RF PERFORMANCE OF MULTIPLE-CHANNEL CARBON NANOTUBE TRANSISTORS

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Carbon nanotube field effect transistors (CNTFETs) are high-mobility devices and expected to operate at very high-speed. Theoretical analyses suggest that the cutoff frequency (f_T) of an ideal CNTFET is from 800 MHz to 1.3 THz when the gate length is 0.1 µm [1][2]. However, measuring the RF performance of CNTFETs, especially their cutoff frequencies, is generally difficult because their output impedances ($\sim 10^5\ \Omega$) are high enough compared with the impedance (50 Ω) of the measurement system using the network analyzer. This large mismatch hinders us from measuring accurate S-parameters and determining the cutoff frequencies of the devices. In this paper, we show the successful results of measuring the RF performance of CNTFETs. This was achieved by a newly developed multiple channel CNTFET structure whose output impedance is much lower than the usual single channel CNTFET, and a de-embedding scheme that removes existing errors in measured S-parameters.

As shown in Fig.1, the evaluated CNTFET was fabricated on SiO_2 insulator on the high-resistive Si substrate. By the CVD method, approximately 200 CNT channels were grown from catalyst (Fe) islands that were patterned by electron-beam lithography. The gate oxide was SiO_2 with the thickness of 40 nm. The top gate structure (L=0.2 µm) was used to reduce parasitic capacitances. The drain and source electrodes were formed by evaporation of Au, and made ohmic contacts with CNT channels. Using high-frequency probes, 2-port S-parameters of the device were measured by the network analyzer. Even using the multiple channel structure, the device impedance was still higher compared with usual RF transistors. Therefore, we applied the calibration method with which the parasitic error matrix can be effectively eliminated and the S-parameters of only the transistor part can be extracted using open-short-through standards on wafer (Fig.2).

Resulting current gain ($|h_{21}|$) and power gain (maximum stable gain) as a function of frequencies are shown in Fig.3. Determined cutoff frequency is 10.3 GHz, and the maximum stable gain is +3.8 dB at 10 GHz. These values are ones of the highest among the previously published papers[3][4][5]. To verify consistencies, we analyzed an equivalent small-signal circuit model of the CNTFET (Fig.4). From this model, the cutoff frequency was derived and approximately represented as;

$$f_T = \frac{g_m'}{2\pi C_g} \quad \text{where} \quad C_g = C_{g-cnt} + C_{gs} + C_{gd}\ , \quad g_m' = \frac{g_m}{1+(R_s+R_d)g_d}\ ,$$

g_m' and g_m are measured and intrinsic transconductance respectively. Cg is gate capacitance which consists of gate-CNT capacitance (Cg-cnt) and parasitic capacitance between the gate and source (or drain) electrodes (Cgs + Cgd). g_m' is obtained by DC measurement, Cg-cnt can be calculated by the theoretical concern[1] and Cgs + Cgd can be estimated by the geometry. It was found that our result of f_T is quite reasonable value when we substitute g_m' = 226 µS, Cg-cnt = 1.2 fF and Cgs + Cgd = 2.2 fF into the above formula (f_T[model]=10.6GHz). This implies that the equivalent circuit model is appropriate, in addition, the device RF performance can be considerably improved by increasing g_m' and reducing parasitic capacitance and resistance of the device in the future study.

References:

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Figures:

