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Finger Length Optimization for AlGaN/GaN HEMT and InGaP/GaAs HBT by Using FDTD Electromagnetic and Device Co-Simulation Technique

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1. Introduction

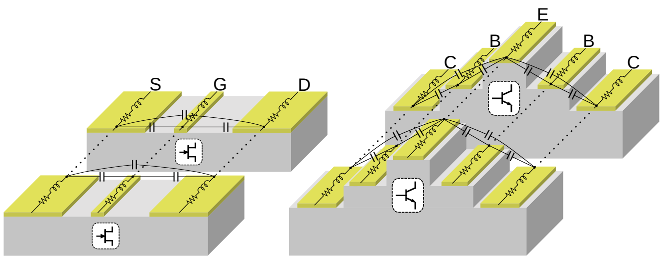
Increasing power output without degrading microwave performance is one of the major concerns for high power transistor design. Wide-gap semiconductor devices such as GaN transistors and SiC transistors are expected to deliver more than several watts class power output from a single cell structure, due to their high-breakdown-voltage characteristics. However, even in such high breakdown voltage devices, a multi-gate finger structure with an optimized gate finger length is required to increase a total current for the transistor retaining uniformity.

A long gate finger length causes a phase rotation and an amplitude reduction along the gate finger length direction. This effect degrades high frequency characteristics. Usually the finger length optimization is time and cost consuming, since the optimization is carried out experimentally for fabricated devices. To overcome this, an FDTD (Finite Difference Time Domain) analysis method for electromagnetic (EM) fields including semiconductor device structures is considered to be effective [1][2]. Thus, we have successfully applied this method to InGaP/GaAs HBT's to obtain long emitter finger effects on RF characteristics [2].

In this paper, the method is applied for AlGaN/GaN HEMT's to determine an appropriate gate finger length. This analysis was done by using Synopsys ISE-TCAD. Maximum available power gain (MAG) and maximum stable gain (MSG) for the devices are analyzed as functions of frequencies, and the results are verified by on-wafer experiments. In addition, gain roll-off characteristics for AlGaN/GaN HEMTs and those for InGaP/GaAs HBT's are compared. A distinguished difference is found between FET type devices and bipolar type devices regarding gain roll-off characteristics.

2. FDTD Analysis for Long-Gate Finger Transistors

Electrode structures for AlGaN/GaN HEMT and InGaP/GaAs HBT are expressed as shown in Fig. 1. A long finger electrode structure on a semiconductor substrate behaves as coupled transmission lines with phase shifts and losses. Characteristic impedance for the finger structure of the HEMT is generally considered to be much larger than that of the HBT. Therefore it is predicted that transmission loss on the HEMT gate finger electrode is suppressed, comparing with the HBT. The effect was numerically estimated from the simulation described in Sect. 3.



(a) HEMT (b) HBT

Fig. 1 Schematic drawing of the electrode structures.

A configuration of the 2-finger AlGaN/GaN HEMT for the FDTD EM and device co-simulation is shown in Fig. 2. The gate length is 0.4 μm, and both drain and source electrodes widths are the same size as 30 μm for the gate-length direction. In order to consider distributed electromagnetic coupling on the finger, a long finger structure is divided into an appropriate number of unit cells. In the unit cell, the phase shift is negligible small and a lumped element approximation is retained. Then, EM data at the center of a unit cell are transformed to voltage and current data using the cell dimension. Those are sent to a device simulation engine of HEMT. The device simulation results are returned to the same point on the FDTD analysis region in the next time step by means of the inverse process [1]. Each divided cell behaves as an independent HEMT unit. In this paper, SPICE circuit simulations were performed as device simulations. An AlGaN/GaN HEMT with a gate width of 50 μm shown in Fig. 2 was used as the unit-HEMT. The circuit parameters of the unit-HEMT were extracted by on-wafer measurements with Agilent IC-CAP.

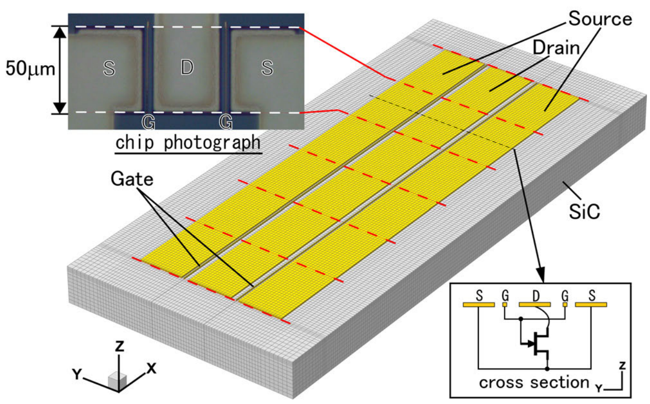


Fig. 2 Configuration of the AlGaN/GaN HEMT for the FDTD EM-device co-simulation.

As a time domain excitation signal for FDTD co-simulation, a gauss-pulse modulated with a sine function is used. Its time response is converted to frequency responses by using Fourier-transformation. S-parameters are indirectly derived from the Y-parameter extraction method, where an opposite terminal on the excitation terminal is shorted in the co-simulation. In this Y-parameter extraction method, intrinsic device characteristics can directly be derived without using 50-ohm microstrip terminal lines, which causes another parasitic EM coupling. Simulation time can be saved comparing with the previous S-parameter extraction method [2] used with 50-ohm microstrip lines as the terminals, due to the simplified configuration.

