OPTICAL CONTROL OF MMIC OSCILLATORS AND MODEL PARAMETER ANALYSIS OF AN ILLUMINATED FET AT THE Ka- AND V-BAND

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ABSTRACT

This paper reports experimental results of optical control of millimeter-wave HJFET MMIC oscillators and FET model parameter analysis with illumination. Using a noncoherent optical source, the maximum optical tuning ranges of 32 MHz around 30 GHz and 260 MHz around 51 GHz were obtained. By means of parameter extraction, variation on Cgd with 46.6% increase and Cds with 19.1% decrease due to the illumination, and their frequency dependence were appreciated.

INTRODUCTION

Optical fiber communication is a key technology of a cable communication system for high-speed and multi-media communication. However, more flexibility to this system such as a wireless terminal has been requested[1]. Recently, to cope with this request, many papers working on incorporation of a microwave or millimeter-wave circuit with an optical detector have been published[2]. In order to realize the wireless terminal of the optical fiber link, good match between the photodetector and the millimeter-wave circuit with low-price as well as small size and light weight is one of significant points. Therefore, integration of a semiconductor photodetector into a millimeter-wave monolithic circuit is necessitated[3]. As one of these techniques, direct illumination on the microwave or millimeter-wave monolithic circuit[4],[5] is very attractive for versatility of applications associated with the optical fiber communication and control systems[6].

From this view point, it is significant to examine optical/millimeter-wave interaction on an FET in a monolithic circuit. So far, chips of MESFETs and HEMT have been investigated[7],[8], but there are few works related to investigation of the variation on the FET model parameters due to the illumination in the millimeter-wave frequencies. In this work, optical control of a Ka-band and a V-band MMIC oscillators with heterojunction FETs (HJFETs) has extensively been investigated. Shifts of operating frequencies due to illumination were observed around 51.4 GHz as well as 30.6 GHz. In addition, variations on small signal FET model parameters with/without illumination and their frequency dependence were appreciated using parameter extraction with a frequency region of 450 MHz to 40 GHz.

CIRCUIT STRUCTURE

The HJFET used was an N-AlGaAs/InGaAs/N-AlGaAs double doped double heterojunction FET (HJFET) with a 0.15 μm long and 100 μm wide gate. The structure of the FET was shown in Fig. 1. Using small signal FET model parameters for this HJFET and microstrip lines, Ka-band and V-band oscillators were designed and fabricated in a monolithic fashion (MMIC). For the design procedure, the model parameters were determined from measured S-parameters and parameter extraction.

The MMIC oscillator chip for the V-band is shown in Fig. 2. In addition, a circuit configuration corresponding to the V-band oscillator is indicated in Fig. 3. Both of the MMIC oscillators have a series feedback at the gate terminal for simplicity and an output port from the drain through a matching

TH
3D

network. The oscillators were designed with the negative resistance of -250Ω at 30 GHz for the Ka-band and -20Ω at 60 GHz for the V-band, respectively. These values were determined by the fact that it is hard to obtain large negative resistance values from an FET in higher frequencies. For the Ka-band oscillator, the gate resonant circuit consists of an inductive microstrip line and a shunt-capacitive microstrip line, while that of the V-band oscillator was made by an inductive microstrip line and an MIM chip capacitor.

RESULTS AND ANALYSIS

The FET chips and the MMIC oscillators were placed on a microwave probe station and illumination on the FET was carried out by adjusting the position. In order to measure photoresponse as well as S-parameters with illumination, a noncoherent optical source (a Halogen lamp) was used for a simple and low-cost experimental set-up.

First, operating frequencies without illumination were measured with a constant drain-bias (3V and 5V) by tuning a gate-bias voltage (-0.2V to -1.5V). Next, the operating frequencies with illumination were observed as well. The Ka-band MMIC oscillator operated around 30.5 GHz and the V-band circuit oscillated around 51.4 GHz. The large difference between the designed frequency and the measured frequency resulted from accuracy of the FET model using in the design procedure. The gate-bias dependence of the operating frequency and their photoresponse for the V-band and the Ka-band oscillators are shown in Fig. 4 (a) and (b), respectively.

A peak-to-peak value from one line in Fig. 4 indicates an electronic tuning range. The maximum electronic tuning range from the Ka-band oscillator was 70 MHz and that from the V-band was 500 MHz. Meanwhile, difference between a couple of a solid line and a dashed line shows the photoresponse. The maximum optical tuning range of 32 MHz and 260 MHz were obtained from the Ka-band oscillator with Vds=3.0 V and Vgs=-1.2 V and from the V-band oscillator with Vds=3.0 V and Vgs=-0.4 V, respectively. On the other hand, a small optical tuning range of 3.0 MHz was observed with Vds=5.0 V and Vgs=-0.4 V. The smaller optical tuning range was observed with the relatively large Vds. This is because that most carriers were swept out by the large drain voltage and there were few carriers which can response the illumination.

