Simulation of Charge Transfer Process in a 2DEG-CCD

M. Aliyari and A. Bozorgmehr

***Abstract*—This paper describes the modeling and simulation charge transfer process of a 2DEG charge coupled device. We have introduced a new approach to calculate the scattering rate of two-dimensional electron gas in the transport channel of a 2DEG-CCD. This technique was applied to the investigation of the charge transfer process with ensemble Monte Carlo method.**

***Index Terms*—2DEG-CCD, charge signal, Monte Carlo, Transfer efficiency, Transit time.**

I. Introduction

Charge Coupled Devices made on silicon have found wide application in imaging and signal processing. These applications have a low-speed operations but, the CCDs for microwave frequency are not suitable. Hetero-junction CCDs, have been demonstrated to have many advantages over earlier silicon and GaAs structures because of their higher low-field mobility and saturation velocity. The operation of these structures are limited only by the saturation velocity of the carriers which results in an upper frequency limit of approximately 40GHz. Microwave frequency filters such as , transversal filtering, correlation, and variable delay line could be accomplished by the CCDs based on this technology. These filters would find many uses in microwave frequency applications such as personal mobile communication devices and in the communication systems [1]-[5]. In this work, charge transfer process of a 2DEG-CCD by ensemble Monte Carlo method is simulated. In the simulation we used a simplified structure that reported in [6] with difference that a cermet film is used to encapsulate the inter-electrode gaps. The cermet film results in a monotonic variation of the surface potential between the electrodes at all clock frequencies [7]. As a consequence, energy troughs which would otherwise be produced in the active layer under the inter-electrode gaps are removed. This eliminates the possible performance degradation caused by the retention of passing signal charges, thus effectively increasing the charge transfer efficiency (CTE) of the device. This structure also eliminate the need of submicron (<0.5gm) inter-electrode gaps[8]. Since the surface potential between the electrodes vary linear calculating the scattering in all mesh point is very complex. Therefore, a simple approximation to this problem is more convenient. Thus we propose a new approach to simulating the charge transfer in the CCD that will be described in the section III. In the following, first, charge transfer is simulated for GaAs channel material system and then effect of choice of material system upon speed of charge transfer is discussed. It was observed that transit speed will be changed with type of channel material that is because of the difference low-field saturation velocity of channel materials.

Manuscript received August 12, 2012; revised October 13, 2012.

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II. Device Architecture

The simplified structure of double delta-doped hetero-structure CCD is shown in Fig. 1, it can be seen that the layer structure and geometrical layout of this device is extremely similar to that of a double delta-doped pseudomorphic HEMT. In the case of the hetero-structure CCD, the length of the gate electrodes is 0.25 μm, and its chosen gate width is 100 μm. The length of the inter-electrode gap is 0.8 μm. Special care has to be taken when the length of the gate contacts is chosen, as this directly affects the time constants of the charge transfer mechanisms [6]. The GaAs transport layer is sandwiched between two doped (> 1018 cm-3) AlGaAs layers. The device is completed with ohmic contacts located at the beginning and at the end of the structure and also the inter-electrode gaps are covered by the cermet film. Charge confinement in the transport layer is important in order to ensure that the device has good charge transfer efficiency.

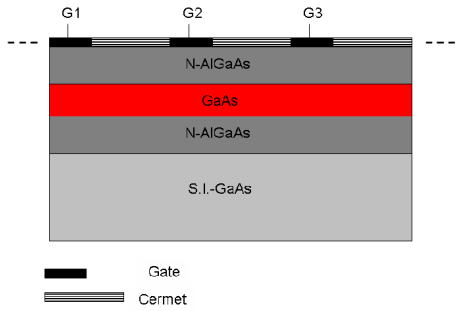


Fig.1. The side schematic of a 2DEG-CCD.

