Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 706-708

A Novel Electron Wave Interference Device Using Multiatomic Steps on Vicinal GaAs Surfaces Grown by MOVPE: Investigation of Transport Properties

Masashi AKABORI, Junichi MOTOHISA, Tomoki IRISAWA, Shinjiroh HARA, Jun-ya ISHIZAKI, Kazunobu OHKURI and Takashi FUKUI

Research Center for Interface Quantum Electronics, Hokkaido University, North 13 West 8, Sapporo 060, Japan, Fax : +81-11-716-6004, Phone : +81-11-706-7172

We have studied the transport properties of a novel lateral surface superlattice type of electron wave interference devices in which multiatomic steps are utilized to introduce periodic potentials into two dimensional electron system. The device structure was fabricated by metalorganic vapor phase epitaxial growth on vicinal GaAs surfaces and spontaneously formed multiatomic steps were embedded at the heterojunction of n-AlGaAs/GaAs. Oscillations of the transconductance as a function of gate voltage were found in two different devices. Our simplified analysis suggests that the oscillations found in the different devices results from the potentials induced by the multiatomic steps but may not totally from coherent interference. Our results also imply the effect of the randomness in the periodic potentials in the characteristics of the electron wave interference devices.

1. Introduction

Recently, much interest have been paid to the fabrication, characterization and application of quantum structures. In particular, various types of electron wave interference devices (EWIDs) have been proposed and their basic characteristics have been reported. Among them, an EWID of a lateral surface superlattice (LSSL) type [1-3] has an advantage that a field effect transistor (FET) type of devices can easily be realized.

In this paper, we report on the electron transport in a new type of EWID [4], in which lateral periodic potential induced by multiatomic steps [5] on vicinal GaAs surfaces are utilized to bring forth and control the interference of electron waves. Since the period of the LSSL is about 60 ~ 80nm, the present device is expected to exhibit a superior characteristics as compared to the previously reported LSSL type of EWIDs [2,3] and offers a new regime in the transport of the modulated two dimensional electron gas (2DEG).

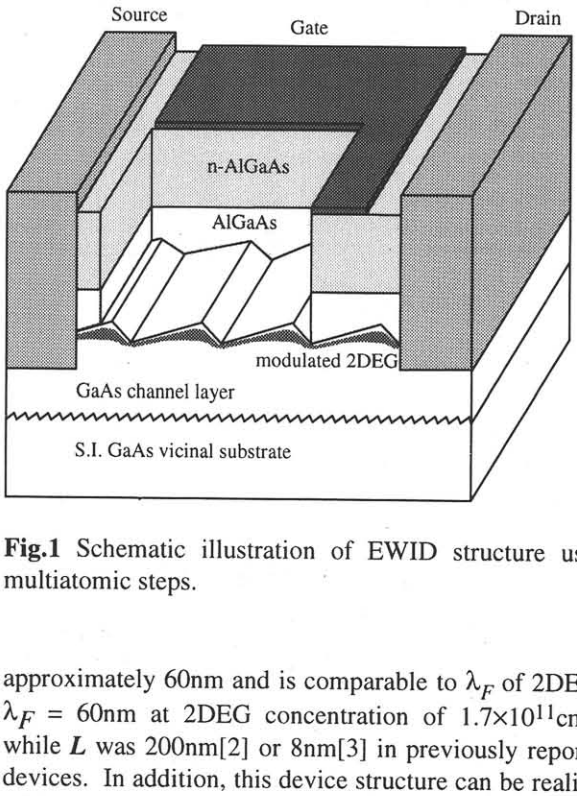

Fig.1 Schematic illustration of EWID structure using multiatomic steps.

2. Device Structure and Fabrication

The proposed device structure is schematically shown in Fig. 1, and is basically a selectively doped AlGaAs/GaAs heterostructure formed on GaAs vicinal substrates by metalorganic vapor phase epitaxy (MOVPE). In this device, the important difference from conventional selectively doped heterostructures is that the interface between GaAs and AlGaAs is periodically corrugated because of the multiatomic steps formed during MOVPE growth of GaAs channel layer. Such corrugation introduces periodic potential modulation into 2DEG at the heterointerface. Due to the LSSL thus formed, the interference of electron waves takes place due to coherent transmission through and reflection by the potential barriers when the current is perpendicular to multiatomic steps. It can also be controlled by changing Fermi wavelength λ_F of electrons via gate electric field.

The present device is expected to exhibit superior characteristics as compared to previously reported LSSL type of EWIDs, because the period L of LSSL approximately 60nm and is comparable to λ_F of 2DEG (λ_F = 60nm at 2DEG concentration of 1.7×10^{11}cm^{-2}), while L was 200nm[2] or 8nm[3] in previously reported devices. In addition, this device structure can be realized without any damage-introducing processes because of in-situ self-organizing nature in the multiatomic step formation. It is also noted that the period and the amplitude of potential modulation in LSSL can be controlled by the crystal growth conditions.

