower and they are better-suited for fabrication on large-area, flexible plastic substrates. They can also be conveniently manufactured at ambient temperature on plastic films using printing and/or roll-to-roll processes. Applications in flexible displays (1,2) and printable wireless tags (3) have been the main motivation behind recent efforts for the development of organic transistors. Our group demonstrated another promising application, large-area, flexible sensors and actuators; an electronic artificial skin for future generations of robots (4,5), a sheet-type image scanner (6) and a sheet-type Braille display for blind people (7).

In the new development of large-area electronics, we have successfully demonstrated the sheet-type large-area wireless power transmission system using printed organic transistors and printed MEMS switches. The 1-mm-thick flexible sheet weighs 50 g. It contains an 8 × 8 cell array comprising both position-sensing and power transmission units. The periodicity is 1 inch.

The position of an object is sensed by electromagnetic coupling, using an organic active transistor matrix. Power is fed to it inductively, by an array of copper coils driven by a printed plastic MEMS-switching matrix. Because the power transmission only occurs selectively when an object is sensed, net power-coupling efficiency is 81.4%. Power levels as high as 40.5 W have been transferred in this fashion.

2. MANUFACTURING PROCESS

The new system comprises organic transistors and sheet-type MEMS switches, both of which can be manufactured by printing technologies and, therefore, the large-area system is potentially inexpensive. Organic transistors realize a contactless position sensing system: Organic transistors quickly scan the position of an object without switching high power. In contrast, sheet-type MEMS switches may be slow, but these realize a high power switching.

Wireless power transmission sheet comprises sheets of the printed MEMS-switching matrix and power transmission coil array, as shown in Fig. 2 (a). A MEMS-switching matrix is manufactured using an inkjet printing machine. The electrodes for power transmission and for electrostatic attraction are patterned on a 75-μm-thick polyimide film. The through holes are made by a CO_2 laser and filled by Ag nanoparticles by inkjet for interconnections. The MEMS-switching matrix has the periodicity of 25.4 mm, and composes 8 × 8 array.

Power transmission coil array is manufactured using screen printing and a numerically controlled (NC) drill machine. A poly(ethylene naphthalate) (PEN) film, whose both sides are coated with 12-μm-thick Cu, is covered with etching resist paste using screen printing, and coils and bit-lines were formed by etching. Through-holes are made using a fine NC drill machine and plated with Ag solder to form interconnections. The power transmission coil array comprises copper coils with an inner diameter of 10 mm and an outer diameter of 1 inch.

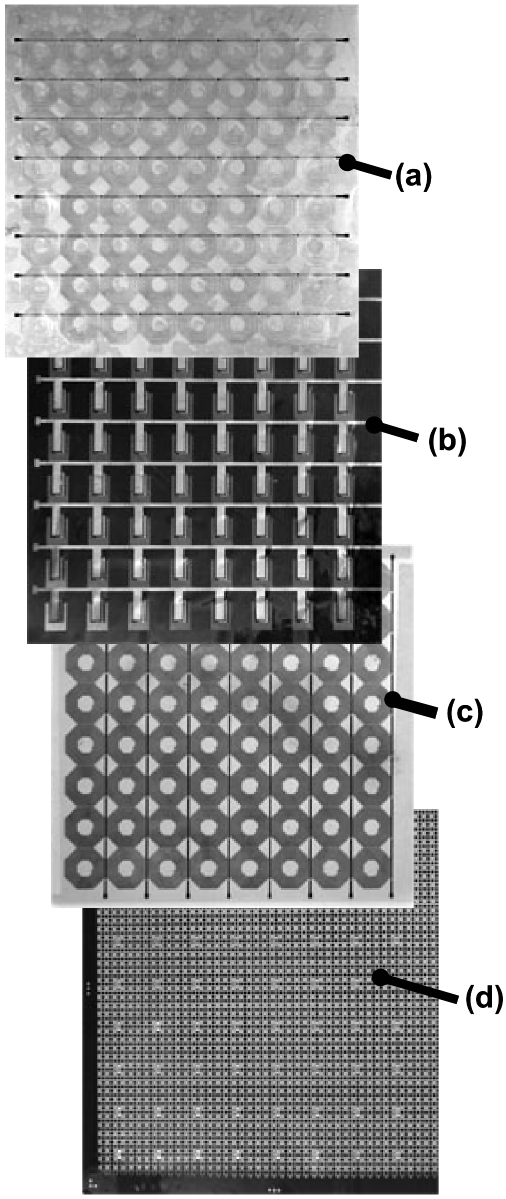

Fig. 2: An assembly of the wireless power transmission sheet, comprising wireless power transmission system (a and b) and contactless position-sensing system (c and d). (a) The coil array for the power transimission , (b) printed MEMS switches, (c) the coil array for position sensing, and (d) printed organic TFTs. The size of all sheets is 21 × 21 cm^2.

