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# Investigation of HEMT and MESFET with Notch in Side of Drain

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**Abstract:** In this study, we investigate the requirement of high electron mobility field-effect transistors with hetero-structure and evaluate its performance at the high-frequency circuits. Needs, benefits and so computing the transistor are fully described. High electron mobility transistors are divided into three groups: pHEMT, mHEMT and induced HEMT. Quantum mechanism of electron in the channel and potential wells provides the most traits for high frequency transistors. Through drift-diffusion simulation shows that gate with small notch in side of the drain, can improve drain current and cutoff frequency. This indicates that without changing the gate length, capacitor of gate-source can be reduced.

**Key words:** Quantum Well FETs (QWFETs), High Electron Mobility Transistor (HEMT), quantum well, two Dimensional Electron Gas (2DEG), drift

## INTRODUCTION

According to the growing pace of development especially in electronics, require fast data transfer, processing and storage of information, it can be seen any more. We know that there are a large number of transistors in each system. So, to speed, it is necessary to use high-speed transistors. As the electrons move faster in the transistor channel and the channel length pass faster, transistors are faster and can be used in high frequency applications. This study examines the field effect transistor metal-semiconductor (MESFET) explains.

To increase the transition guidance (conductance transmission) in MESFET, the channel conductance increased as much as possible. Obviously, the conductivity can be increased by increased doping impurities in the channel (Sze and Ng, 2007). This increases the density of carriers in the channel. But, increasing carrier density increases collision and dispersion (scattering) by ionized impurities that reduce mobility. Equation 1 shows the inverse relationship of increase impurity with electron mobility due to scattering of carriers. Mathematical equation derives from the behavior of actual transistors:

$$\mu_i \propto \frac{T^{3/2}}{N_L m^{1/2}} \qquad (1)$$

That $\mu_i$ is mobility of impurities and $N_L$ is ionized impurity density. T and m parameters are electron temperature and mass, respectively (Streetman and Banerjee, 2009). Figure 1 shows this subject to the right. Thus, increasing the impurity cannot solve the problem. Another way to increase the speed of the electron mobility in the channel can be applied to the use of energy gap features in the channel by the structure of heterogeneous (Hetero-Structure). The transistor using this feature is named high electron mobility transistor, say briefly HEMT which provides increased the electron mobility in the channel.

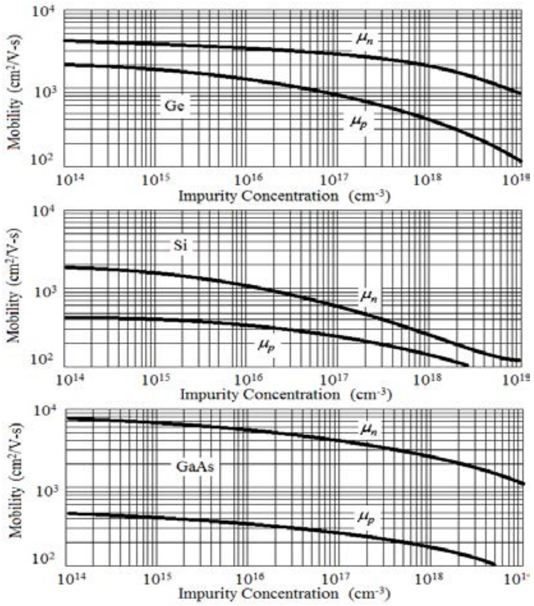

Fig. 1: Carrier density versus mobility of electrons and holes of Ge, Si, GaAs semiconductors, sequentially (Sze and Ng, 2007)

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This research goes back about 50 years ago by two Frenchmen on 28 March 1979 the final model to be recorded eventually (Mimura *et al*., 1980; Dingle *et al*., 1987; Delagebeaudeuf *et al*., 1980).

## MATERIALS AND METHODS

**Quantum mechanism:** HEMT structure that combines at least two different lattices constant is used in the channel of a transistor. Different lattice constant creates different energy gap between the two materials. So that a narrower band gap material is surrounded by a material with a wider band gap. This behavior is known modulation doped (Tsividis, 1998).

For more efficiency, impurity injection and HEMT structure can be used together. It means that there are not any impurities in the material which used in the channel. But next to it is a material cause of formation of impurities to give donors. It is therefore important to use group III-V of Mendeleev table in our transistor in order to have a different lattice constant and different energy band. Thus heterojunction structure causing the quantum wells.

The compounds can be used in these structures are: $In_xGa_{1-x}As$, $Al_xGa_{1-x}As$, InGaAsP, $In_xAl_{1-x}As$, InAs and InSb with GaAs and InP. Among these materials, the first two compounds most used, due to higher efficiency in practice. Because they have better answers.

