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World First Integrated Circuit Created Using Only Carbon Nanotubes —Electronic device thermoforms into transparent and arbitrary three-dimensional shapes—

Associate Professor Yutaka Ohno at Nagoya University, Japan,(1) as well as Professor Esko I. Kauppinen at Aalto University, Finland, have succeeded in creating the world's first 'all-carbon integrated circuit' consisting of transistors and wiring using only carbon nanotubes and achieving a mobility that exceeds 1,000 $cm^2V^{-1}s^{-1}$, with expected applications to transparent high-performance flexible devices. Furthermore, all such carbon integrated circuits can be thermoformed into arbitrary three-dimensional shapes. The results of this study make it possible to achieve a fusion of electronic devices with plastic products, which can lead to the creation of plastic electronic devices that feature both designability and functionality.

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(Note 1) He is also visiting professor at the Department of Applied Physics, Aalto University School of Science via Aalto University MIDE (Multidisciplinary Institute of Digitalisation and Energy) program.
(Note 2) http://www.nature.com/ncomms/index.html

1. Background

Plastic products are used in a wide range of applications including articles for daily use, children's toys, chassis for electrical appliances, and medical equipment, because plastic materials soften when heated and become freely formable. However, the fusion with plastic products into integrated circuits, the principal components of electrical appliances formed on silicon wafers, which are rigid and brittle, is limited.

In recent years, this research group has promoted the study of integrated circuits using carbon nanotubes, and thus far, they have had a number of achievements such as the creation of high-performance carbon nanotube thin-film transistors on transparent plastic as well as an integrated circuit using such components. They have also been searching for wiring materials and insulating film materials that can lead to relatively high flexibility and elasticity in devices. In this study, carbon nanotube thin films have been used for electrodes and wiring materials, and an acrylic resin is used as insulating film material to successfully develop an all-carbon integrated circuit that is extremely flexible and transparent. Further, the research group has demonstrated that this all-carbon integrated circuit can be thermoformed into three-dimensional shapes.

2. Features of Accomplishment

(1) Development of the all-carbon integrated circuit

Studies on flexible devices using organic materials and carbon nanotubes in semiconductor layers have been actively carried out in the recent years, and the development of displays that can be bent is almost complete. In order to create electronic devices that are flexible and ultimately elastic as well, it is essential that not only the semiconductor layers but also the electrodes, wiring materials, and insulating materials be made elastic. However, non-organic materials, which have been used in the past, such as metal films and oxide films, have no elasticity. An all-carbon integrated circuit, which is transparent and extremely flexible, has been developed in this study by using carbon nanotube films to form electrodes and wiring, and an acrylic resin is used instead of conventional oxide films to form insulating materials (Figure 1). The integrated circuit developed in this study consists of a ring oscillator*[1] and various logic gates and memories (SRAM)*[2]. Despite the use of a 660-nm-thick acrylic resin for the gate insulator film, the operation of the integrated circuit can be accomplished at a voltage as low as 5 V by utilizing the electric-field concentration effect*[3] in the nanostructure.