In order to understand the mechanism of the optical / millimeter-wave device interaction, frequency dependence and photoresponse of the FET model parameters were appreciated using the parameter extraction. A microwave circuit simulator used is a commercial available simulator (HP-EEsof/Microwave Design System). Since an experimental set-up for a large signal measurement is not easily constituted in the higher frequencies, small signal S-parameters of the HJFET chip with/without illumination were measured in this paper. A small signal FET model used for the parameter extraction is shown in Fig. 5. Fig. 6 indicates the frequency dependence of extracted parameters such as gm, Ri, Cds and Cgd with/without illumination. On gm and Ri, small frequency dependence but photoresponse were observed. However, relatively large photoresponse was observed on Cds with 19.1% decrease as well as on Cgd with 46.7% increase at 15 GHz. Eventually, these two parameters have the same value and its value was 40.9% of Cgs under the illumination. As expected, Rds showed square or cubic dependence with respect to a frequency with slight influence by illumination. Based on this analysis, a new FET model was found to be required to explain the optical/millimeter-wave device interaction.

CONCLUSIONS

Optical tuning ranges were observed from HJFET MMIC oscillators operating at 51 GHz as well as 30 GHz. Using the parameter extraction, frequency dependence and the photoresponse were appreciated. Frequency dependence and large variation due to the illumination were observed on Cgd with 46.7% increase as well as Cds with 19.1% decrease. Using these data, research on a new FET model for the optical control of the MMIC oscillator with the HJFET has been started. In addition, fundamental data for the optical control of a millimeter-wave MMIC oscillator have been obtained, which is very useful for conversion between optical signals through the optical fiber and millimeter-wave radiation and receiving.

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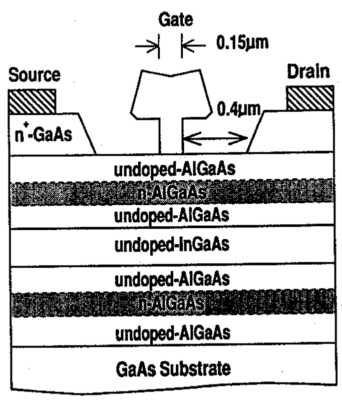


Fig. 1 Structure of HJFET for MMIC Oscillator

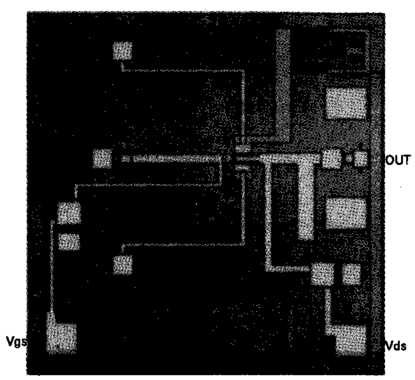


Fig. 2 Chip of V-Band MMIC Oscillator
(1.07mm by 1.07mm)

