Carbon Nanotube Film Flexible Terahertz Detectors on Polymer Films with Series Electrodes for Sensitivity Enhancement

K. Li[1], **D. Suzuki**[1], **Y. Ochiai**[1], **M. Sun**[1], **and Y. Kawano**[1]
[1]*Laboratory for Future Interdisciplinary Research of Science and Technology, Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo 152-8550, Japan*
lee.k.al@m.titech.ac.jp

1. Introduction

Terahertz (THz) imaging has been attracting much attention for its strong possibility of powerful applications such as non-destructive in-line inspection and non-contact bio-sensing [1]. Nevertheless, conventional unbendable THz detectors have been unavailable to scan three dimensional objects whose surfaces are curved. To solve this problem, we have developed flexible THz imagers which consist of macroscopically bendable carbon nanotube (CNT) films [2-3] for multi-view THz imaging. However, the electrode shape of the CNT film THz detector remains unclear, and there is still room for improvement.

In this work, we clarified key parameters of the electrode structure that are directly linked to the sensitivity of THz detection, and also developed a fabrication method and device structure of CNT film THz detectors with better performances. We achieved the sensitivity enhancement by a factor of about 60, compared to the earlier type of CNT film THz detector.

2. Results

The mechanism of THz detection with our CNT film THz detectors is based on the photothermoelectric effect, and the THz response ΔV can be calculated as follows:

$$\Delta V = \left| S_{CNT} - \frac{t_{Electrode}\sigma_{Electrode}S_{Electrode} + t_{CNT}\sigma_{CNT}S_{CNT}}{t_{Electrode}\sigma_{Electrode} + t_{CNT}\sigma_{CNT}} \right| \Delta T \qquad (1)$$

where S_{CNT} and $S_{Electrode}$ are the Seebeck coefficient of the CNT film and electrode, ΔT is the temperature gradient generated by the THz irradiation, t_{CNT} and $t_{Electrode}$ are the thickness, σ_{CNT} and $\sigma_{Electrode}$ are the electrical conductivity, respectively. Based on the Equation (1), THz response is suppressed when the CNT film is much thicker than the electrode, resulting in low sensitivity of THz detection. Our previous CNT film THz detectors suffer from this technical difficulty regardless of type of electrode materials.

Here, we propose a refined device structure as shown in Figure 1 (a). We deposited the series electrode next to a hole on the polymer film, and then formed CNT film on the hole. The THz response detected with the present device structure can be described as:

$$\Delta V = |S_{CNT} - S_{Electrode}|\Delta T \qquad (2)$$

Since we used p-type CNT film in this work, we used Bi (S_{Bi}= -77μV/K) as the series electrode, whose surface was covered with Au thin layer to protect Bi from the surface oxidation. Figure 1 (b) compares THz responses between the conventional and present structures. This result clearly shows that the THz response was dramatically enhanced through the present method, where the sensitivity of THz detection was enhanced by a factor of 58.5 compared to the conventional device design.

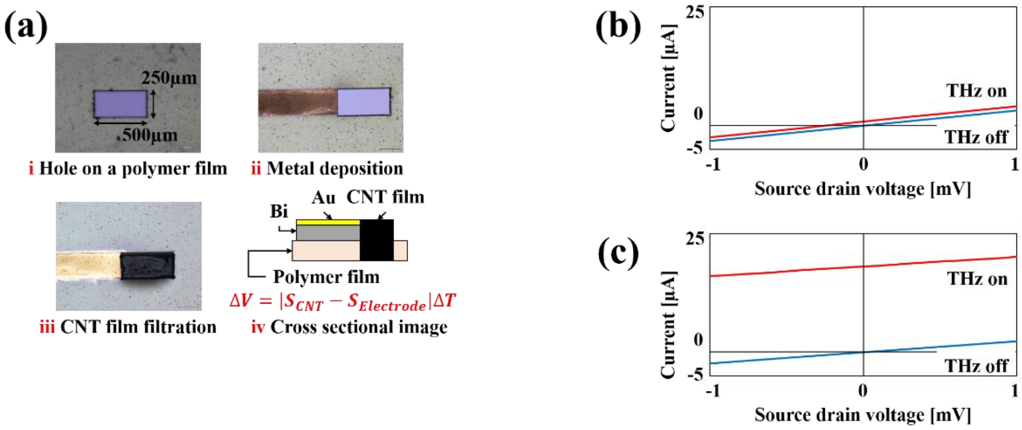

Fig.1 (a) Optical images of fabrication processes and schematic image of the present device structure. (b) Current-voltage characteristic of the conventional device under 29-THz irradiation. (c) Current-voltage characteristic of the present device under 29-THz irradiation.

References

[1] M. Tonouchi, *Nature Photonics*, 1, pp. 97-105 (2007)
[2] D. Suzuki, S. Oda, and Y. Kawano, *Nature Photonics*, 10, pp. 809-814 (2016)
[3] D. Suzuki, Y. Ochiai, and Y. Kawano, *ACS Omega*, 3, pp. 3540-3547 (2018)