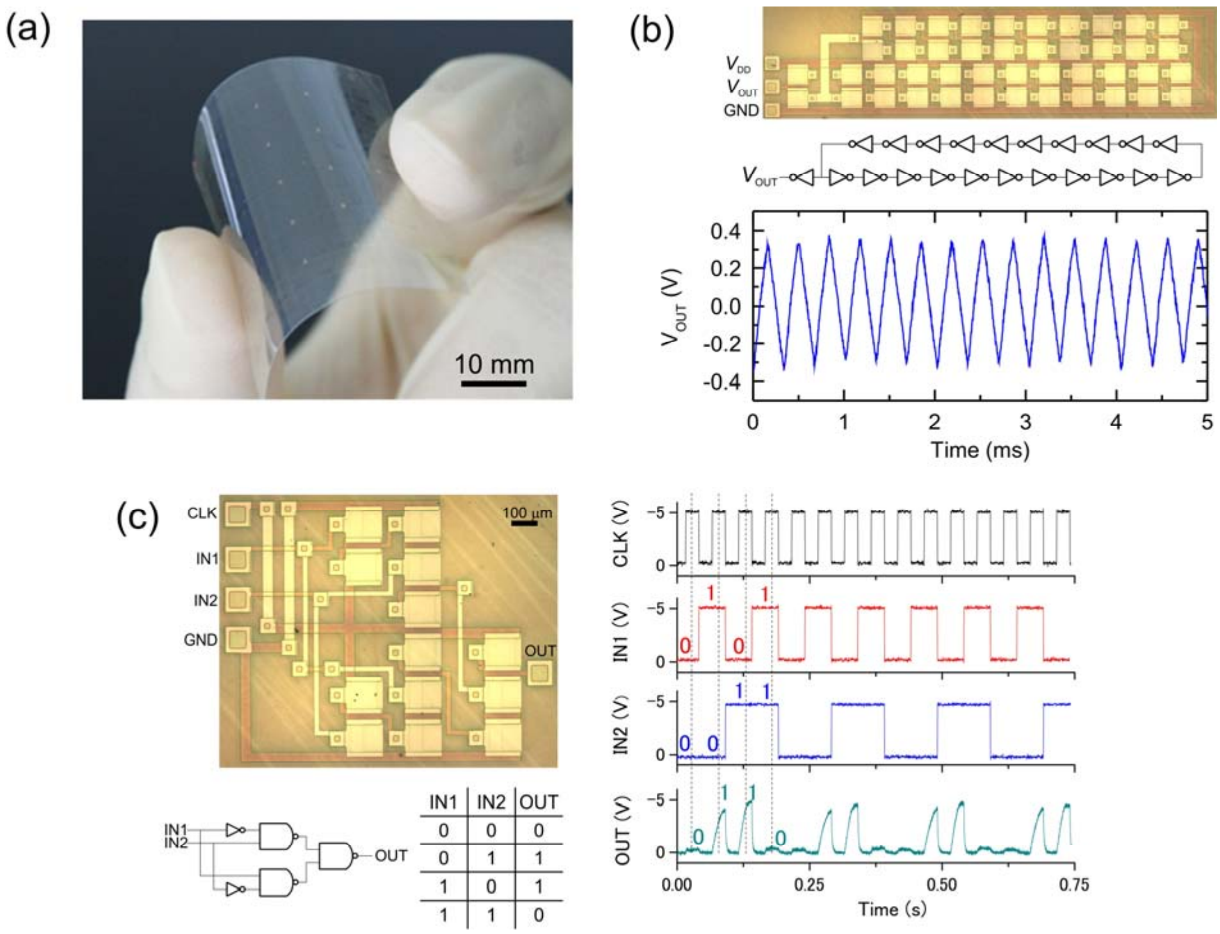

Figure 1: All-carbon integrated circuit. (a) Photograph, (b) ring oscillator, and (c) exclusive OR (Ex-OR).

(2) Achievement of a high mobility greater than 1,000 $cm^2V^{-1}s^{-1}$

The mobility of thin film transistors fabricated on plastic was approximately 0.01 to 50 $cm^2V^{-1}s^{-1}$ in the past. Previously, this study group successfully fabricated a thin film transistor with a mobility greater than 600 $cm^2V^{-1}s^{-1}$ by developing a technology for forming a long, yet pure, carbon nanotube film on plastic. Progress on the optimization of the film forming technology has been made in this study in order to achieve a mobility of 1,027 $cm^2V^{-1}s^{-1}$. This mobility is higher than that of an MOSFET, which uses monocrystalline silicon, and is an astonishing value for a thin film transistor fabricated on a plastic substrate.

(3) Thermoforming into arbitrary three-dimensional shapes

Materials used in the fabricated all-carbon integrated circuit were either carbon nanotube films or plastic, having extremely high elasticity along with flexibility, which made it possible to form it into arbitrary shapes using the thermoforming technology. The circuit was thermoformed into a dome shape as a demonstration sample, and the operation of the thin film transistor and the integrated circuit were verified (Figure 2). When formed into a dome shape, the transistors and wiring were elongated in biaxial directions; however, problems such as cracks or detachments did not occur with the carbon nanotube thin film. In the case of the all-carbon thin film transistor developed in this study, it operated normally when elongated by 18% in the biaxial directions. Normal operation was also confirmed with the integrated circuit for an elongation of up to 7.2%.

If the thermoforming of electronic devices is possible, as in the case of the all-carbon integrated circuit developed in this study, electronic functions can be easily mounted on plastic products, and it will become possible to broaden the designability of the electronic devices.

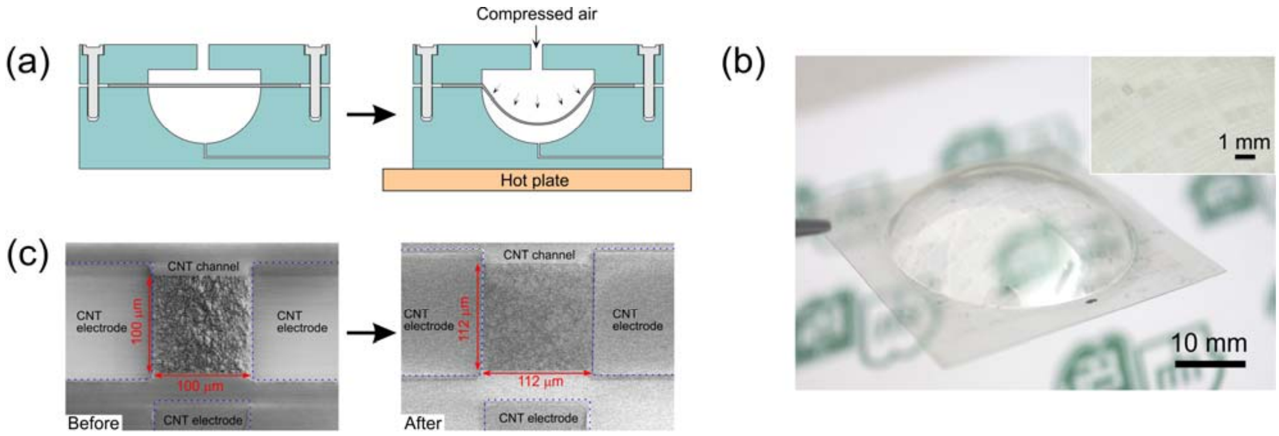

Figure 2: Thermoforming of an all-carbon integrated circuit. (a) Thermoforming process, (b) all-carbon integrated circuit formed into a dome shape, and (c) structural change of a carbon nanotube TFT by the forming (12% elongation in the biaxial directions).

3. Enquiries

(Contact for enquiries regarding the details of this press release)

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[Glossary]

*1 Ring oscillator:
An oscillating circuit connected to an inverter in a ring shape. It is used as a clock for a built-in timer or as a standard clock for the entire circuit. It is also used for evaluating the operating speed of inverters, as the oscillating frequency is determined by the delay time of the inverter as well as the number of inverters.

*2 SRAM (static random access memory):
This is random access memory that stores data using a sequential circuit such as the flip-flop and is currently considered to be an essential basic circuit for calculators. It does not require any periodic refreshing (memory holding operations). It operates at high speeds with low power consumption.

*3 Electric-field concentration effects:
Electric fields tend to concentrate on microstructures and sharply pointed structures. This is a phenomenon used for electron-emission-type electron sources.