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Katsuaki Suganuma

Introduction to Printed Electronics

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Chapter 1
Introduction

1.1 Printing Technology in Electronics Manufacturing

Printed electronics (PE) has emerged as one of the key technologies not only for electronics but also for all kinds of electrically controlled machines and equipment. PE is a technology that merges electronics manufacturing and text/graphic printing. By this combination, one can manufacture high-quality electronic products that are thin, flexible, wearable, lightweight, of varying sizes, ultra-cost-effective, and environmentally friendly. All these features reflect the deep involvement of engineers in the development of PE technology.

This blended technology is, however, not new; it originated before the 1950s. Back then, some people started using printing to make circuits on printed wiring boards. In fact, there are reports on printing solutions for wiring in the 1950s. Figure 1.1 shows an example [1]. The researchers of Nippon Telegraph and Telephone found gravure printing was one of the promising printing methods for fine pitch accuracy. Nevertheless, printing did not emerge as the ultimate solution for wiring; the lithography of copper films bonded on glass-fiber-reinforced organic printed wiring boards came to be the standard technology for wiring board assembly. At the same time, ceramic substrate wiring boards processed by screen printing, though they had been in use in the production of ceramic packaging for one generation, is only a minor presence in the printed wiring board market, especially for server applications.

The next printing solution was displays. Shadow masks of TV cathode tubes had been fabricated by the combination of printing and etching. Fine pitch printing of original masks, down to 100 μm, was crucial for manufacturing fine display panels. Nowadays, flat panel displays, such as liquid crystal displays (LCDs) and plasma displays, are replacing cathode tube displays. LCDs in particular have become the main standard display technology. Such flat panel displays are also assembled with coating and printing processes.

On the other hand, ceramic passive components, such as capacitors, resistors, and antennas, required a fine printing process. Gravure printing and screen printing have been widely used for the production of ceramic passive components. Figure 1.2

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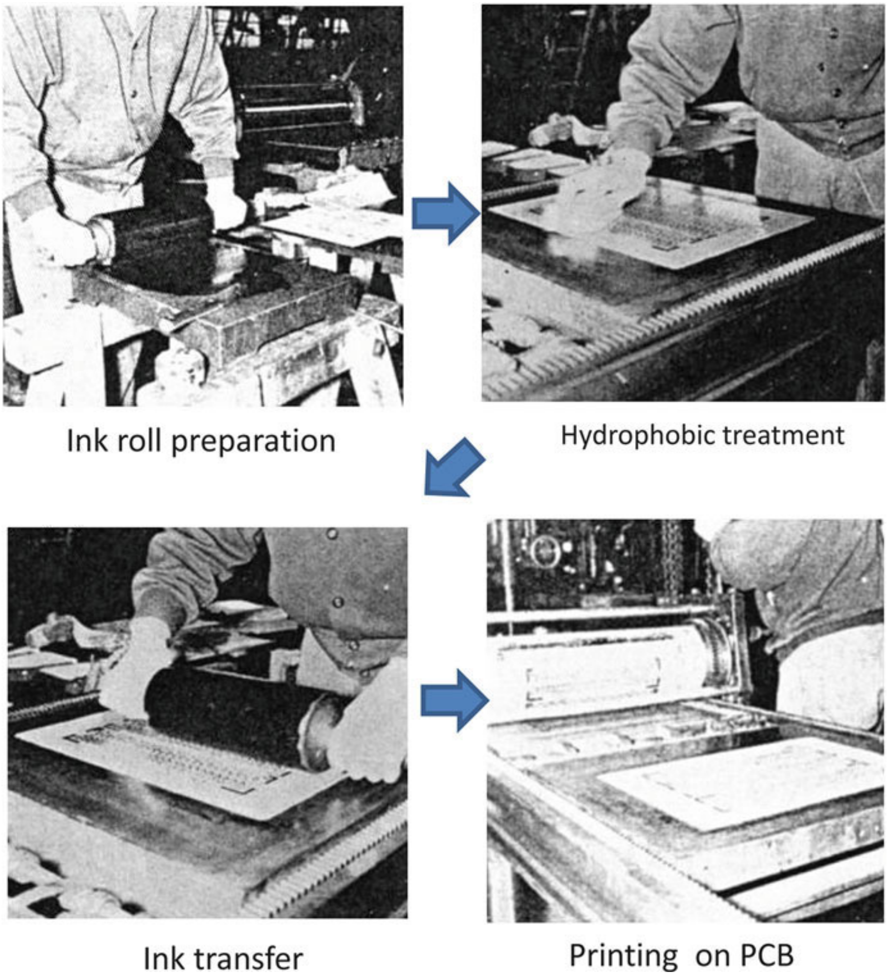

Fig. 1.1 Offset gravure printing of printed circuit board at Nippon Telegraph and Telephone, Tokyo, Japan [1]

shows a typical roll-to-roll screen printing of ceramic capacitors. Today, billions of tiny chip components, of which the smallest size is 0.4×0.2 mm, are manufactured continuously with Ni nanoparticle ink on ceramic green sheets.

