Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 664-665

P11-5

Large Conductance Modulation in Interdigital Gate HEMT Device due to Surface Plasma Wave Interactions and Its Device Application

Abdul Manaf Hashim, Mariko Takeuchi, Seiya Kasai, Tamotsu Hashizume and Hideki Hasegawa

Research Center for Integrated Quantum Electronics (RCIQE) and
Graduate School of Information Science and Technology, Hokkaido University
North 13, West 8, Sapporo 060-8628, Japan

1. Introduction

Frequency-power limitation of conventional transit time devices can be lifted, in principle, by utilizing traveling wave interaction. Attempts to realize solid state analog of traveling wave vacuum tubes using carrier waves in semiconductor plasma were intensively pursued in the past up until early 1970's [1,2], but they died away without significant success. Recently, revival of such a concept has been made in a THz detector worked by Dyakonov and Shur [3] where a plasma wave in a HEMT structure was utilized under non-drift conditions.

Being stimulated by such a revival, we recently have performed a TM mode analysis of surface plasma wave in drifting carriers of 2DEG channel and its interaction with electromagnetic space harmonics produced by an interdigital slow wave structure [4]. The result indicated occurrence of negative conductance in the two-terminal interdigital admittance, when the carriers drift velocity slightly exceeds the phase velocity of the fundamental component of electromagnetic space harmonic waves. Theory has predicted that, although the magnitude of negative conductance peak is small at low microwave frequencies, it increases rapidly with frequency toward THz region due to reduction of collision per cycle. However, direct confirmation of such an effect in the THz region requires a sophisticated set-up presently beyond our reach.

The purpose of this paper is to investigate existence of surface plasma wave interactions at low microwave regions, using an interdigital gate HEMT structure, and explore possible device application of such a plasma HEMT device.

2. Device Structure

The device structure is shown in **Fig.1(a)**. It is an AlGaAs/GaAs HEMT having an interdigital slow-wave circuit. MBE-grown AlGaAs/GaAs heterostructures with an AlGaAs barrier thickness of 50 nm was used. The carrier mobility and carrier sheet density obtained by Hall measurements were 7540 $cm^2/Vsec$ and $5.6x10^{11}$ cm^{-2}, respectively, at room temperature. Using electron beam lithography and lift-off technique, gate electrode pattern shown in **Fig. 1 (b)** was fabricated. It had interdigital gate electrodes and source and drain ohmic contacts. Devices having 50 gate fingers with a pitch, p, of 1 - 20 μm and the channel width, W, of 50 μm were fabricated.

3. Results and Discussion

1) Result of two-terminal admittance measurements

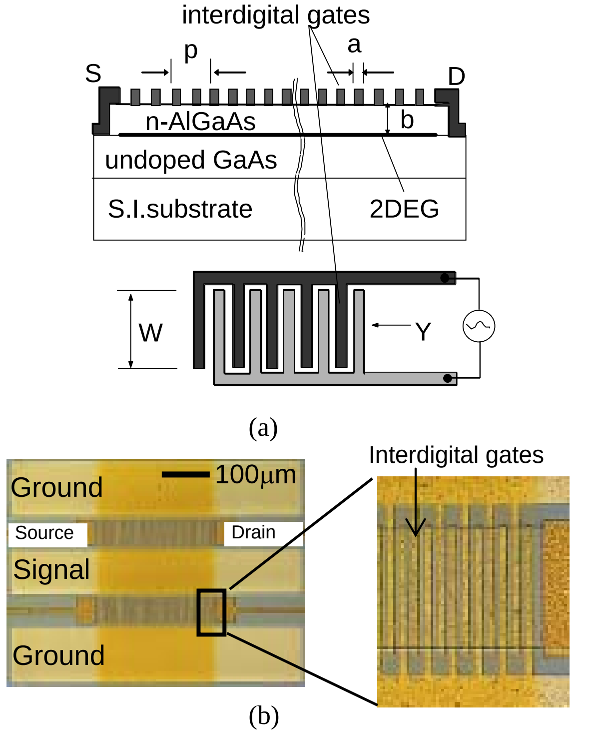

Fig. 1(a) The AlGaAs/GaAs HEMT structure with interdigital gates and (b) a plan-view photograph of the fabricated device.

The device showed well behaved I-V characteristics as shown in the inset of **Fig.2**. In order to measure the two terminal admittance, Y, of the interdigital gate shown in **Fig.1**, reflection S-parameter measurements were carried out at room temperature for 1 to 20 GHz, using an Agilent network analyzer HP8510C and a Cascade on-wafer microwave prober GSG 150. The source and drain were biased so as to avoid pinch-off.

The measured conductance of the interdigital gate is plotted versus drain voltage in **Fig. 2**. Although no net negative conductance was observed, a very large change of microwave conductance was observed particularly at frequencies between 5 GHz and 10 GHz.