Special property of these materials is that they can easily be used as high doped or non-doped semiconductor. According to tests, the energy gap of each of these compounds can be defined as a mathematical expression. In the following two equations for the energy gap of $In_xGa_{1-x}As$ and $Al_xGa_{1-x}As$ are presented, respectively:

$$Eg_x^{(ev)} = 1.425-(x\times 1.501)+(x^2\times 0.436) \tag{2}$$

$$Eg_x^{(ev)} = 1.422-(x\times 1.2475) \tag{3}$$

In Eq. 2 and 3, the variable x represents the ratio of the composition. For example, if $Al_xGa_{1-x}As$/GaAs is used; donor impurities or electrons fall into GaAs potential well from AlGaAs. So, we can make a channel with a large number of carriers without the effect of n-type material that is characterized by the scatter of ionization donors (Fig. 2).

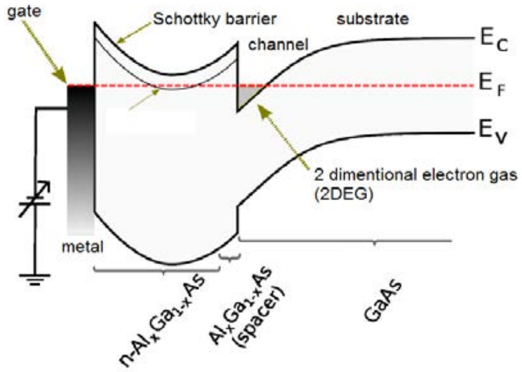

Fig. 2: A view of the energy band MESFET transistors heterojunction using AlGaAs/GaAs. The Fermi level of the metal gate is aligned with the other Fermi levels. Schottky barrier is created by a metal-semiconductor junction. Because of the field, depletion region is created in semiconductor near the metal contact. Also at the contact of two semiconductors, the depletion region in AlGaAs and electron accumulation in two dimensional electron gas GaAs are created

This heterojunction, causing the accumulation of electrons in GaAs and the border forming a very thin layer of Two-dimensional Electron Gas (2-DEG) which reduces ionizing impurity scattering by electrons away from the donor and high electron mobility in the channel. So, scattering is low in well and electron mobility is very high in the channel. This effect especially in low temperature that lattice scattering (phonons) is low is significant.

AlGaAs layer in junction area, completely emptied from electrons and in GaAs layer, at a distance of <100 Angstroms accumulate high density. Therefore, due to the drain of the transistor MESFET, this structure behaves like a MOSFET. Due to the greater electron affinity GaAs ($\chi$ = 4.04 eV), quantum well with bends and steep side of the GaAs channel is formed.

**Types of HEMT:** Based on the different lattice constant between two dissimilar semiconductors and contact conditions and link them together, three HEMT is defined (Mimura, 2002).

**pHEMT:** pHEMT is abbreviation for Pseudomorphic HEMT. Typically two materials with the same lattice constant are used for heterojunction connect. In practice, e.g., AlGaAs on GaAs, the lattice constants are typically slightly different, resulting in crystal defects. As an analogy, imagine pushing together two plastic combs with a slightly different spacing. At regular intervals, you'll see two teeth clump together. In semiconductors, these discontinuities form deep-level traps and greatly reduce device performance. A HEMT where this rule is violated is called a pHEMT or pseudomorphic HEMT. This is achieved by using an extremely thin layer of one of the

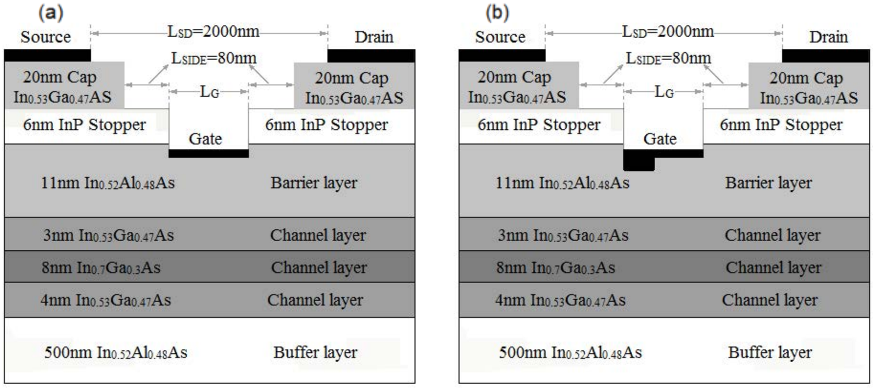

Fig. 3: A view of the simulated transistors In0.7Ga0.3As. TINS is barrier layer thickness (separation), TCH is channel thickness, LSD is distance between the source and drain and LSIDE is distance between the gate and drain and source contacts layers. The gate length is considerate 50 nm: a) MESFET without notch in side of drain and b) MESFET with notch in side of drain. Indent height is 3 nm and indent length is 20 nm

materials so thin that the crystal lattice simply stretches to fit the other material. This technique allows the construction of transistors with larger bandgap differences than otherwise possible, giving them better performance.

