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RF Characterization and equivalent circuit modeling of Ge nanowires

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1. Introduction

One-dimensional semiconducting nanowires such as Si and Ge nanowires are considered as building blocks for various nano devices and systems ranging from biological sensors to conventional field-effect transistors and interconnections [1]. The most important merit of these bottom-up synthesized semiconducting nanowires is in-situ control of the diameters and doping concentration.

Germanium has larger electron and hole mobilities than Si, and therefore, Ge nanowires are expected to have better radio frequency (RF) performance than Si nanowires. Despite of this better characteristic and possibly wider RF application areas, RF characteristics of Ge nanowires have rarely been reported so far.

Here, we report the fabrication and RF characterization of coplanar wave guides (CPWs) incorporating Ge nanowires. The measured scattering matrix parameters (S-parameters) are fit with an equivalent circuit model to extract the intrinsic resistance and inductance of the nanowires.

2. Experiments

Nanowire Synthesis

The Ge nanowires were synthesized by conventional Au catalyzed vapor–liquid–solid (VLS) chemical vapor deposition (CVD) method [2]. An ultra thin layer of gold was deposited on a clean silicon wafer by thermal evaporation system. This thin layer acted as the Au catalyst for the growth. The substrate was then transferred into a reaction chamber, which was evacuated down to ~10^{-3} Torr and annealed at 300 °C for 10 min. The phosphorous-doped Ge nanowire growth was done at 290 °C subsequently, for 20 min at a pressure of 80 Torr using 80 sccm GeH_4 (10% in H_2) and 10 sccm PH_3 (100 ppm in H_2). Figure 1 shows a typical scanning electron microscope (SEM) image of the synthesized Ge nanowires.

Device Fabrication

Figure 2 (a) shows the schematic of fabricated Ge nanowire devices for the RF measurements. High resistivity wafer (~ 2 kΩ cm) was used to reduce losses at high frequencies. The CPW structures were patterned on the oxide layer (100 nm) using photolithography and lift off of the Ti/Au metal layer (10 nm, 100 nm). Ge nanowires were aligned across the signal electrodes of CPWs by using AC dielectrophoresis method [3].

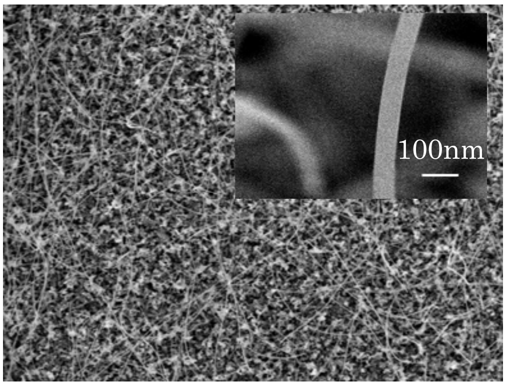

Fig. 1 SEM image of synthesized Ge nanowires.

After a droplet of Ge nanowire suspension was placed on the substrate, AC voltage with $15V_{p-p}$ was applied at 1 MHz between the electrodes. This AC signal captured individual Ge nanowires between the electrodes. Subsequently, e-beam lithography and lift off of NiCr/Au metal layer (70 nm/80 nm) were performed to form the electrical contact between aligned Ge nanowires and electrodes. The SEM image of fabricated devices with Ge nanowires is shown in fig. 2 (b).

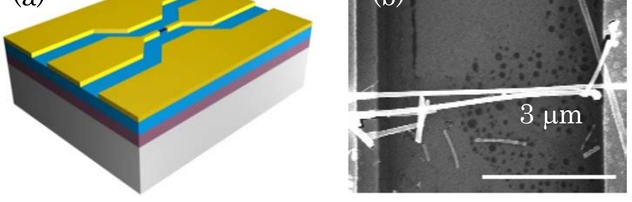

Fig. 2 (a) Schematic of CPWs with Ge nanowires. (b) SEM image of the measured device

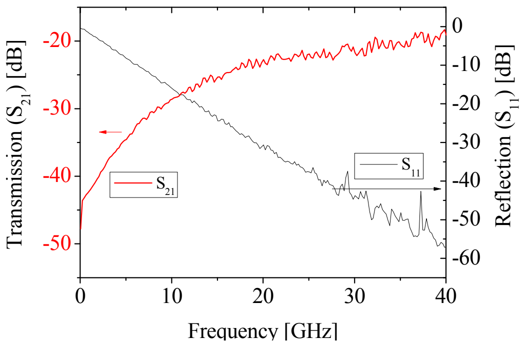

Fig. 3 Measured S-parameter data of a typical CPW with Ge nanowires.

RF Measurements

On wafer RF measurements were performed up to 40 GHz by using a vector network analyzer of Agilent 8722ES and a Cascade Microtech Summit 9000 microwave probe station with ground signal ground (GSG) infinity coplanar probes. Before measurements of CPWs with Ge nanowires, typical short-open-load-thru calibration was done using impedance standard substrate. Furthermore, de-embedding of open circuit was done to eliminate the parasitic components from probes and substrates. Figure 3 shows a typical measured S-parameter data of the device with Ge nanowires. The transmission (S_{21}) increases and the refection (S_{11}) decreases monotonically as the frequency increases.

Equivalent circuit modeling

The inset of fig. 4 shows the equivalent circuit model of the CPW with Ge nanowires. The symbol R_{Ge} denotes the intrinsic resistance of the Ge nanowires. The components R_J and C_J denote the junction resistance and junction capacitance in depletion region between the NiCr metal layer and the Ge nanowires, respectively. The symbols L_1, L_2, R_1, and R_2 denote the parasitic components of the two signal electrodes. The symbol C_1 and C_2 denote the parasitic capacitances between the signal and the ground electrodes. The symbol C_g denotes the parasitic capacitance between the two signal electrodes of the CPW.

First of all, the parasitic component values were obtained from the measured results from a CPW without Ge nanowires. The parameters R_{Ge} and L_{Ge} then were obtained from the data measured from the CPW with Ge nanowires using those parasitic component values. We used ADS for the optimization of the equivalent circuit parameters. The obtained parameters are R_{Ge} = 15 kΩ, L_{Ge} = 1.5 nH. Figure 4 shows S_{21} from the measurement data and the equivalent circuit model. The measured data are consistent with the modeled data within a reasonable accuracy.

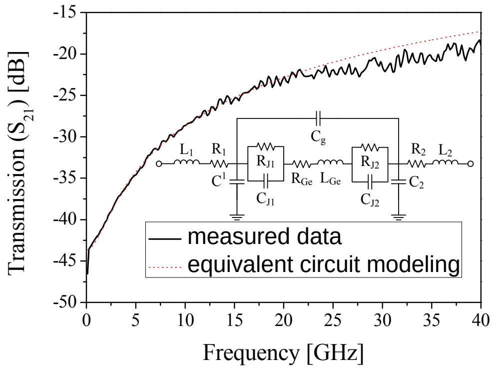

Fig. 4 S21 obtained from the measurement data and the equivalent circuit model. The inset shows the equivalent circuit mode.

3. Conclusions

In this presentation, we performed the RF measurement of the Ge nanowires. We fabricated coplanar wave guides (CPWs) whose signal line is bridges by Ge nanowires, and obtained the S-parameters of the CPW in the frequency range from 0.5 to 40 GHz. From the analysis using equivalent circuit modeling, we found the intrinsic inductance and resistance of Ge nanowires.

Acknowledgements

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