2) Theretical analysis and comparison with experiment

Obviously, the observed behavior of the admittance of the interdigital gate can not be explained at all by the conventional transit time picture. An electromagnetic field analysis was made by using the following expression for the ω- and k- dependent effective permittivity, ε_{eff} (ω,k) for 2DEG plasma wave [4].

$$\varepsilon_{eff}(\omega,k)=\varepsilon_{AlGaAs}\left[1-\left(\frac{e^2 n_{so}}{m^*\varepsilon}\right)\frac{k}{(\omega-k\upsilon_d)(\omega-k\upsilon_d-i\nu)}\right.$$
$$\left.\times\frac{1}{1-(k\upsilon_{th})^2/\left[(\omega-k\upsilon_d)(\omega-k\upsilon_d-i\nu)\right]}\right] \qquad (1),$$

where υ_d is the electron velocity, m^* is the electron effective mass, υ_{th} is the thermal velocity of electrons, n_{so} is the sheet density of electron in the 2DEG and ν is the collision frequency. The interdigital admittance was calculated by a Fourier analysis described in ref. [4].

It was found that non-occurrence of negative conductance is due to non-uniform field distribution along the channel which leads to non-uniform drift velocity. The calculated result taking account of the non-uniformity of the field is shown in **Fig.3.** A reasonably good agreement between experiment and theory is seen. This result clearly shows that the surface plasma wave interaction does exist between 2DEG carriers and electromagnetic space harmonic waves. This gives a good hope for use of this effect in the sub-millimeter and THz regions.

3) Possible device application

As summarized in **Fig.4**, the observed change of microwave conductance, ΔG, is extremely large and it shows a peak at a certain frequency whose position can be controlled by changing the pitch of the interdigital gate. Due to use of traveling wave interactions, the electrode width and pitch can be much larger than those of transit time devices. Additionally, the electrode pattern forms a coplanar waveguide (CPW) structure, as shown in **Fig.1(b),** which is very suitable for planar integration.

These features seem to be very attractive for use as a large amplitude conductance modulation device. An effort is also being made in this study to integrate this plasma conductance modulator with an on-chip dipole antenna for use in an RFID device, or in an IQ chip proposed by our group [5]. The fabricated antenna and its return loss characteristics are shown in **Fig.5**. The characteristics of such a responder will be reported at the conference.

This work is partly supported by the 21st century COE program "Meme-media technology approach to the R&D of next generation ITs" from MEXT, Japan.

References

[1] L.Solymar and E.A.Ash, Int. J. Electronics Vol. **20** No.2 (1966) 148.
[2] M.Sumi, Jpn. J. Appl. Phys. **6** (1967) 688.
[3] M.Dyakonov and M. Shur, IEEE Trans Electron Devices **46** (1996) 380
[4] A.M.Hashim, T.Hashizume, K.Iizuka and H.Hasegawa, Superlattices and Microstructures (2004), in press.
[5] IQ chip in 21st COE program at http://www.rciqe.hokudai.ac.jp/index.html

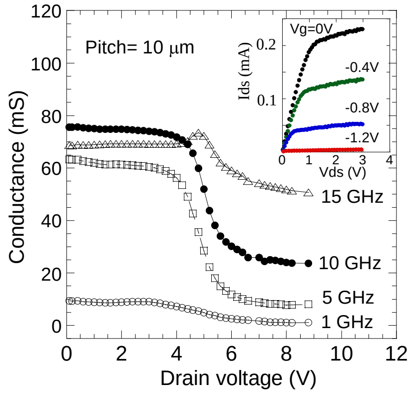

Fig.2 Measured conductance as a function of drain voltage. The measured dc I-V characteristics are shown in the inset.

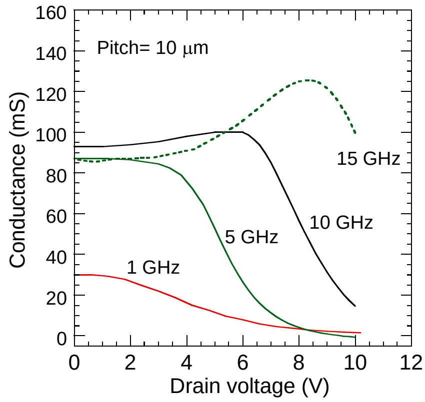

Fig.3 Calculated conductance as a function of drain voltage.

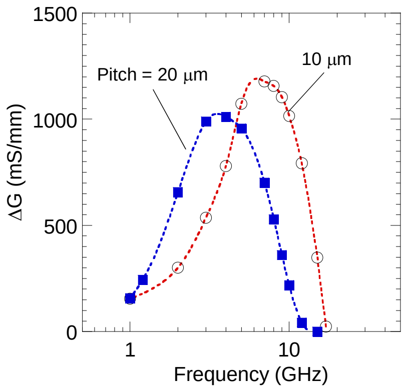

Fig.4 Change in measured conductance as a function of frequency.

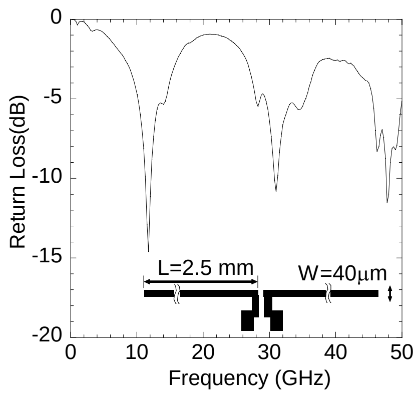

Fig.5 Measured return loss as a function of frequency. The schematic figure of fabricated antenna is shown in the inset.