**mHEMT:** Another way to use materials of different lattice constants is to place a buffer layer between them. This is done in the mHEMT or metamorphic HEMT, an advancement of the pHEMT. The buffer layer is made of AlInAs, with the indium concentration graded so that it can match the lattice constant of both the GaAs substrate and the GaInAs channel. This brings the advantage that practically any Indium concentration in the channel can be realized, so the devices can be optimized for different applications (low indium concentration provides low noise; high indium concentration gives high gain).

**Induced HEMT:** In contrast to a modulation-doped HEMT, an induced high electron mobility transistor provides the flexibility to tune different electron densities with a top gate, since the charge carriers are "induced" to the 2DEG plane rather than created by dopants. The absence of a doped layer enhances the electron mobility significantly when compared to their modulation-doped counterparts. This level of cleanliness provides opportunities to perform research in the field of Quantum Billiard for quantum chaos tidies or applications in ultra-stable and ultra-sensitive electronic devices.

## RESULTS AND DISCUSSION

In this study, we design a new structure of mHEMT. Figure 3 shows the structures of simulation. Our design (Fig. 3b) improves the cutoff frequency and drain current. Also the power and operating frequency of these kinds of transistors goes up.

Usually the threshold voltage ($V_t$), Sub threshold Slope (SS), Drain Induced Barrier Lowering (DIBL) and the ratio of on curren ad of current ($I_{ON}/I_{OFF}$) are considered. The optimum condition occurs when $V_t$ and $I_{ON}/I_{OFF}$ great values as well as DIBL and SS are low. The transistors were put in bias supply (Kim *et al*., 2007) and Fig. 4-6 were obtained. One of the goals of heterojunction transistors is reducing short channel effects due to the channel length is reduced. Try that Moore's law, the size of the transistor channel length decreased, especially to increase the number of transistors on a chip.

Increasing the gate length is causing a change in the depletion region capacitor and causing reduced sub threshold slop and thereby increases the threshold voltage and DIBL (Kim ***et al***., 2007). $V_t$ is defined as a value of gate voltage where the drain current (ID) corresponds to 1 μA/μm. Then, $I_{ON}$ is determined from the value of ID at which $V_{GS}$ corresponds to approximately, two-third of $V_{CC}$ above $V_t$ In a similar manner, $I_{OFF}$is chosen as ID where $V_{GS}$ is one-third of $V_{CC}$ below $V_t$. So, the ratio $I_{ON}/I_{OFF}$ increases. But, this condition is caused by the long channel. HEMT structure that makes use of these terms in shorter gate lengths is provided.

In the long-channel transistors, the effect of bulk is dominant to check mobility carrier in the channel. But the little gate, caused by ballistic effect, channel length dependence of the channel resistance is low and the channel resistance can be neglected in the shortest channel. Because the dimensions of the transistor (gate length) with the mean free path of electrons in the channel are comparable.

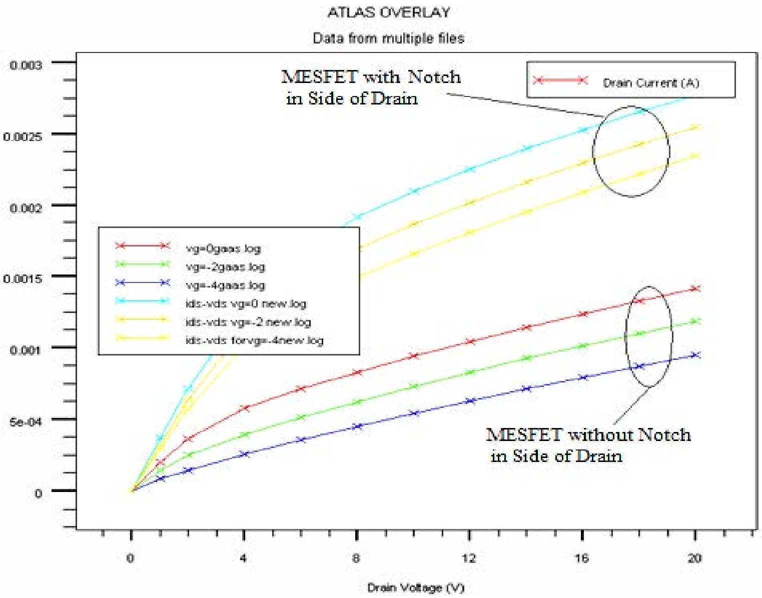

Fig. 4: The n characteristic curve. MESFET with and without notch in side of drain. It shows that notch in gate improves the current and so power

