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An Analysis of THz Oscillator using Negative Differential Resistance Dual Channel Transistor (NDR-DCT) and Integrated Antenna

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1. Introduction

For the easily treatment of terahertz (THz) applications, for example imaging system, the indoor wireless communication etc., the ultra-high frequency oscillator device as THz wave source is hoped to be easy handling. For the purpose, the Negative differential resistance dual channel transistor (NDR-DCT) proposed by AIST can be utilized[1]. We have already shown that our oscillator device using NDR-DCT on which antenna as resonant circuit is integrated can oscillate at about 100GHz and 300GHz within the THz band analytically[2]. The equivalent circuit model of NDR-DCT was based on the analogy with the resonant tunnelling diodes (RTDs)[3]. It was shown that the antenna on the wafer which consists of the electrodes of the transistor could be realized with the slit reflector that we proposed by numerical analyses.

In this report, we simulated, as making another attempt to confirm the validity of our design of the antenna at any frequencies, the oscillation frequency of this device at about 170GHz mainly, where we specified the dependency on the gate length of the NDR-DCT characteristics as the NDR part of the oscillation circuit for the first time

2. Negative differential resistance dual channel transistor (NDR-DCT)

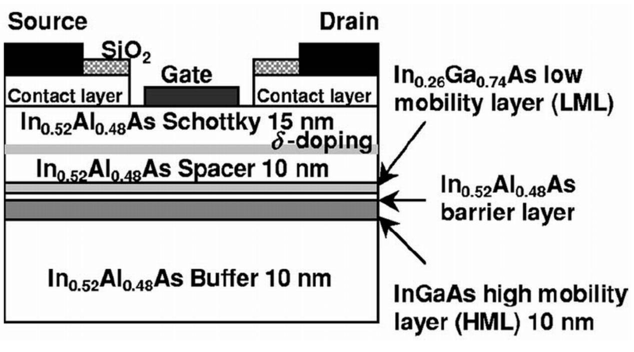

Fig. 1 Pattern diagram of NDR-DCT (Negative differential resistance dual channel transistor).

For this transistor, the negative resistance appears by the electron's transit from the high mobility channel to the low mobility channel by the drain voltage. This device differs from conventional real space transition FET, and use the coupling quantum wells structure has the barrier layers of 2-3nm thickness as the dual channel. By the tunnelling (transition between sub-bands) between the coupling wells and very short (100-200nm) gate, ultra-high-speed operation of this device is expected. Moreover, this device is three terminal structure, and negative resistance can be controlled by the gate voltage. This characteristic is related to a frequency changeable characteristic. Figure 1 shows the NDR-DCT. Please refer to reference[1] for more details concerning this NDR-DCT.

3. Oscillation device and oscillation frequency analysis

On this oscillation device, the metals are as transistor's electrodes and a resonant circuit, and they are also an antenna on the wafer. The desired oscillation function is achieved with entire of such device. Figure 2 shows a device structural chart. Let admittance of NDR-DCT and other structures(electrode, antenna, and semiconductor substrate, etc.) be Ydct and Ya respectively. The equivalent circuit of the device is shown in Figure 3. In order for this circuit to begin oscillating, the following conditions about Ydct and Ya must be satisfied at the same time.

$$\mathrm{Re}(Ydct)+\mathrm{Re}(Ya) \le 0 \quad \text{: Gain condition} \qquad (1.1),$$
$$\text{where } \mathrm{Re}(Ydct) < 0 \text{ : NDR},$$
$$\mathrm{Im}(Ydct)+\mathrm{Im}(Ya) = 0 \quad \text{: Phase condition} \qquad (1.2).$$

For deriving the property, admittance Ya, of the antenna as resonant circuit, we used a numerical analysis tool, HFSS (Ansoft Japan K.K.). To achieve the antenna whose wavelength and sharpness of the resonance can be controlled, the method of making a gap between a couple of the electrodes (source and drain) into a slot antenna has been utilized. For this method, we proposed the slit reflector[2] that is considered to be different width on the gap as slot waveguide and realize the impedance mismatch.

-Gd and Cd are the negative differential conductance and capacitance that appear by the transition of the carrier (electron) between dual channels under the gate region, and can be derived from the analogy with RTD[3]. They depend on the gate length and Ydct is also so.

Please refer to reference[2] for more details of analysis.

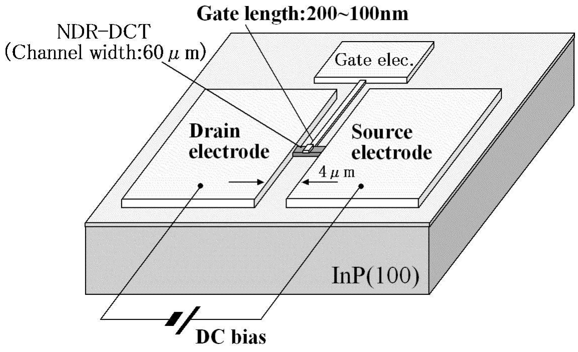

Fig. 2 Oscillation device structure.

