A large-area flexible wireless power transmission sheet using printed plastic MEMS switches and organic field-effect transistors

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Abstract

We have successfully manufactured a large-area *power transmission sheet* by using printing technologies. The position of electronic objects on this sheet can be contactlessly sensed by electromagnetic coupling using an organic transistor active matrix. Power is selectively fed to the objects by an electromagnetic field using a plastic MEMS-switching matrix.

Introduction

Ubiquitous electronics or ambient intelligence is attracting attention because of its potential to open up a new class of applications. This paper reports the first implementation of a large-area wireless power transmission system (Fig. 1) using organic transistors (1-9) and MEMS switches. The system realizes a low-cost sheet-type wireless power source of more than several watts. 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 *wireless power transmission sheet* has been manufactured on a plastic film by using printing technologies. The effective power transmission area is 21×21 cm^2. The sheet contains a two-dimensional array of 8×8 cells comprising position-sensing and power transmission units. The position of electronic objects on the sheet can be contactlessly sensed by electromagnetic coupling using an organic transistor active matrix. Then, power is selectively fed to the objects by an electromagnetic field using a two-dimensional array of copper coils that are driven by a printed plastic MEMS-switching matrix. Due to selective power transmission, we achieved a coupling efficiency of power transmission of 62.3%, and a power of 29.3 W was wirelessly received. The thickness and weight of the entire sheet are 1 mm and 50 g, respectively.

Device manufacturing process

The entire system comprising 8×8 cells is manufactured by integrating the position-sensing and power transmission sheets, as shown in Fig. 1. The periodicity is 25.4 mm.

The contactless position-sensing sheet (Fig. 2) comprises sheets of the position-sensing coil array and organic FET active matrix.

<u>An organic FET active matrix</u> is fabricated on a polyimide film. Silver gate electrodes and polyimide gate dielectric layers are patterned by using inkjet printing. A pentacene channel layer and gold source/drain electrodes are deposited in a vacuum. The channel length and width are 13 μm and 48 mm, respectively.

<u>A position-sensing coil array</u> is manufactured by screen printing. The inner diameter of the copper coils is 10 mm. Both the width and spacing of the copper lines are 100 μm. The number of turns is 38. The inductance and resistance are 20 μH and 17 Ω, respectively.

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The power transmission sheet (Fig. 3) comprises sheets of the printed MEMS-switching matrix and power transmission coil array.

A MEMS-switching matrix is formed by using inkjet printing and screen printing. The electrodes for power transmission and those for electrostatic attraction are patterned on a 25-μm-thick polyimide membrane.

The power transmission coil array comprises copper coils with an inner diameter of 10 mm. Both the width and spacing of the copper lines are 300 μm. The number of turns is 13. The inductance and resistance are 3 μH and 1 Ω, respectively.

Device characteristics

The contactless position-sensing sheet (Fig. 4): The pentacene transistors in DC characterization exhibit mobility of 1 cm^2/Vs and an on/off ratio of 10^5. A voltage of ±10 V at a resonance frequency (2.95 MHz) is applied to the position-sensing cells. The on/off ratio of the transistors at 2.95 MHz exceeds 500. When the distance between the position-sensing coil and the receiver coil reduces, the change in output voltage increases and reaches 91%.

A stand-alone plastic MEMS switch (Fig. 5) is characterized. When 70 V is applied to the electrodes for electrostatic attraction, the resistance changes from $>10^6$ Ω to 15 Ω and the frequency response extends up to 4 Hz. After 300,000 switching cycles, the change in the resistance of the MEMS switch is below 5%.

The power transmission sheet (Fig. 6): Wireless power transmission is performed at 13.56 MHz. The on/off ratio of the MEMS switch in power transmission exceeds 700. We achieve a coupling efficiency of 62.3%, and a power of 29.3 W was wirelessly received. The variation in the power efficiency is less than 5% among the 8 devices on the same line.

Demonstration of power transmission: Figure 6 (f) shows the power transmission to a Christmas tree decorated with twenty-one light-emitting diodes that require a power of 2 W.