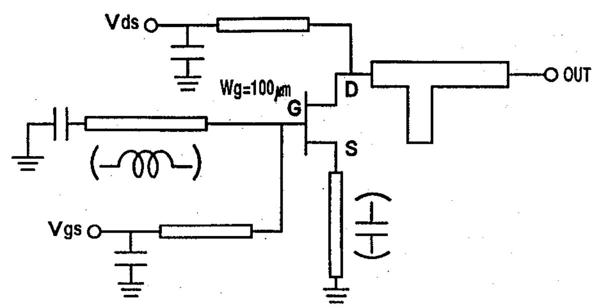


Fig. 3 Configuration of V-Band Oscillator

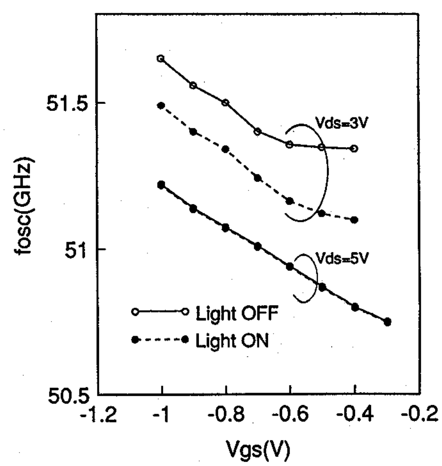


Fig. 4 Operating Frequency Variation
and Photoresponse of Oscillators

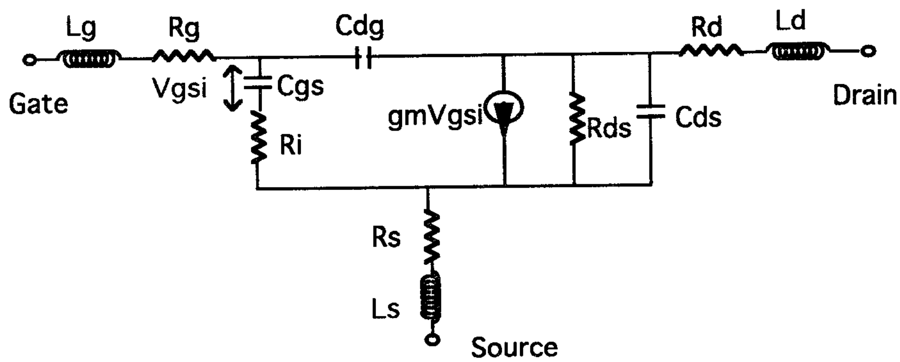
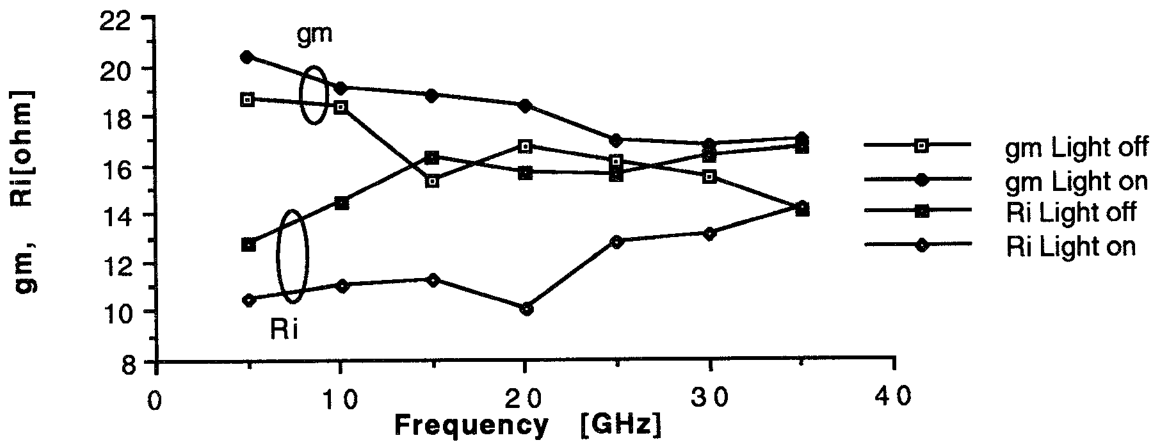
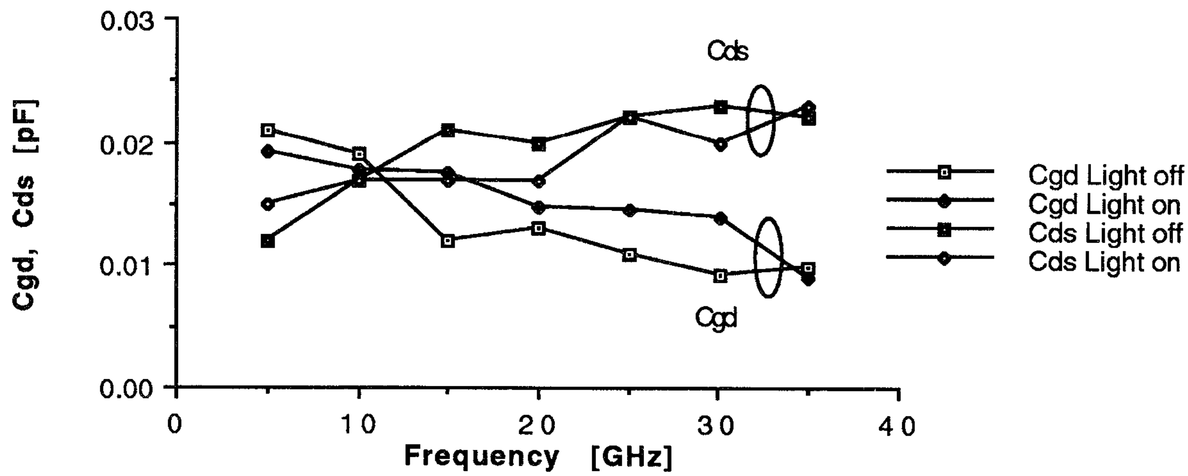


Fig. 5 Small Signal FET Model



(a) Photoresponse on gm and Ri



(b) Photoresponse on Cgd and Cds

Fig. 6 Frequency Dependence of Photoresponse on FET Model Parameters