We grew and fabricate the device structure of Fig. 1 by MOVPE growth, where TEAl, TEGa, AsH_3 and SiH_4 were used as source materials. First, 1μm GaAs channel layer was grown on GaAs (001) vicinal substrates to form multiatomic steps. The substrates were misoriented by 2.0° towards the $[\bar{1}10]$ direction. Next, 10nm undoped and 60nm doped AlGaAs, and 10nm GaAs cap layer were successively grown. After the growth, a hall-bar pattern with a gate was formed by conventional photolithography, wet etching and lift-off technique, so that the channels are defined *across* the multiatomic steps. The width and length of the gate were 50μm and 400μm, respectively. In the present study, we prepared two types of devices from epitaxial layers grown in the different growth conditions. In sample A, the GaAs channel layer was grown at TEGa partial pressure of 8×10^{-6} atm, whereas in sample B, the TEGa partial pressure was 4×10^{-6} atm. This change in the growth conditions lead to the change of the morphology of the GaAs surfaces and the multiatomic steps, as will be described later. The growth temperature was 600°C in both samples.

3. Experimental Results and Discussions

3.1 Surface morphology of GaAs channel layer

We first investigated the surface morphology of GaAs channel layers by atomic force microscopy (AFM). For this purpose, GaAs layers were grown in the same conditions as in the channel layer growth of sample A and B. The results of AFM observations are shown in Figs. 2(a) and 2(b), which respectively correspond to the GaAs surface grown at higher and lower TEGa partial pressures. We can see the drastic difference in the surface morphology between two samples. At higher TEGa partial pressure ($=8\times10^{-6}$ atm), extremely coherent and regular array of multiatomic steps was observed as shown in Fig. 2(a). The average period L and height of multiatomic steps was measured to be 54.4nm and 1.90nm, respectively. The standard deviation σ_L for the distribution of the period of the multiatomic steps was also measured to be 5.81nm. On the other hand, as shown in Fig. 2(b), when the TEGa partial pressure was 4×10^{-6} atm, although the straightness of multiatomic steps was much improved, we can see considerable variations in the spacing of multiatomic steps. In fact, the standard deviation σ_L for this surface was measured to be 17.5nm, with the average period L of 78.3nm.

As discussed in the previous paper [4], the randomness in the periodicity of LSSL in EWID influence greatly on the characteristics and transport properties in EWID and may lead to the degradation of the performance of EWID. Therefore, these differences in the morphology are expected to result in the change of the device characteristics.

3.2 Transport properties of fabricated devices

Next, the drain characteristics of two EWIDs were measured as a function of gate voltage V_G at low temperature with constant drain bias voltage V_D. Figure 3(a) shows the characteristics of the transconductance g_m of sample A. We can clearly see the peak of g_m around $V_G = 0.17$V and $V_G = 0.25$V, and the valley of g_m around $V_G = 0.20$V. To clarify the origin of oscillations of g_m, we estimated the electron concentration and Fermi wavelength in the device and compared with the LSSL period. For simplicity, we assumed that the electron concentration linearly changes as V_G above the threshold voltage ($V_{th} = 0.15$V) and is uniform regardless of the periodic potential. The results are summarized in Table 1, where the commensurability condition that $2L/\lambda_F$ should be a half integer at peaks and an integer at valleys shows reasonable agreement with theoretical expectation.

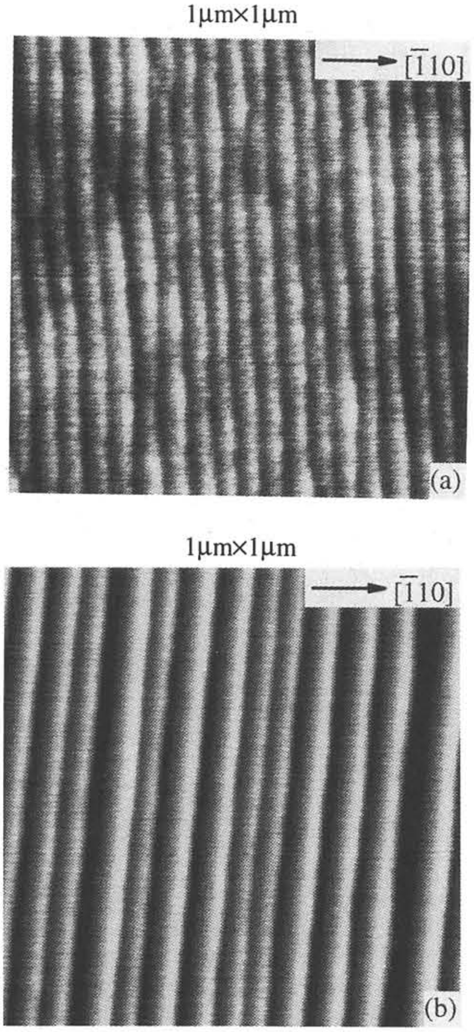

Fig. 2 AFM images of GaAs channel layer surface for EWID. (a) TEGa partial pressure is 8×10^{-6} atm (sample A). (b) TEGa partial pressure is 4×10^{-6} atm (sample B).

These results clearly indicates that the oscillations of g_m in sample A originate from the coherent electron wave interference effect.