Acknowledgements

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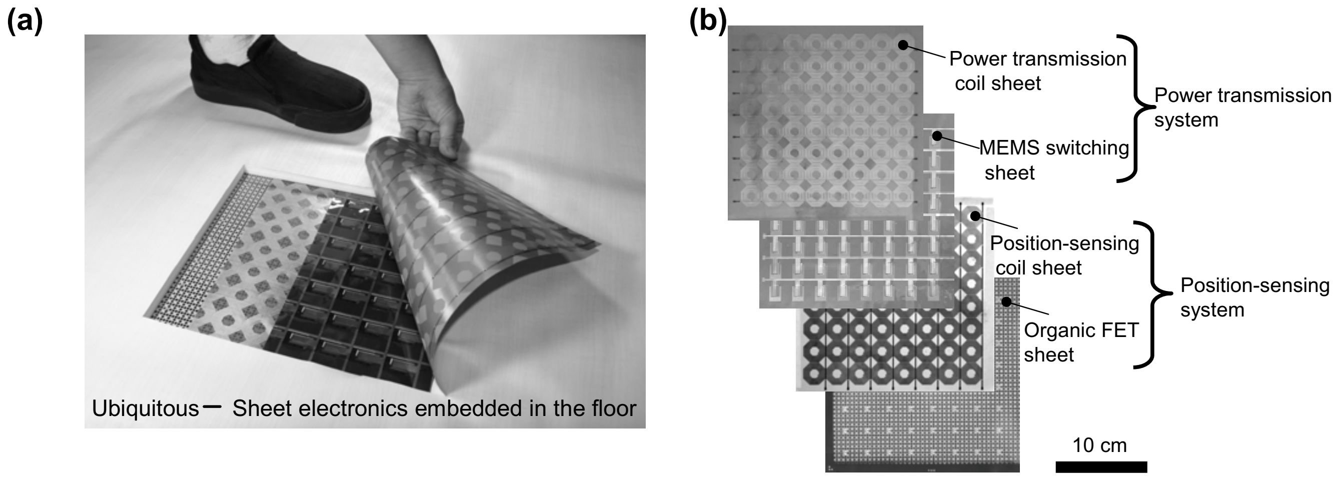

Fig. 1: ***Wireless power transmission sheet.*** (a) An image of the world's first large-area *wireless power transmission sheet* embedded in the floor. A part of the cover layer is peeling off. (b) A picture of the device assembly comprising a power transmission system driven by an 8 × 8 MEMS-switching matrix and a position-sensing system driven by an 8 × 8 organic FET active matrix. The power transmission area is 21 × 21 cm^2.

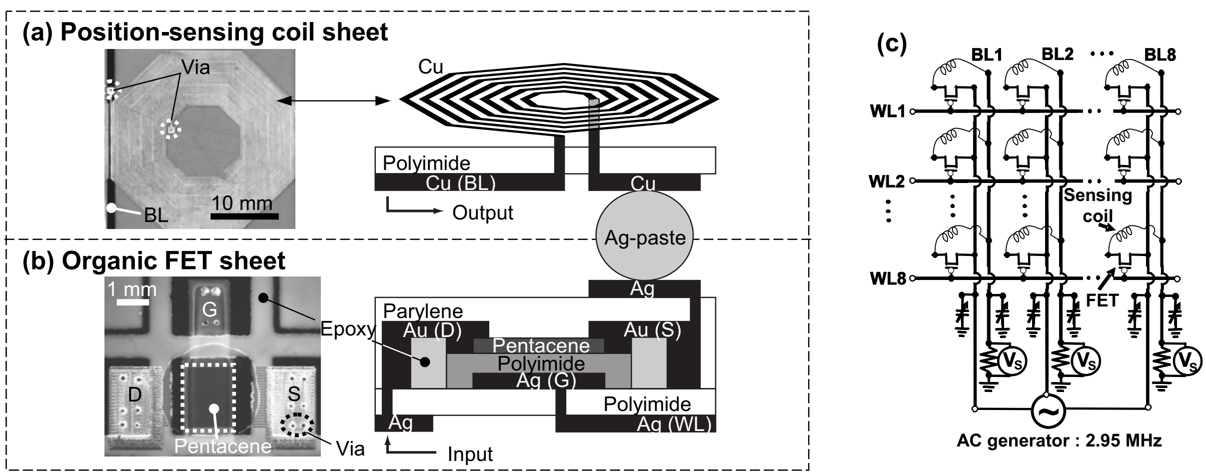

Fig. 2: The contactless position-sensing sheet comprising (a) position-sensing coil sheet and (b) organic FET sheet. Pictures and cross-sectional illustrations are shown. S, D, and G represent the electrodes for source, drain, and gate, respectively. The organic FET sheet is laminated with the position-sensing coil sheet using silver paste islands. (c) The circuit diagram of the position-sensing sheet. A resonance frequency of 2.95 MHz is used in the position-sensing system. WL and BL represent word-line and bit-line, respectively.