3. Simulation results and Experimental Verification

Figure 3 shows the simulated and measured MAG and MSG. The simulated MAG decreases with increase in the finger length. Moreover, a conversion point frequency from MAG to MSG decreases with increase in the finger length. Retaining the conversion point frequency to be high is an essential viewpoint for microwave and millimeter wave circuit applications. The degradation is due to increase in resistance and phase shift on the electrodes. These simulated results were reproduced in the measurement as shown in Fig. 3. Figure 4 (a) shows the MAG degradation for the increase of the finger length at 26 GHz. As the comparison, the similar calculation results for an InGaP/GaAs HBT at 12 GHz, which was re-simulated by the improved Y parameter extraction method, is shown in Fig. 4 (b). The finger length was converted into a ratio of the equivalent wavelength assumed as a plane wave in a material with an effective relative permittivity, where arithmetic mean of a relative permittivity of air and that of the semiconductor is used. The decay factors of the degradations were about 1 dB/0.01λ for the AlGaN/GaN HEMT and 2 dB/0.01λ for InGaP/GaAs HBT, respectively. An origin for MAG degradations is found to be due to the resistive loss on the electrodes by simulations, when the finger length was enough shorter than the equivalent wavelength.

4. Conclusions

Influence of increasing gate finger length for the AlGaN/GaN HEMT was analyzed by using the FDTD EM-device co-simulation technique. The MAG and MSG characteristics were calculated and the results were verified experimentally. Additionally, the MAG degradation of the AlGaN/GaN HEMT for the increase of the finger length was estimated as 1 dB/0.01λ using the equivalent wavelength, λ. As the comparison with the InGaP/GaAs HBT, about half of the decay factor was obtained.

Acknowledgements

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References

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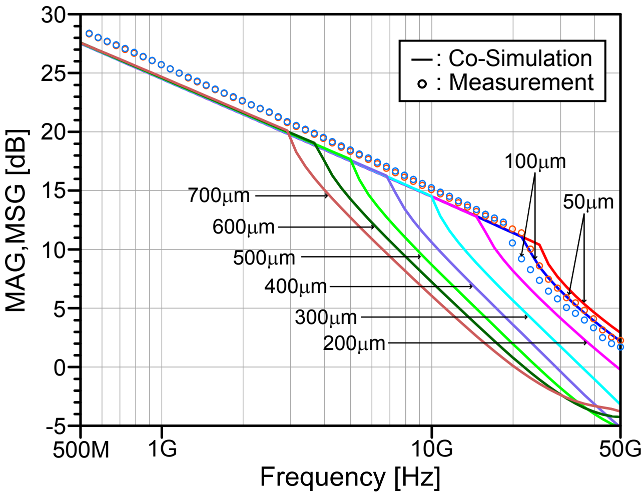
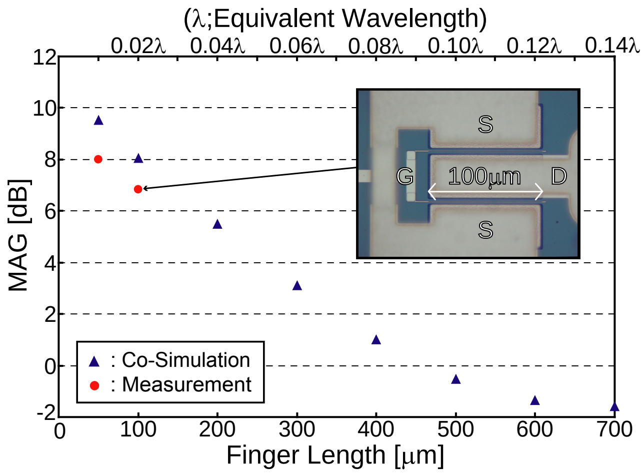
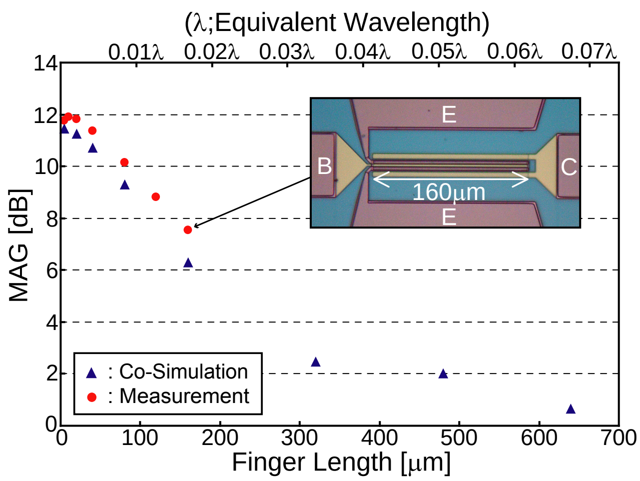


Fig. 3 Simulated MAG and MSG for the AlGaN/GaN HEMT with various finger length. The measured results are also shown.



(a) For the AlGaN/GaN HEMT at 26 GHz



(b) For the InGaP/GaAs HBT at 12 GHz

Fig. 4 MAG degradation for the increase of the finger length.