$$V_{CH}(x)=\left(\frac{-qQ_C(x)}{\varepsilon_A}+\frac{qN_{d2}d_{d2}\varepsilon_G}{\varepsilon_A^{\,2}}\right).d_{d1}+\frac{qN_{d1}d_{d1}}{\varepsilon_A}\left(\frac{d_{d1}}{2}\right)+V(x)-\phi_B+\Delta E_C \quad (1)$$

Conventionally, the study of any new CCD structure begins by obtaining an equation that relates the channel potential in the device to the charge packet density in the channel and to the applied gate voltage as it is the "formation and destruction" of potential wells in the device that provides the mechanism of charge transfer. Under the assumption that channel quantization effects can be neglected, a 1-D Poisson's equation is solved in order to obtain a simplified approximation of the 2-D electron gas CCD (2DEG-CCD)'s channel potential beneath a single Schottky gate. The approximated channel potential equation for this device structure is found to be as follows:

where dd1 is the first doped AlGaAs layer, dd2 is the

DOI: 10.7763/IJIEE.2013.V3.286

thickness of the second doped AlGaAs layer, ϕ_B is the Schottky barrier height, εG is the dielectric permittivity for GaAs, εA is the dielectric permittivity for AlGaAs, ΔE_C is the conduction band discontinuity, $V(x)$ is the surface voltage, and QC is the electron channel density per unit area.

III. Model

The main difficulty of the Monte Carlo simulation of this device arises from the variation of the surface potential in the inter-electrode. In order to overcome this problem we employ a new approach that based on the triangle potential approximation model described in the [9]-[11], The approach is the calculating of scattering rate in the stepwise potential, instead calculating the scattering rate in all mesh point .we can perform this function by assuming a stepwise changes of the potential in the inter-electrode and calculating the scattering in some limited mesh points. Indeed, we modeled the linearity to step change. Two type step approximations are shown in the Fig. 2. But, In this paper we consider second state (Fig. 2-b). In order to simplicity the simulation process, the below approximations are employed:

1) The potential profile perpendicular to the channel is assumed to be a triangle (triangle potential approximation).
2) The lowest three subbands are taken into account and the wave functions given in are employed.
3) The scattering processes taken into account due to acoustic-phonon, non-polar optical phonon, intervalley and poplar optical phonon scattering.
4) A two-valley model is employed.
5) The current flowing in direction perpendicular to the semiconducting layers is negligible.
6) The current flowing in the active channel is one-dimensional.

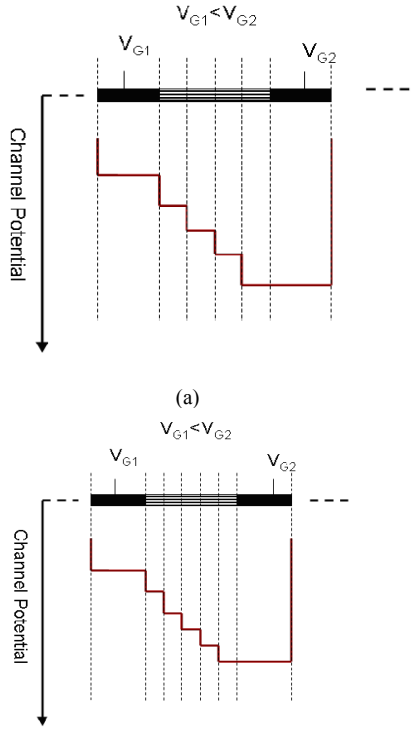


Fig. 2. The stepwise changes of the maximum potential profile along device for two states.

IV. Simulation

Charge packets in a 2DEG-CCD are normally attracted to wells of higher potential, and as these wells fill up, their potential level reduces accordingly, and vice versa, as can be derived from equation (1). In the simulation, Charges signal were assumed to be confined initially under the first electrode. Squared initial charge distribution was assumed throughout. Charge transfer was affected by raising the potential on one of the outer electrodes. The charges emptied from under the first electrode to the potential maximum under the destination electrode. In order to investigating the performance of the CCD, in the following, evolution of the charge signal and charge transfer efficiency were simulated for two material systems.