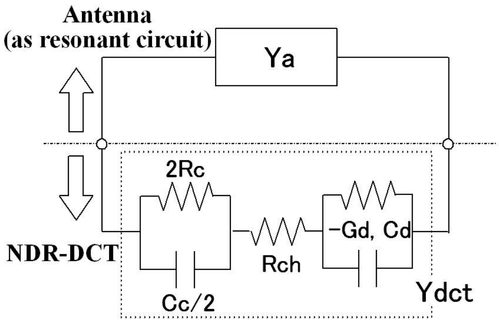

Fig. 3 Equivalent circuit of the oscillation device.

4. Results

The device of Figure 4(a) achieves the slot antenna of 500μm in length. To decide both ends of the slot antenna, the slit reflector of width 20μm and 400μm in length is made. The gap width between the Source and the Drain electrodes is 4μm. The square conductor of $100\times100\mu m^2$ at top of the figure is the gate electrode from which the gate expands to the channel. The channel width of the NDR-DCT is 60μm. There is another pair of slit reflector of $15\times15\mu m^2$ that is also made at both sides of the channel.

Figure 4(b) shows the admittance characteristics of analytical results. At first, the Gate length, l_G, is assumed to be 200nm. If it was without a pair of the slit reflector at both sides of the channel (S.R. b.s. Chan.), the devices can not satisfy the above-mentioned oscillation conditions (eq. (1.1) & (1.2)), while resonance sharpness of the device with them is slightly improved to satisfy the conditions at about 170GHz, when the gain condition is realized narrowly. A pair of the S.R. b.s. Chan. acts effectively when the slot antenna is thick[2], in other words, when the aspect ratio of width to length of the antenna is relatively large. In this report, however, the antenna is thin enough, and room for improvement is little.

Then, assuming that the l_G is 100nm, the admittance characteristics of the device is derived and shows greatly improvement. There is little change in the oscillation frequency in this case, and it maintains about 170GHz. Resonance frequency of the slot antennas show about 130GHz equally. If the relative permittivity for the electromagnetic field on the slot is assumed the average of them in air and InP (1. and 12.11, respectively), the calculated half wavelength at 130GHz is almost equal to the slot antenna length.

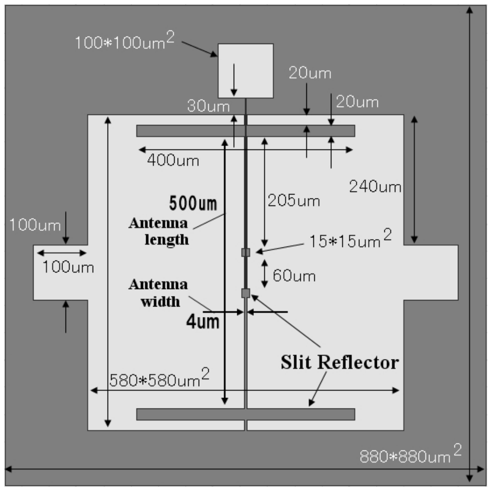

Fig. 4(a) Top view of the device for about 170GHz oscillation.

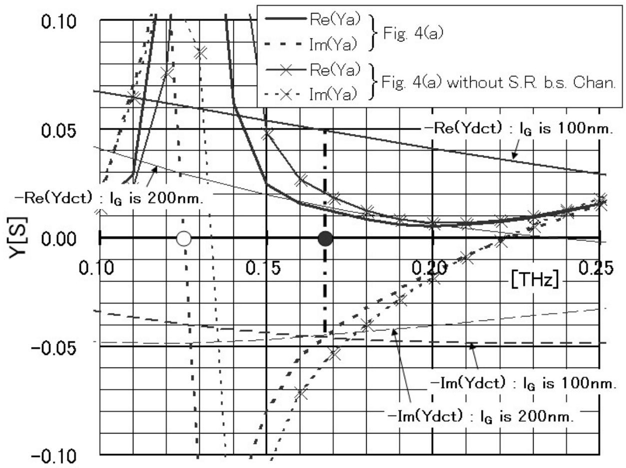

Fig. 4(b) Admittance characteristics of NDR-DCT(Ydct) and resonant circuit(Ya) of the device in Fig. 4(a).

5. Conclusions

The oscillation frequency of the THz oscillator using NDR-DCT was evaluated by analysis. The oscillation condition can be satisfied better at about 170GHz by reducing the gate length. The slit reflector was able to be used for the achievement of the slot antenna on the wafer. Our THz oscillator device can satisfy the oscillation conditions better by appropriate design of the Gate length.

In future, trial manufacture and experimental examination for confirming the actual device operation will be executed based on this result in present report.

References

[1] T. Sugaya et al., Appl. Phys. Lett., **88**, 142107(2006).

[2] K. Furuya et al., IEICE Trans. Commun., Vol.E91-B, No.6 June 2008 (to be published).

[3] N. Orihashi et al., Jpn. J. Appl. Phys., **44** (2005) 7809.