Another example is solar cells. Solar cells based on Si technology also require screen printing and ink-jet printing in their manufacturing process. Finger grid lines and bus lines are formed by screen printing with Ag pastes containing glass flits (Fig. 1.3). The back plane contact is also formed by screen printing Al pastes. In addition, ink-jet printing is usually applied to form a doping line beneath the Ag lines on front planes.

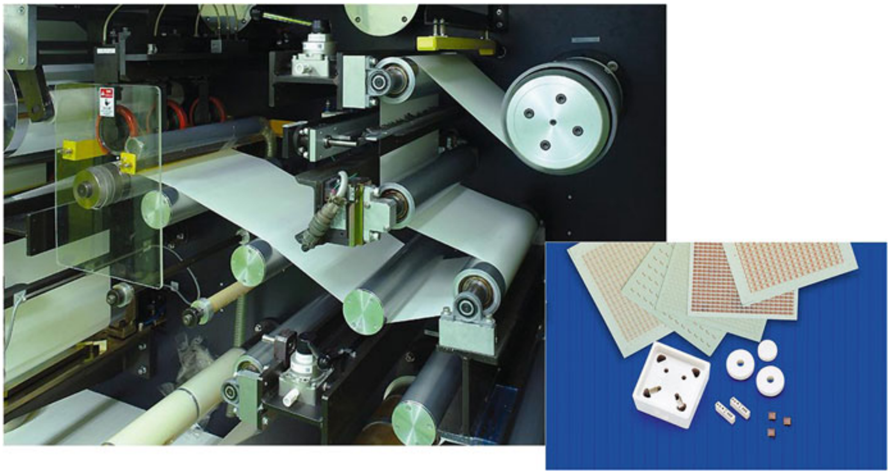

Fig. 1.2 Fabrication of ceramic capacitor on substrate green sheet by roll-to-roll screen printing (Courtesy of Murata Manufacturing, Kyoto, Japan)

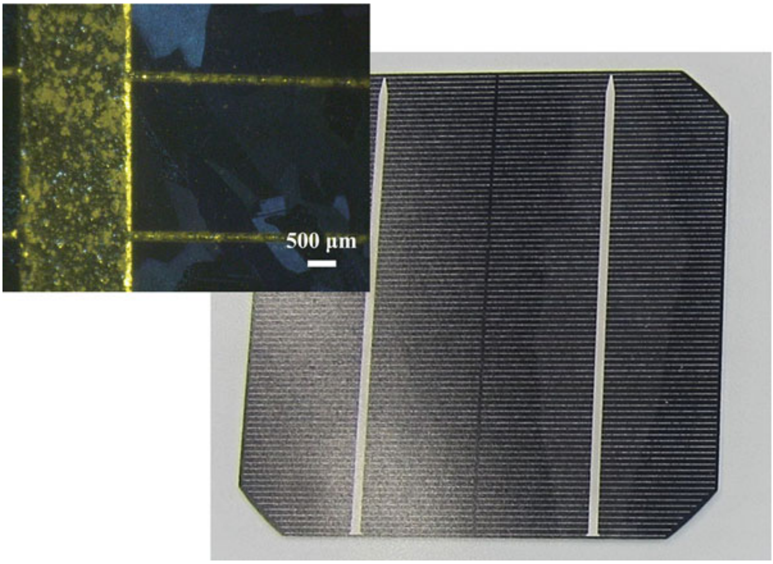

Fig. 1.3 Si solar panel and printed Ag paste grid and bas-bar

Most current electronics products possess surface-mount-type printed circuit boards that require wiring and soldering as one of the essential technologies. In soldering especially, the quality of screen printing of solder pastes plays a key role in the manufacture of small and high-functional products. Today, the smallest solder interconnection size comes in at below 100 µm. Figure 1.4 shows such a fine printed