A. Evolution of the Charge Signal

The peak charge density of the signal is assumed to be 2×1012cm-2 and the applied voltages were 0, 1, and -1 V for the neighboring electrodes. In the following, time evolution of signal for AlGaAs/GaAs system at four times is calculated and shown in the Fig. 3. As observed, after 2ps all of the initial charge had been emptied from the first electrode. This time is shorter than transit time of GaAs-CCD, It means that the use of the hetero-structure will be optimized the operation of CCDs[12].

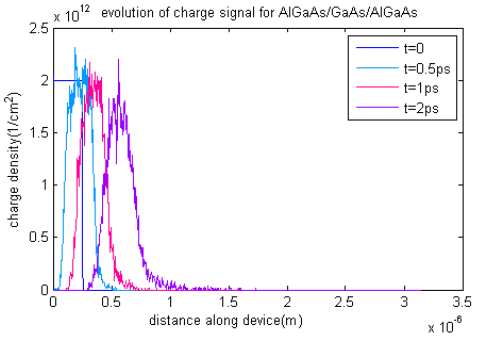
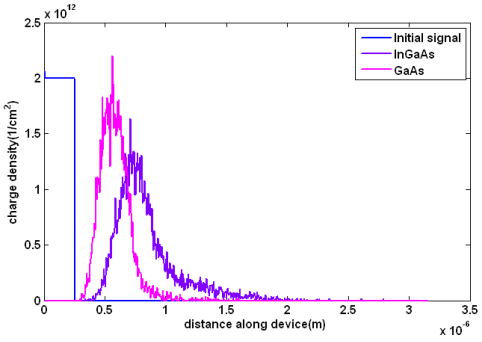


Fig. 3. Time evolution of the charge signal at t=0, 0.5, 1, 2ps for AlGaAs/GaAs material system.

B. Effect of Choice of Material System upon Speed of Charge Transfer

One of the important material systems used for the 2DEG-CCD is InAlAs /InGaAs /InP system. The time evolution of charge signal for this system at time=2ps is shown in the Fig. 4. As observed, the speed of charge transfer in the InAlAs/InGaAs system is higher than the AlGaAs/GaAs system. It means the charge signal is transferred in the shorter time.



(b)

Fig. 4. Comparing the transit speed of charge signal at t =2ps for two material systems.

Usually, the performance of the CCD is analyzed with the transfer efficiency quantity, which is defined as the ratio of Qtr/Q0 where Qtr is the amount of charge transferred forward to the collecting electrode and Q0 is the initial charge under the emptying electrode. The time dependent charge transfer efficiency (CTE) of two the systems is shown in Fig. 5. It was observed that transit time (1.2ps) in the InAlAs /InGaAs system, is shorter than the AlGaAs/GaAs system. This is because of the higher low-field saturation velocity of InGaAs versus GaAs. Therefore, the charge signal in the InAlAs /InGaAs system will be transferred with high speed.

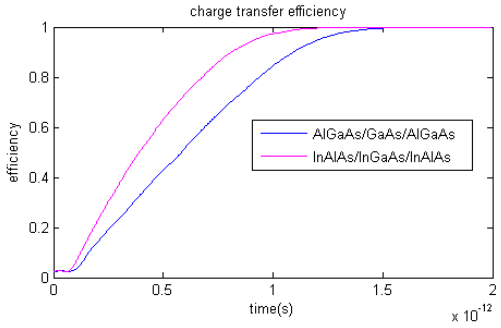


Fig. 5. Comparing the time dependent charge transfer efficiency of two material systems.

V. Conclusion

A detailed study and simulation of the 2DEG-CCD structure has been presented. As shown the charge transfer process with a new approach that described above could be simulated with M.C method. The important result is that this type structure potentially could be used to design 2DEG-CCD delay lines or shift registers and by applying the appropriate material, speed of the device will be optimal.

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