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# Self-Assembled InAs Quantum Dots Buried in AlGaAs Barrier and Their Application to Split-Gate HEMT Operating at 77K

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## 1. Introduction

There have been keen efforts to study transport phenomena in semiconductor devices such as high electron mobility transistor (HEMT) structures with self-assembled InAs dot[1][2][3] and the charging of InAs dots with up to 6 electrons were observed in the split-gate HEMT structure [3]. However, the maximum temperature for observation of charging effect was limited to approximately 40K due to the electron confinement strength in InAs dot buried in GaAs. We have fabricated a split-gate double heterojunction field-effect transistor (DHFET) structure with InAs dots buried in AlGaAs barrier for higher temperature observation of single electron transfer. In this report, fabrication of self-assembled InAs dots on AlGaAs is described and charging effect of InAs dots on the current voltage characteristics measured at 77K will be discussed.

## 2. Experiment

The heterostructure of the device is shown in Fig. 1(a). The 6000 Å of GaAs buffer layer was grown on semi-insulating GaAs substrate, followed by 3000Å of AlGaAs buffer, 1.5 mono-layers (ML) of InAs, 100Å of AlGaAs barrier, 100Å of GaAs channel, 100Å of AlGaAs barrier layer, 700Å of n-AlGaAs barrier layer, and 100Å of n-GaAs cap layer. The InAs dots were formed during the 1.5 ML of InAs layer growth 100Å below the GaAs channel. The InAs dots were grown by Stranski-Krastanov mode which has been extensively studied so far [4]. The average areal density of the dots grown on AlGaAs was estimated to be $1.1\times10^{11}cm^{-2}$ which is higher than the counterpart grown on GaAs, i.e., $2.5\times10^{10}cm^{-2}$. The energy band diagram near the channel and InAs dots is shown in Fig.1(b). The average size of the InAs dots grown on AlGaAs were estimated to be 25Å in height and 190Å in base width which turned out to be smaller than InAs dots grown on GaAs layer by a factor of 1/3 in volume and 2/3 in base width or in dot height by AFM observation as shown in Fig.2. This difference corresponds to self capacitance difference by a factor of 1/2. Therefore, the effect of InAs dot charging through the modulation of the gate potential is expected to be seen at high temperature because of the smaller dot size and higher electron confinement.

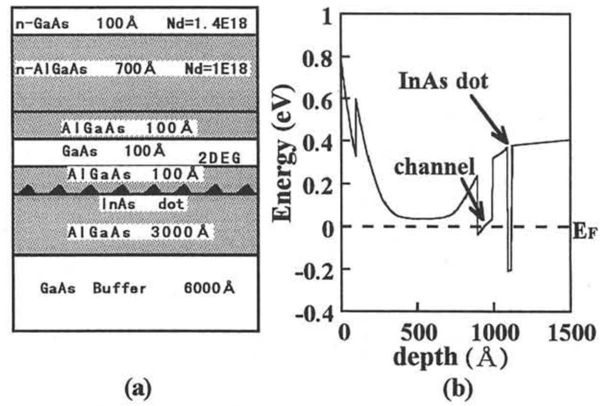



Fig.1 Heterostructure of the double heterojunction split-gate HEMT device (a). The energy band diagram of the DHEMT with InAs dot (b).

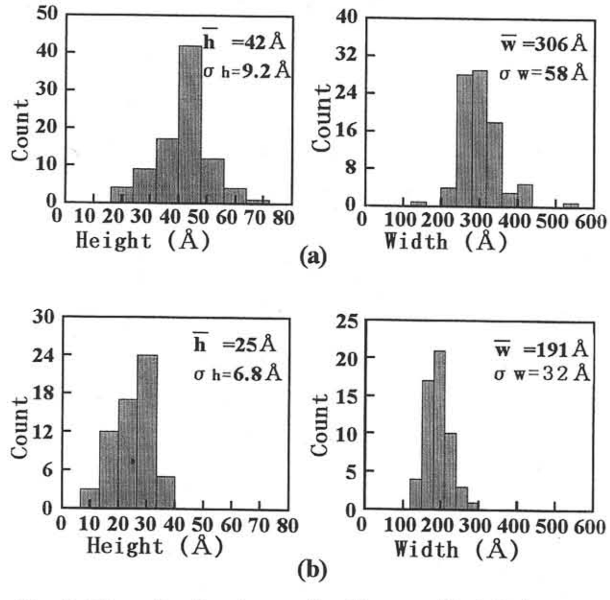
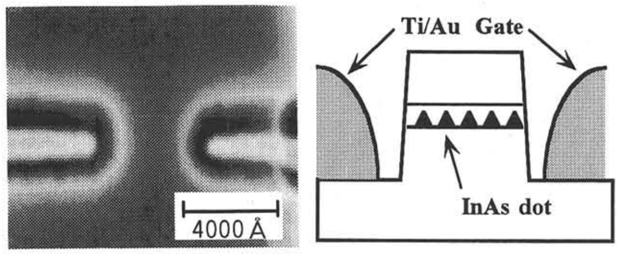