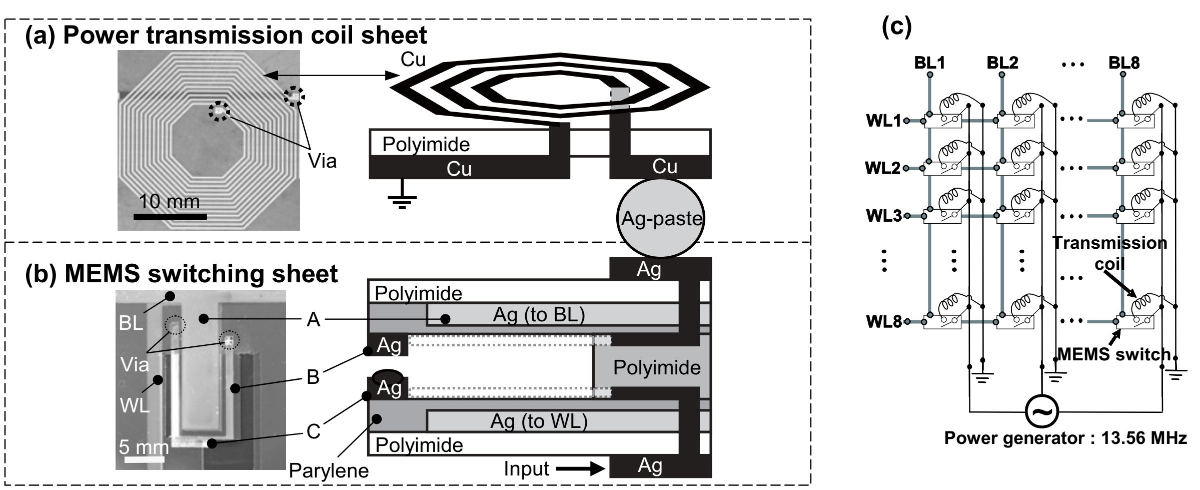

Fig. 3: The power transmission sheet comprising (a) power transmission coil sheet and (b) MEMS switching sheet. Pictures and cross-sectional illustrations are shown. A: Electrodes for electrostatic attraction connected to the word-line (WL) and bit-line (BL) of MEMS switch. B and C: Electrodes for power transmission connected to coils and a power generator. (c) The circuit diagram of the power transmission sheet. A frequency of 13.56 MHz is used in the power transmission system.

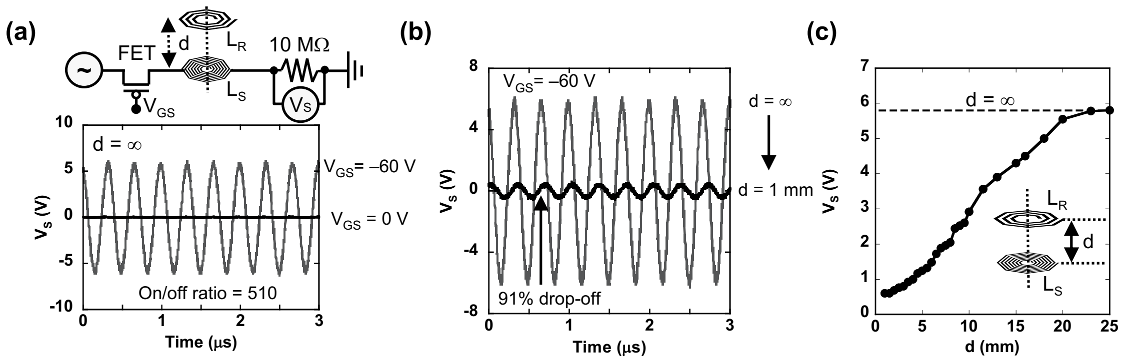

Fig. 4: Position sensing. (a) Detected voltages (V_S) at gate voltage (V_{GS}) = –60 V and 0 V, where vertical distance d between the position-sensing coil (L_S) and the receiver coil (L_R) is infinite (∞). A voltage of ± 10 V at a resonance frequency (2.95 MHz) is applied to the position-sensing cells. (b) V_S at d = ∞ and 1 mm, where V_{GS} of –60 V is applied. V_S decreases as L_R approaches because of electromagnetic coupling. (c) V_S is shown as a function of d. A change in V_S of 91% is attained at d = 1 mm. The dashed line represents the voltage at d = ∞.

