BIAS AND GEOMETRICAL EFFECTS ON OPTICALLY CONTROLLED MESFETS

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ABSTRACT

A detailed characterization of the optical response of illuminated MESFETs due to several operating and geometrical conditions is presented. The characterization targets important optical performance factors including terminal photocurrent peak value and discharge time. A figure-of-merit is defined to quantify the overall response to these effects. The simulation results should be very useful in device operation and optimization.

I. INTRODUCTION

The performances of modern high-speed optoelectronic devices and circuits are improving at a fast pace and there is a growing interest in their modelling. Device modelling for circuit simulation provides an important facility towards linking new device development and its applications. Reliable modelling methods and simulation codes are becoming the basis for the optimizations development of emerging and future optoelectronic devices. Traditionally, the optoelectronics industry has relied mainly on experimental optimization - a costly and time-consuming process. Equivalent circuit models are very useful in describing the overall functionality of the circuits but not in providing accurate accounts of the physical phenomena.

For microwave and millimetre wave applications, simplified physical models based on the drift-diffusion equations and local field models are not adequate. These models assume that the carrier transport takes place under quasi-static and equilibrium conditions. The Boltzmann's Transport Equations (BTE), on the other hand, provide time-dependent representations of the carrier density, carrier energy and carrier momentum, and take care of sub-picosecond non-equilibrium transport. A numerical FDTD-based simulation algorithm that consistently solves the BTE under illumination conditions has been developed and rigorously validated and tested in several publications [1]-[3]. In this paper, a detailed analysis of the effects of biasing, geometrical and illumination conditions on the optical response of MESFETs is presented. The analysis targets two optical performance factors: terminal photocurrent peak value and discharge time. A figure-of-merit is defined to quantify individual effects on the efficiency of the device

II. DEVICE MODEL

In order to describe the illumination effects on the behavior of the active device, accurate modeling of the carrier transport as well as the illumination interaction mechanisms has to be accounted for. The carriers in sub-micrometer gate-length devices transport under non-isothermal and non-equilibrium conditions. As a result, appropriate account for the relationship between carrier transport parameters and carrier energy has to be made. Also, the spatial and temporal variations in the carrier momentum cannot be neglected. A transport model based on Boltzmann's transport equations, which account for these variations, is employed. On the other hand, illumination effects inside the active device are appropriately included by adequate representation of carrier photo-generation. The model equations are given by [3],

$$\frac{\partial n}{\partial t} + \nabla . J = G - R \qquad (1)$$

$$\frac{\partial e}{\partial t} + v.\nabla e + \frac{1}{n}\nabla.(nk_B T v) = -q(E).v - \frac{e-e_o}{\tau_e} \qquad (2)$$

$$\frac{\partial (mv_{x,y})}{\partial t} + v.\nabla(mv_{x,y}) + \frac{q}{n}\frac{\partial}{\partial x,y}(nk_B T) = -qE_{x,y} - \frac{v_{x,y}}{\tau_m} \qquad (3)$$

where, n is the electron density, v is the electron velocity, e is the electron energy, E is the electric field intensity, m is the electron effective mass, T is temperature and τ_e and τ_m are the energy and momentum relaxation times, respectively. The generation rate, G, is a function of optical intensity, I_o, material absorption coefficient, α, and spatial distribution, and is given by:

$$G = I_o \, \alpha \, e^{-\alpha y} \qquad (4)$$

A number of recombination processes can take place inside the active device such as the Shockley-Read-Hall process and the Auger recombination process. All of these processes contribute to the recombination rate, R.

Carrier generation due to the absorption of light and the subsequent recombination processes alter the distribution of carriers inside the device as given by the carrier conservation equation (equation 1). The absorbed light creates a disturbance in the carrier distribution inside the device, which in turn results in a change in the current densities. The moving free charges behave as sources of electric fields which alter the carrier velocity and energy. In this fashion, energy exchange between the device and the optical input is established.

The model equations are solved numerically using the finite-difference time-domain (FDTD) technique. The FDTD formulation is complemented with the definition of appropriate boundary conditions around the simulated structure. The dielectric constant of each region of the structure is incorporated in the formulation of Poisson's equation that is solved self-consistently with the device model equations. This procedure is marched in time until transient as well as steady state solutions are achieved. Details of the formulation and set-up of the numerical scheme can be found in [1].

III. RESULTS AND DISCUSSIONS

The current investigations are concerned with the optical response of the illuminated MESFET due to three groups of effects; electrical bias, geometrical variations and optical input conditions. In the first group, the variations in the gate-source and drain-source voltages are independently studied. In the second group, the variations in the device gate length and drain-gate spacing are studied. Finally, the third group includes the effects of the intensity and width of the input optical pulse. The MESFET is connected in a common-source amplifier configuration. Time-domain simulations of the device response to an optical Gaussian pulse with a spot size of 25 μm are shown in figures 1 and 2. All curves in all figures have been normalized to make relative comparisons readily observed and meaningful. The following simulation settings are used as general values unless the effect of a given parameter is studied; gate length=0.2 μm, drain-gate spacing=0.7 μm, active layer thickness=0.1 μm, active layer doping=2×10^{17} cm^{-3}, V_{ds}=2.0 V, V_{gs}=0.0 V, peak optical flux density=2×10^{21} $cm^{-2}.s^{-1}$, pulse width= 10.0 ps. Figure 1 shows the variation of output photocurrent in response to the three groups of effects. Each parameter is studied independently of the other effects. Whereas increasing V_{ds} will cause the output current to saturate, the drain-gate separation effect on the output current looks interesting. It increases sharply as the separation is increased from 0.3 μm to 0.9 μm because more MESFET surface is exposed to illumination resulting and more carriers are being generated and transported to the drain by the high field region. However, as the drain-gate separation is increased further, the increase in photocurrent peak value slows down. This behavior is due to the long journey that carriers have to travel to the drain contact. Chances of recombination become greater and less current is expected. Figure 2 shows the results due to the same kinds of parameter variations as in figure 1 but on device output discharge time. Both drain bias and drain-gate spacing significantly affect the discharge time. Large values of V_{ds} reduce the channel length and help flush-out the carriers out of the device effectively. On the other hand, the transit time from gate to drain delays the removal of excess charge from the device, and hence, increases the discharge time.