We also measured the transconductance g_m of sample B and the results are shown in Fig. 3(b). The series of oscillations in g_m can also be seen with peaks at $V_G = -0.22$V, -0.20V and -0.18V. We note here that the g_m characteristics of an FET, which is fabricated from the same epitaxial wafer as sample B but has the channel *along* the multiatomic steps, showed no characteristic oscillations. Such anisotropic characteristics indicates that the oscillations of sample B shown in Fig. 3(b) results from the lateral potential modulation induced by the multiatomic steps at the heterojunction. The peaks in Fig. 3(b), however, cannot be explained by the naive picture of the electron wave interference based on the same analysis carried out in sample A.

As discussed in the previous section, there are considerable randomness in the period of the multiatomic steps if the GaAs channel layers are grown in the condition for sample B. Since the contribution of the coherent interference becomes weaker as the degree of

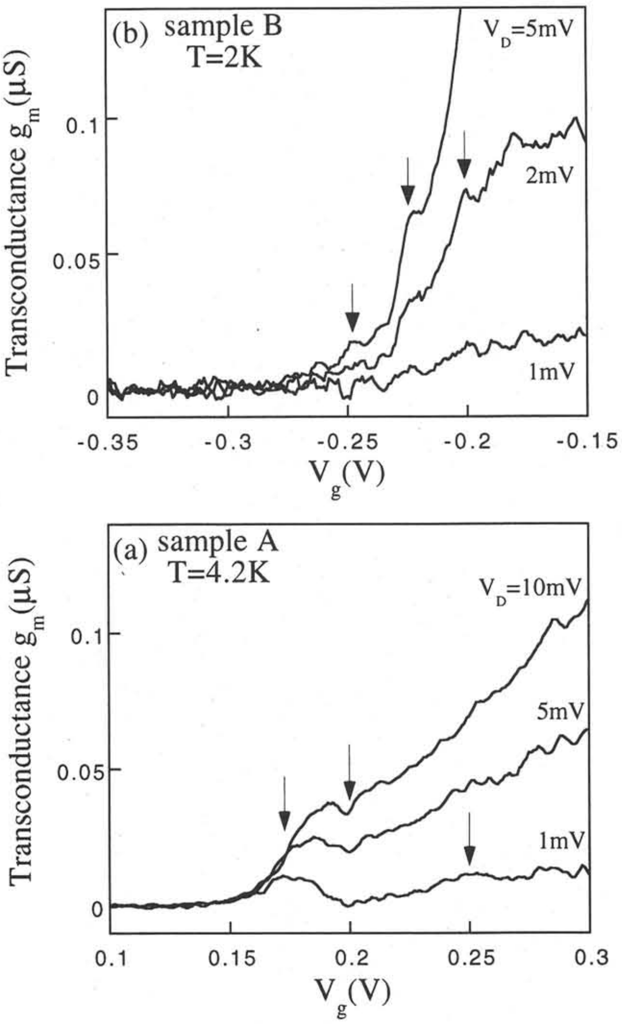

Fig. 3 EWID characteristics of transconductans g_m measured at low temperature for different drain bias V_D. (a) sample A. (b) sample B.

Table 1 Comparison of period and Fermi wavelength λ_F at peaks and valleys in sample A.

	peak 1	valley 1	peak 2
V_G(V)	0.17	0.20	0.25
λ_F(nm)	159	80	53.4
$2L/\lambda_F$	0.68	1.36	2.03
$2L/\lambda_F$ (ideal)	1/2	1	3/2

randomness σ_L/L is increased [5], it is more difficult to observe the coherent interference of electron in sample B than in sample A. Therefore, we think the oscillations of g_m in sample B cannot be ascribed to the coherent interference effect. Its origin of oscillations in sample B, however, is not clear at present. The anisotropic characteristics suggests that the potential modulations introduced by the multiatomic steps are still playing an important role, but further investigations are required to clarify it.

4. Conclusions

We studied the electron transport in a new, LSSL type of electron wave interference device using multiatomic steps on vicinal GaAs surfaces. Clear oscillations were found in the transconductance g_m of two EWIDs. By comparing the Fermi wavelength at the oscillation peaks and valleys with the period of multiatomic steps, it is found that the oscillations observed in one sample results from the coherent electron wave interference effect, while the other is not. Our results clearly demonstrate the possibility to realize novel EWIDs by utilizing multiatomic steps, and suggest the importance of the formation of the coherent multiatomic steps.

References

[1] H. Sakaki, K. Wagatsuma, J. Hamasaki and S. Saito, Thin Solid Films 36, 497 (1976).
[2] K. Ismail, W. Chu, D. A. Antoniadis and H. I. Smith, Appl. Phys. Lett. 52, 1071 (1988).
[3] K. Tsubaki, Y. Tokura, T. Fukui, H. Saito and N. Susa, Electron. Lett. 25, 728 (1988).
[4] J. Motohisa, M. Akabori, S. Hara, J. Ishizaki, K. Ohkuri and T. Fukui, submitted to Phisica B.
[5] T. Fukui and H. Saito, Jpn. J. Appl. Phys. 29, 1483 (1990).