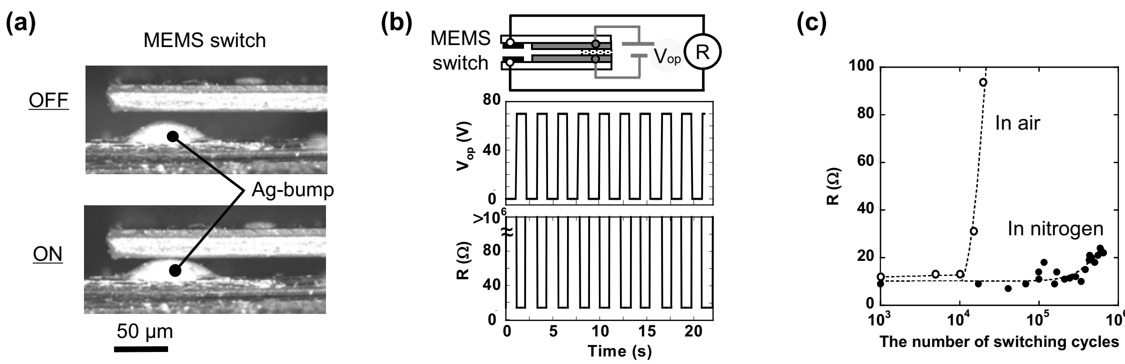

Fig. 5: Stand-alone plastic MEMS switch. (a) Micrograph of cross-sectional surface of MEMS switch. Top electrodes for power transmission are connected to bottom electrodes when the operation voltage (V_{op}) is applied to electrodes for electrostatic attraction. (b) When a rectangular wave of V_{op} = 70 V is applied to the MEMS switch, the resistance changes from >10^6 Ω to 15 Ω and the frequency response extends up to 4 Hz. (c) MEMS switch resistance is shown as a function of the number of switching cycles.

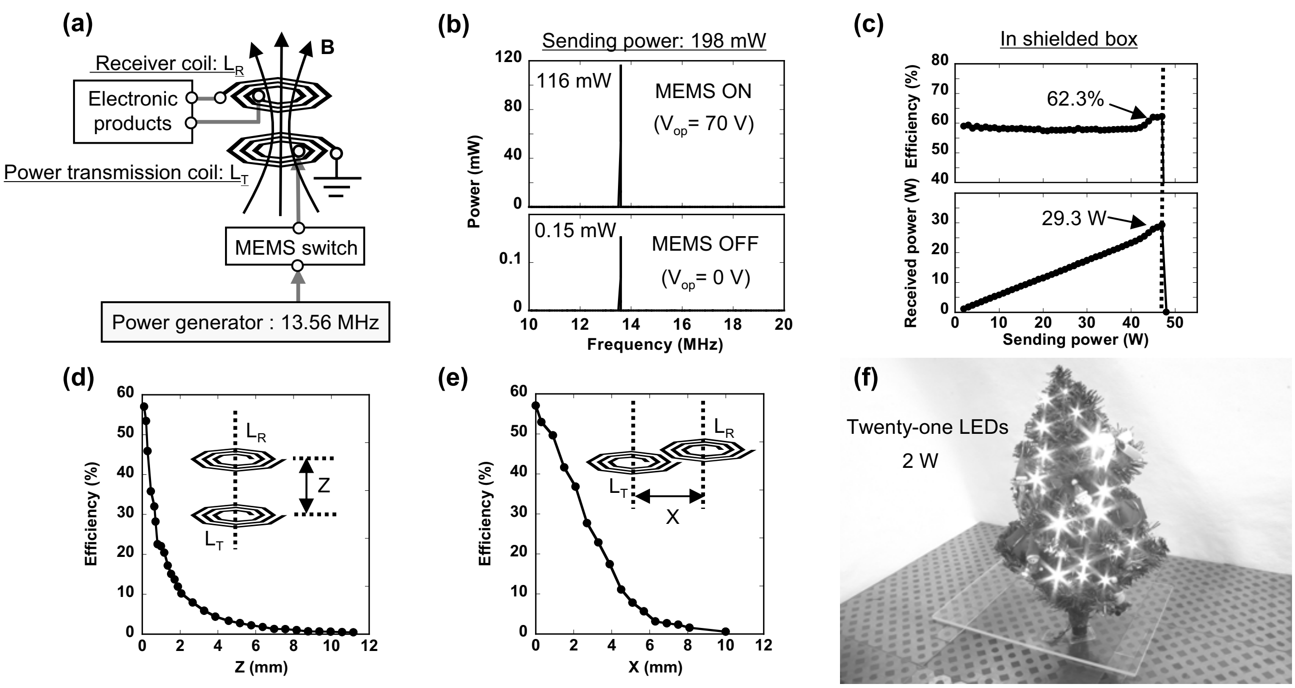

Fig. 6: Power transmission. (a) Schematic illustration of the power transmission system. (b) Power at the receiver coil (L_R) is shown with the MEMS switch operation voltage (V_{op}) of 70 V and 0 V. Sending power of 198 mW and frequency of 13.56 MHz are applied from the power transmission coil (L_T). (c) The power efficiency and received power are shown as functions of the sending power. The dashed line represents the power at which the MEMS switch is broken. (d) and (e) The power efficiency is shown as a function of vertical distance Z and horizontal distance X between L_T and L_R. (f) Demonstration of power transmission to a Christmas tree decorated with twenty-one light-emitting diodes (LEDs) that require a power of 2 W. The space between the power transmission coil and the receiver coil is 5 mm.