To quantify the trade-off between conversion efficiency and device switching characteristics, it is important to sum-up these effects in a single representative quantity. A figure of merit can be defined as

$$FoM = \frac{Peak\ Current\ Value}{Discharge\ Time} \qquad (5)$$

To maintain the highest possible level of optical-to-electrical energy conversion without significantly limiting the device switching speed, the *FoM* has to be maximized. In figure 3, the *FoM* is plotted versus all effects in the three groups. The plot is normalized by the maximum value of each case independently. The only case that the *FoM* shows a maximum within the range of consideration is in the drain-gate spacing curve, making this parameter a very important player in the device optimization process.

IV. CONCLUSION

The effects of operating and geometrical parameters on the optical response of illuminated MESFETs have been presented. The FDTD simulations of an energy-based model of carrier transport under illumination conditions were produced and analyzed. The optical performance of the device in response to a short-pulse illumination has been studied in terms of terminal photocurrent peak and discharge time. Using a defined figure-of-merit, the simulation results showed that optimum device operation under illumination can be predicted. In particular, electrode spacing plays an important role in device optimization.

Acknowledgments

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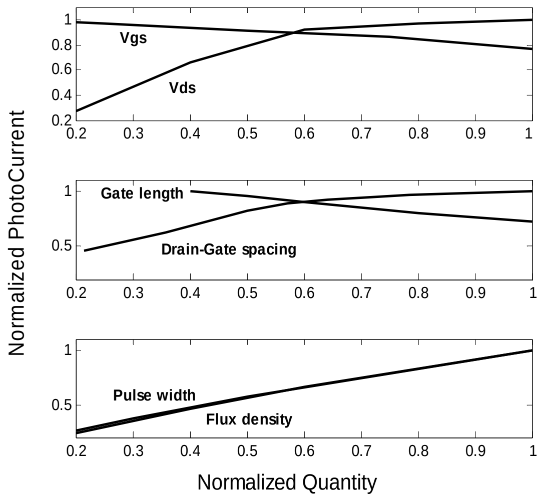

Figure 1. Effects of electrical bias, device geometry and optical input on output photocurrent. The output photocurrent in the figure is normalized to the maximum value in each case. The normalized x-axis corresponds to the following ranges: Vgs: 0 to -0.8 V, Vds: 1 to 5 V, gate length: 0.2 to 0.5 μm, drain-gate spacing: 0.3 to 1.4 μm, pulse width: 2 to 10 ps and flux density: 1 to 20 x10^{21} cm^{-2}.s^{-1}.

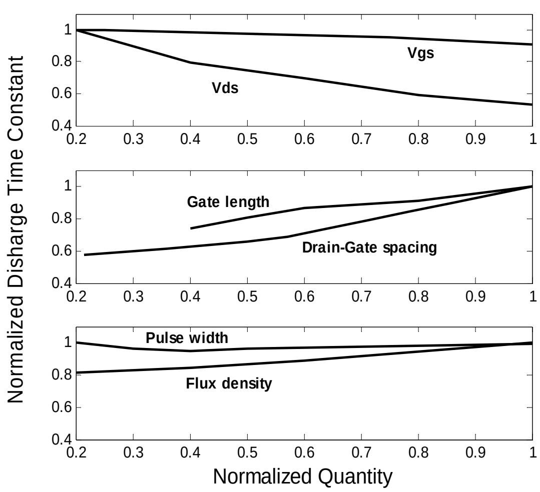

Figure 2. Effects of electrical bias, device geometry and optical input on output discharge time.

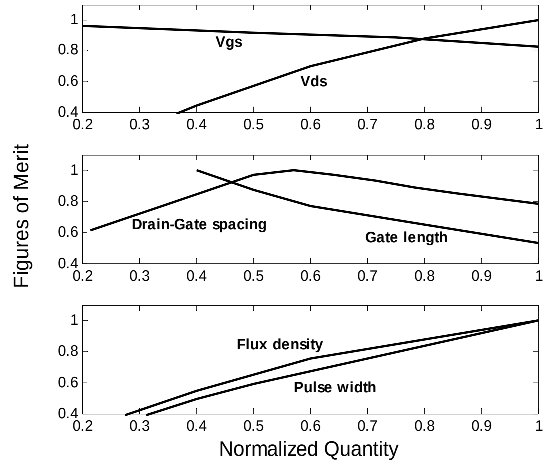

Figure 3. Figures of merit.