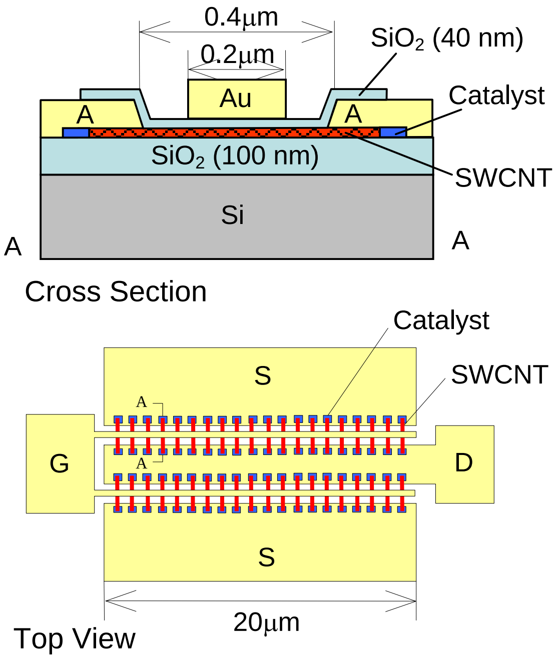


Fig.1: Multiple channel CNTFET structure

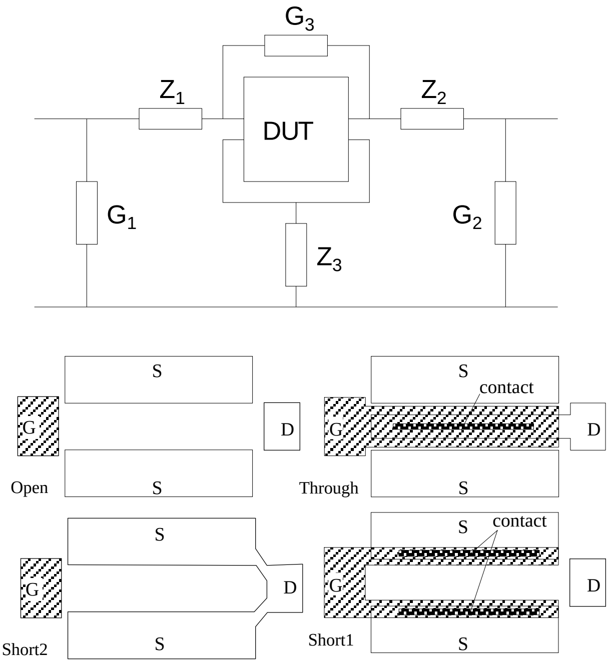
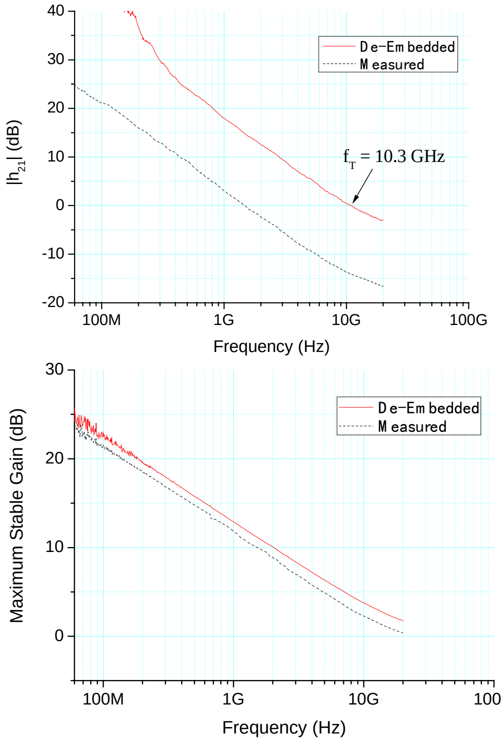


Fig.2: Parasitic errors and de-embedding standards



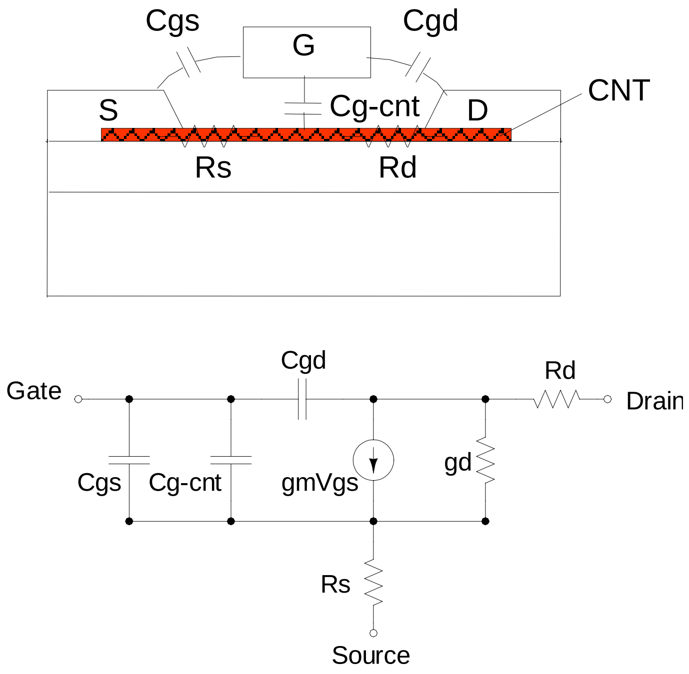


Fig.3: Current gain (|h21|) and power gain

Fig.4: Equivalent small-signal circuit model