Contactless position-sensing sheet comprises sheets of the position-sensing coil array and organic FET active matrix, as shown in Fig. 2 (b). Organic FETs are manufactured using inkjet, screen printing, and vacuum evaporation. The base film is a 75 μm thick polyimide film. Ag nanoparticles are patterned using inkjet and cured in 180 °C to form a 300-nm-thick gate electrodes and word-lines. Epoxy partitions are formed using screen printing around gate electrodes. Diluted polyimide precursors are inkjetted and cured at 180 °C to form 1-μm-thick polyimide gate dielectric layers. A 50-nm-thick pentacene layer and a 50-nm-thick gold layer are deposited using vacuum evaporation through the shadow masks to form a channel layer and source and drain electrodes, respectively. The channel length (L) and width (W) are 13 μm and 48 mm, respectively. Finally, a 8-μm-thick poly-chloro-para-xylylene (parylene) is uniformly coated to form an passivation layer. Each via interconnection is made using a CO_2 laser. Fabrication process is described in ref. 8.

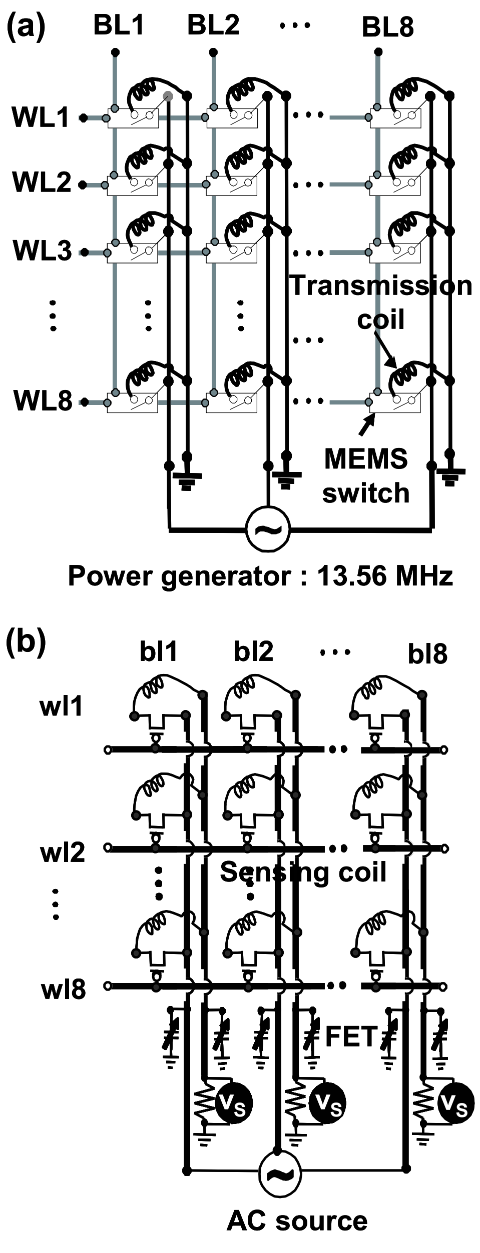

Fig. 3: The circuit diagrams of (a) wireless power transmission system and (b) contactless position-sensing system.

Position-sensing coil array is also manufactured using screen printing. The fabrication process is completely the same as that of power transmission coil array. The inner and outer diameters of the copper coils are 10 mm and 1 inch, respectively.