Fig.2 Size distributions of self-assembled InAs quantum dots grown on (a) GaAs and (b) $Al_{0.3}Ga_{0.7}As$.




(a) (b)

Fig.3 The SEM microphotograph of the channel area. The split-gate was defined by electron beam lithography resulting in confined channel area to be 4000Å x 4000Å.

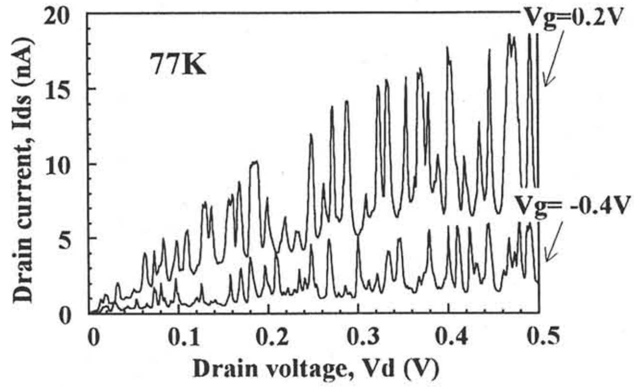



Fig.4 Id-Vd characteristics of the device measured at 77K. The observed current peaks are presumably caused by tunneling of electrons into InAs dots from the channel.

The split-gate HEMT structure with InAs dots was fabricated and its channel area were defined by electron beam lithography to be 4000Å x 4000Å as shown in Fig.3, resulting in approximately 170 InAs dots in the channel area surrounded by source, drain and split-gate. Only a few dots near the source edge of the channel are expected to play a crucial role in charging effect on the current transport through adjacent quasi 1-dimensional channel created by split-gate potential modulation.

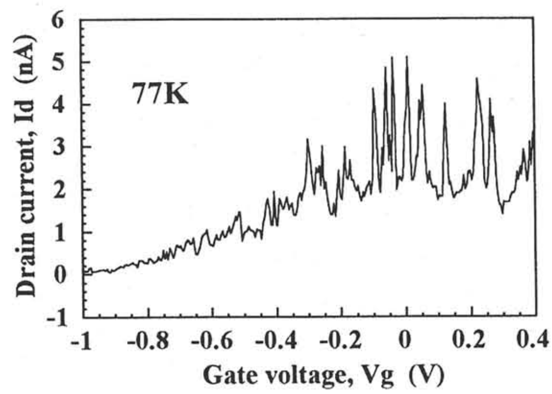



Fig.5. Id-Vg characteristics measured at 77K. The peak period of ≈ 50meV corresponds to ≈3.2 aF in terms of Coulomb energy.

## 3. Results and Discussions

Current voltage characteristics of the device measured at 77K is shown in Fig.4. The peculiar current peaks are seen against drain voltage where gate voltage was taken as a parameter. Id-Vg curve in Fig.5 shows pronounced current peaks when the gate voltage exceeds approximately -3.0V. The current oscillations are presumably caused by tunneling of electrons into InAs dots from the channel and subsequent potential modulation[5]. The peak period of ≈ 50meV in Id-Vg curve corresponds to 3.2 aF in terms of Coulomb energy, which turns out to be in the same order as the self-capacitance of the InAs dots buried in the AlGaAs barrier in adjacent to the channel. The randomness and the complexity of the current peaks in both Fig.4 and Fig.5 possibly originate from the involvement of multiple InAs dots in the I-V characteristics as suggested above.

## 4. Conclusions

A series of distinct current peaks measured at 77K has been reported for the first time in a GaAs/AlGaAs HEMTs with self-assembled InAs dots formed on the bottom of the channel. These peaks are attributed to the tunneling of electrons from the channel to the InAs dots.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