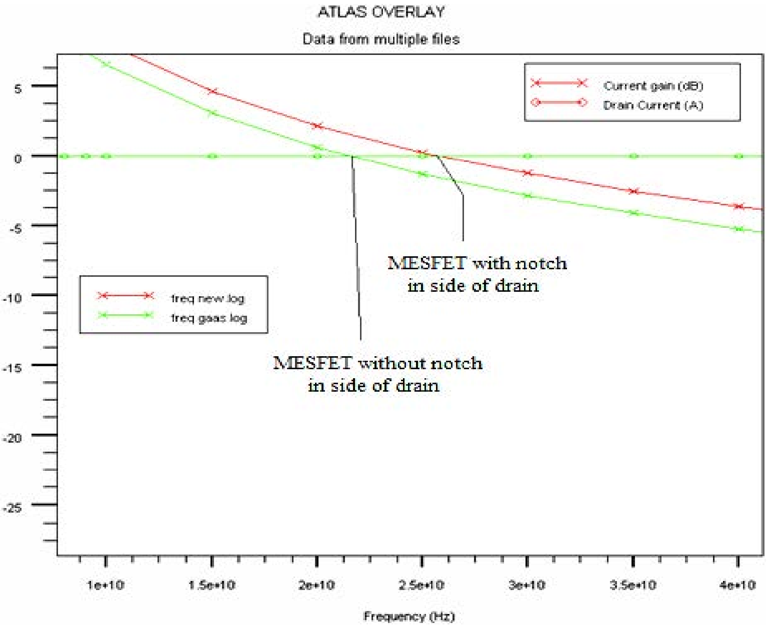

Fig. 5: Cutoff frequency. MESFET with and without notch in side of drain. It shows that notch in gate improves the cutoff frequency

## CONCLUTION

Using the indented area without changing the gate length, gate-source capacitance decreases. Because the edges of the gate capacitance decrease cause of notch drain drifted region, expand the depletion layer of the source drain reduced effectively.

We simulated two kinds of MESFETs: with the notch in side of the drain and without a notch in side of the drain. The gate length is equal in both cases and can be seen in the case of the indented area, there is a decrease in the capacitance of the gate-source considerable increase in cutoff frequency.

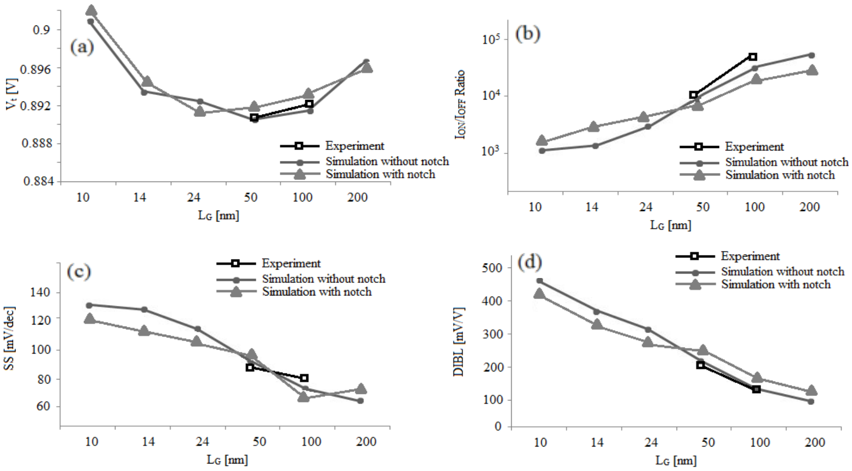

Fig. 6: Vt, ION/IOFF, SS and DIBL at high electrom mobility transistor In0.7Ga0.3As with different gate length. The thickness of the barrier layer (separator) is 7 nm, the distance between the gate and the source and drain is 80 nm and channel thickness is 15 nm. Bias values by Kim *et al*. (2007) is obtained. Gate length varying from 10-200 nm is considered

An interesting feature of the HEMT is that in a very thin layer near the gate, high density of electrons can create without any injection impurities and reduce the effect of scattering.

Using the compounds InGaAs, InAs or InSb with a high proportion of In, gives capable of fast transfer of electrons in the channel. These features include: low-valley electron mass, reduced impurity scattering due to modulation doping, reduced interface roughness scattering because of epitaxially grown smooth interfaces and large energetic separation between and L-valleys Fig. 6. The low electron transport mass coupled with minimal back scattering from the channel back into the source gives rise to higher source side effective injection carrier velocity ($v_{eff}$).

The high performance HEMT appears for high cutoff frequency components of access time (access time) prompt. Therefore, for applications in high frequency switching circuits can be a good choice.

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