3. POWER TRANSMISSION

We first characterized the contactless position-sensing system (9). The pentacene transistors exhibit mobility of 1 cm^2/Vs and an on/off ratio of 10^5. The electrical performance is characterized at a resonance frequency (2.95 MHz) of this position-sensing system. A voltage of±10 V at 2.95 MHz is applied to the position-sensing cells. Figure 4 shows Vs as a function of the vertical distance between the position-sensing coil and the receiver coil. As the receiver coil approaches to the position-sensing coil, output voltage decreases and the change reaches 91% at the distance of 1 mm, demonstrating the excellent functionality of the present contactless position-sensing system.

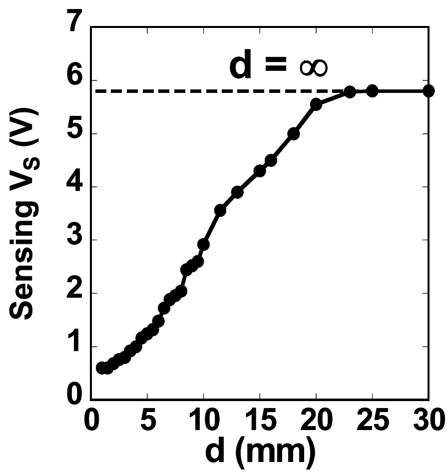

Fig. 4: Detected voltage (Vs) as a function of the vertical distance between the position-sensing coil and the receiver coil.

The electrical performance of the wireless power transmission sheet is characterized at a frequency of 13.56 MHz. Figure 5 shows the transmission efficiency and received power at receiver coils as a function of sending power. With increasing sending-power, received power linearly increases, and maximum transmitted power is achieved to be 40.5 W. On the other hand, transmission efficiency is almost constant which is achieved to be 81.4%. Further sensing power results in disconnection of power transmission electrodes formed using inkjetted Ag nanoparticles.

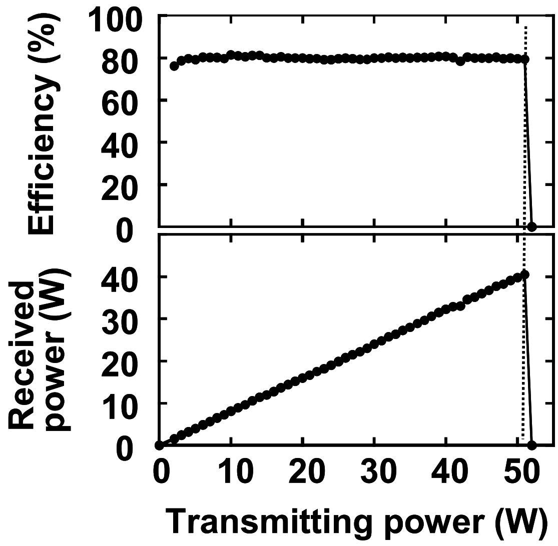

Fig. 5: Transmission efficiency and received power at receiver coils as a function of sending power.

4. MEMS SWITCHES DRIVEN AT 6.6 V

The operation voltage of plastic MEMS switches was relatively high (50−100 V) and the frequency response was typically of the order of 1 Hz. Therefore, a reduction in the operation voltage and improvement in frequency performance are desirable for many practical applications. Recently we have fabricated plastic MEMS switches using an inkjet printing technology and characterized the operation voltage and frequency response (10,11). By reducing the device dimensions, an operation voltage of 6.6 V has been successfully achieved (Fig. 6). When the operation voltage is increased, the frequency response improves significantly, and it exceeds 1 kHz at an operation voltage of 20 V or more.

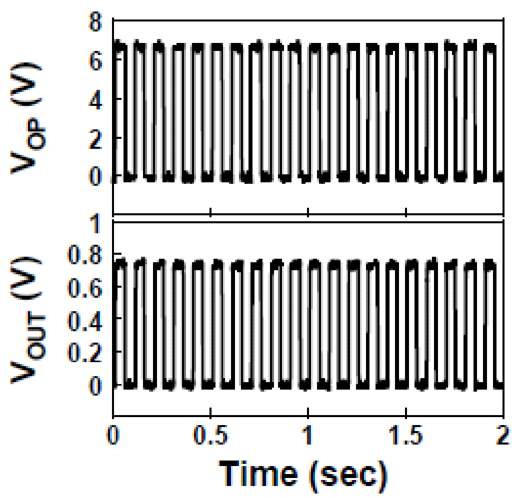

Fig. 6: Input output characteristics of printed plastic MEMS switches at operation voltage of 6.6 V.

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