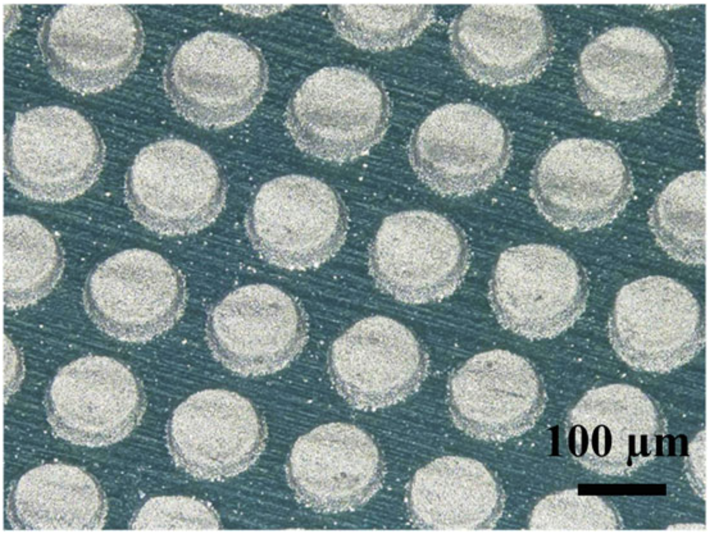

Fig. 1.4 Fine pitch solder bumps printed by screen printing (Courtesy of Harima Chemical, Hyogo, Japan)

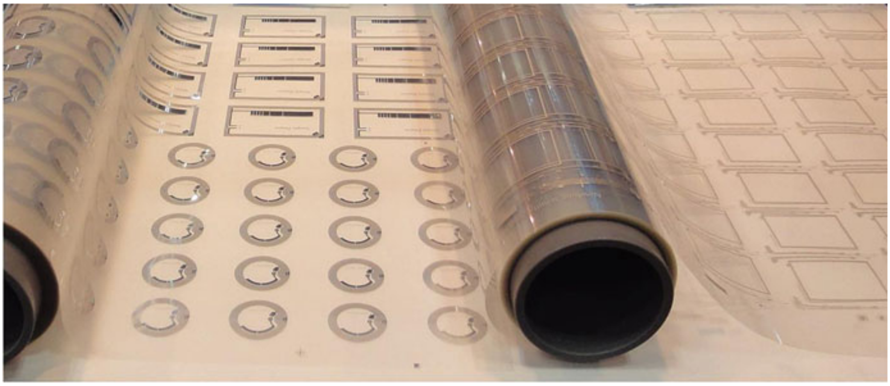

Fig. 1.5 RFID antenna and touch panel wiring with Ag-based conductive adhesive on PET film by rotary screen printing

solder paste on a printed circuit board. In some applications, conductive adhesives are used instead of solder pastes. For printed electronics, conductive adhesives, whether conventional micron-sized metallic flake pastes or newly developed nanoparticle pastes, are emerging as an essential interconnection technology that includes both wiring and bonding, which will be discussed in Chap. 6. Typical applications of conductive adhesives are the membranes of keyboards and touch panels (Fig. 1.5) and the antennas of radio-frequency identification (RFID) tags, which can be considered conventional printed electronics. Such products have been manufactured using an ultrafast printing method, i.e., rotary screen printing.

Thus, in recent decades, printing technology has grown with advances in electronic manufacturing technology, and there is great potential to significantly expand its field of use by combining this technology with the various advances in nanomaterials for electronics applications.

1.2 PE Technology and Its Benefits

As mentioned in the first section, PE is not a new idea that appeared in the twenty-first century; it grew gradually as part of electronics manufacturing in the twentieth century. In fact, many PE products already exist in the market. Nevertheless, great advances have been made in the past decade with the merging of print technology with nanomaterial technologies. The discovery of the basic nature of metallic, organic, and inorganic nanomaterials and their mechanisms and processes for synthesis, printing capabilities, electronic properties, and even evaluation methods have undergone tremendous advances thanks to the efforts of many scientists and engineers.

Let us now discuss some of the typical applications and major benefits of advanced PE technology. First, consider the cartoon in Fig. 1.6, which shows the PE products that are expected to make their way into our homes in the near future.

