Carbon nanotube-based analog circuits for wearable sensor applications: Device modeling, circuit design and fabrication

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1. Introduction

Wearable healthcare devices have the potential to revolutionize preventive medical care and health promotion technologies. Carbon nanotube (CNT) thin films are promising electronic materials for transistors and integrated circuits [1-3], biosensors [4,5], and other passive components to build flexible and stretchable devices with excellent wearability and performance because of the high-carrier mobility, mechanical flexibility, and biocompatibility. Recently, high-yield and reproducible fabrication of CNT TFTs became possible by using purified semiconducting CNTs, leading extensive study on circuit applications.

An integration of analog circuits with a sensor is essential for wearable sensor devices to amplify the sensing signal as preventing external noise. A differential amplifier is a fundamental analog amplification circuit used for various sensor devices. In this work, we are focusing on the analog circuit application of CNT TFTs. To design CNT-based analog circuits, circuit simulations have been performed by using a precise device model which has been built on the basis of electrical characterizations of CNT TFTs. We have realized differential amplifiers on a flexible and transparent plastic film.

2. Device modeling for circuit simulation

Device modelling is indispensable for circuit design. We built the RC-ladder device model based on the charge based model for CNT TFTs, where a correction of pinch off condition was taken into account, considering the contact resistances between CNTs. In order to fit the subthreshold current, the charge equation in weak inversion characteristics was modified. The proposed model well expresses the output characteristics. The frequency dependence of capacitance-voltage characteristic was also built by considering the non-quasi-static effect in the Mayer model.

3. Differential amplifier: circuit design and fabrication

CNT-based differential amplifiers were designed by using the circuit simulation with proposed device model. We also demonstrated the differential amplifiers on a flexible plastic film as shown in Fig. 1. Bottom-gate CNT TFTs with purified semiconducting CNTs were used as the active device. A differential output was obtained with respect to a differential input. Maximum voltage gain of 16.3 (24.3 dB) was achieved for a sinusoidal wave input of 100 mVpp at 100 Hz with a power source of -12 V. Figure 2 shows the gain as a function of frequency, exhibiting -20 dB/ decay. The voltage gain cut-off frequency was 210 kHz.

Acknowledgments
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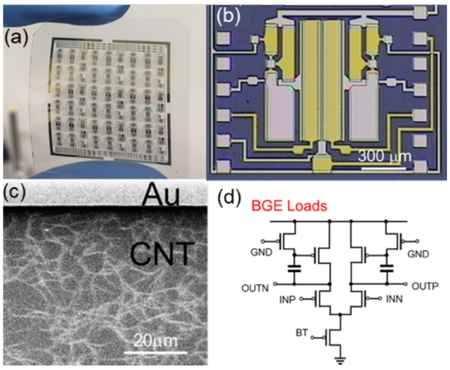

Fig. 1 CNT differential amplifier on plastic film. (a) Photograph of chip, (b) photograph of circuit, (c) SEM image of CNT thin film, (d) circuit diagram.

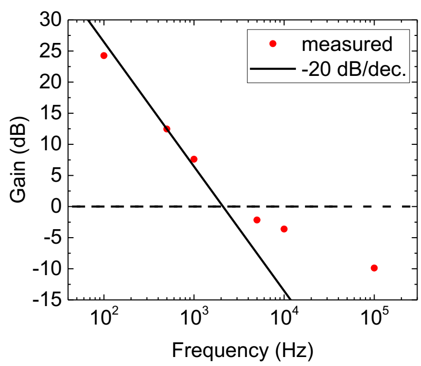

Fig. 2 Frequency dependence of voltage gain.