As can be seen, a large-screen TV hangs on the wall. This TV is lightweight, thin, and, perhaps, flexible. The TV panel itself is made of a self-light-emitting organic light-emitting diode (OLED) with an active matrix back plane made of

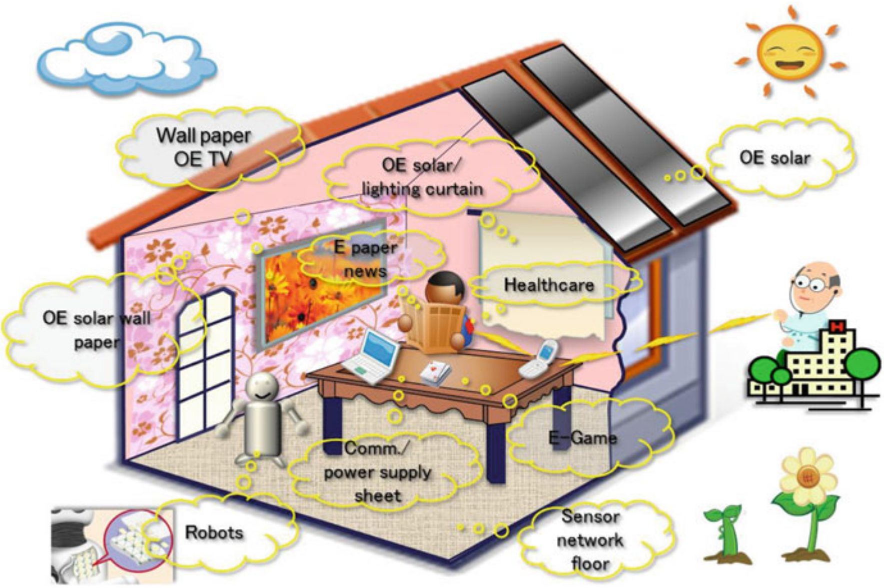

Fig. 1.6 PE technology in the near future

organic transistors with metallic nano ink circuits. The person sitting at the table is reading a newspaper, but it is not a simple paper. It is a actually a foldable display paper, perhaps like a future Kindle or iPad. Fresh content streams in throughout the day by wireless transmission over the Internet. The wall behind the TV with a pattern design is not a simple pattern but a dye-sensitized solar cell (DSSC) wall that recycles electrical energy from the lighting inside the house. The gadgets on the table—a smartphone, game cards, and notebook PC—are not merely sitting there but are being wirelessly charged by the communication sheet on the table and are also wirelessly connected to the Internet and an intranet. A robot is walking in the room. Because such humanoid robots must not injure people or pets or damage furniture, they must have a soft skin with a sensor network all over their bodies in every direction. The floor also has a sensor network beneath the carpet that senses any objects moving on the floor. The floor sensor network must also be soft. The curtain is not a simple cotton cloth. The outside face is an organic thin-film type of solar cell, and the inside face is an OLED lighting panel. The solar cell provides electricity to the internal lighting. The curtain itself works as a standalone flexible device. On the roof, of course, there is a solar cell module, possibly a thin-film inorganic type of module, such as a copper–indium–gallium–selenium (CIGS) one. Again, close inspection of the person sitting at the table reveals that he has some sort of device on his shoulder—a health monitor seal on his shirt. The seal monitors his temperature, blood pressure, pulse, sugar level, and other important health parameters. This sensor also works a standalone device and transmits health data to his doctor via cell phone.

Thus, a variety of PE products will be a regular feature of our lives in the near future and will provide valued comfort in our daily routines. These devices will not be noticed by people because they will be so thin, lightweight, form-fitting to walls, clothes, or even skin, energy efficient, and, above all, affordable. In other words, these will be the required features of PE technology.

The major benefits of PE technology can be summarized as follows:

1. It must be thin, lightweight, and be useable in large electronic devices—TV, solar, and lighting equipment can be larger than those made with conventional Si technology. Printing can make large products up to several tens of meters wide. Figure 1.7 shows one of the roll-to-roll screen printing examples of a RFID tag device on a PET (polyethylene terephthalate) film.
2. It reduces production cost and takt time: nowadays, Si technology has reached its ultimate fine pitch resolution, 13 nm, and a huge investment is required for the establishment of the production foundry. There are considerable risks associated with manufacturing short-lifetime products like cellular phones, tablets, and PCs. The most advanced semiconductor foundry cannot be maintained by a single enterprise even though it is very large one. Printing production requires less than approximately 1/10–1/100 the investment, and takt time is reduced considerably.

   Figure 1.8 shows the typical production of a printed semiconductor in a roll-to-roll process. Only four printers with pre- and post-treatment equipment are needed, just like a full-color gravure printing of graphic products. At the first printer, source and drain conductors are printed on a film. At the second printer,