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Cross-Sectional Potential Imaging of Compound Semiconductor Heterostructure by Kelvin Probe Force Microscopy

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1. Introduction

It has recently been demonstrated that the cross-sectional potential profile of AlGaAs/GaAs HEMTs was successfully measured using Kelvin probe force microscopy (KFM) [1]. In order to develop the full potential of KFM, it is necessary to clarify the spatial resolution and the effects of amplitude of alternating voltage (V_{ac}) applied to measure the electrostatic force. The potential difference measurement for the heterointerface is also an important issue. In this paper, the effects of V_{ac} amplitude on the measurement and spatial resolution are studied. Cross-sectional potential image of the heterostructure was successfully obtained.

2. Experimental

The KFM measurements were performed in an air ambient at room temperature. After cleaving the wafer, the sample was mounted on a piezo-ceramic sample holder. An alternating voltage $V_{ac}sin(wt)$ was applied between the sample holder and KFM tip to measure an electrostatic force. KFM operation principle is based on this electrostatic force which arises when potential difference exists between the cantilever tip and the sample surface. The details of the measurement technique were described elsewhere [1].

GaAs/AlAs MQW structure shown in Figure 1 was measured to study the influence of V_{ac} on the potential distribution. $Al_{0.5}Ga_{0.5}As$(301.5 nm) was sandwiched by GaAs(69.6 nm)/AlAs(83.1 nm) MQWs. Fig. 2 shows the potential distribution along the AA' line of GaAs/AlAs MQW structure for V_{ac} of 1, 4, and 7 V. The smaller the V_{ac}, the clearer the potential distribution. Considering that the voltage fluctuation decreased when V_{ac} increased [2], V_{ac} of 1~2 V was used for the heterostructure measurement. Fig. 3(a) shows the measured topographic image at V_{ac}=1 V. The ridges with 30 nm height were formed due to AlAs oxidation. Fig. 3(b) shows the measured potential image. The potential of AlAs was higher than that of GaAs. The GaAs/AlAs MQWs are clearly observed, which suggests that the spatial resolution of KFM is less than 70 nm.

Next we measured lattice-matched InAlAs/InGaAs layer structures on InP substrate with flat surface to avoid the effects of the ridge of the sample. The oxidation of InAlAs and InGaAs is not so pronounced as AlAs. Two kinds of layer structure, sample A and B, were prepared for the measurement as shown in Fig. 4. In sample A, the thickness of InAlAs is changed from 200 to 20 nm keeping the thickness of InGaAs layer constant (200 nm). In sample B, on the other hand, the thicknesses of both InAlAs and InGaAs are changed from 200 to 20 nm. The surface of the measured sample was so flat that the interface between InAlAs and InGaAs could not be distinguished by AFM. Fig. 5(a) shows the measured potential image of sample A at V_{ac}=2 V. The clear potential image of the heterostructure was obtained. The potential of InAlAs was higher than that of InGaAs. The 20 nm InAlAs barrier layer sandwiched between InGaAs (200 nm) is clearly observed. Fig. 5(b) shows the measured potential image of sample B. In this case, the minimum resolved thickness was about 40 nm. These results suggest that the spatial resolution of the present KFM is less than 40 nm.

3. Conclusions

The potential image of the GaAs/AlAs MQW and InAlAs/InGaAs heterostructures have been successfully obtained. The spatial resolution of the present KFM is estimated to be less than 40 nm. The present technology can be applied for various heterostructures and devices.

References

1) T. Mizutani, M. Arakawa and S. Kishimoto: *Technical Digest, IEDM, San Francisco 1996* (1996), p.31
2) M. Arakawa, S. Kishimoto and T. Mizutani: *Extended Abstracts of the 1996 Int. Conf. on Solid State Devices and Materials, Yokohama, 1996* (1996) p.100

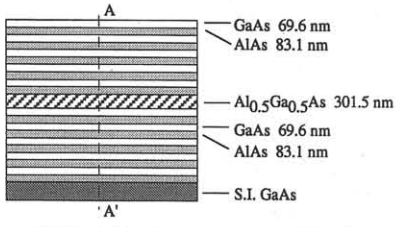


Fig. 1 GaAs/AlAs MQW structure used for the measurement.

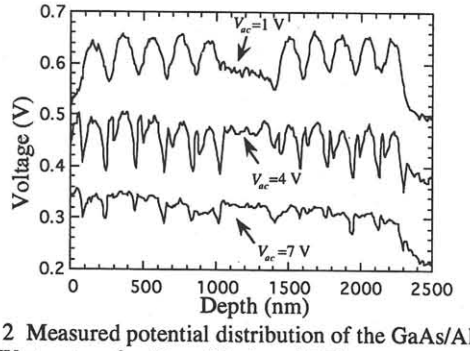
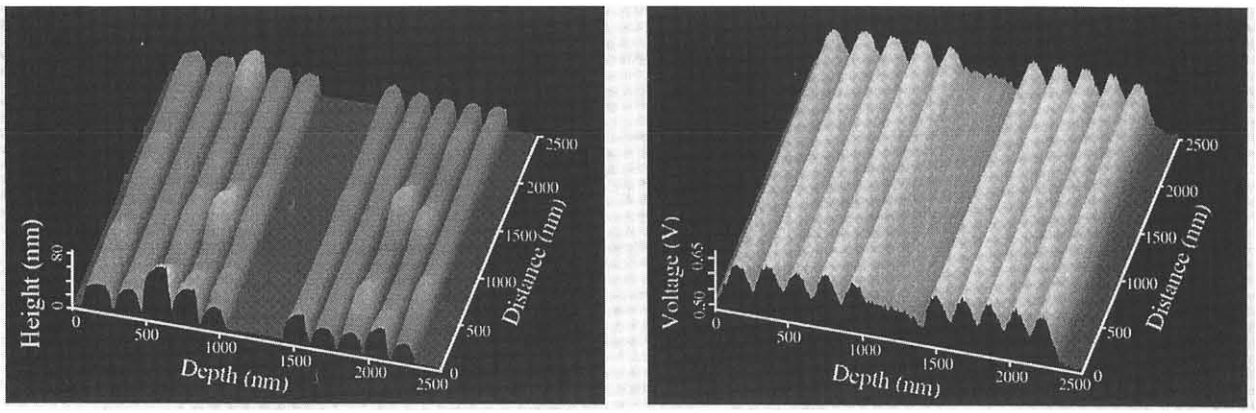
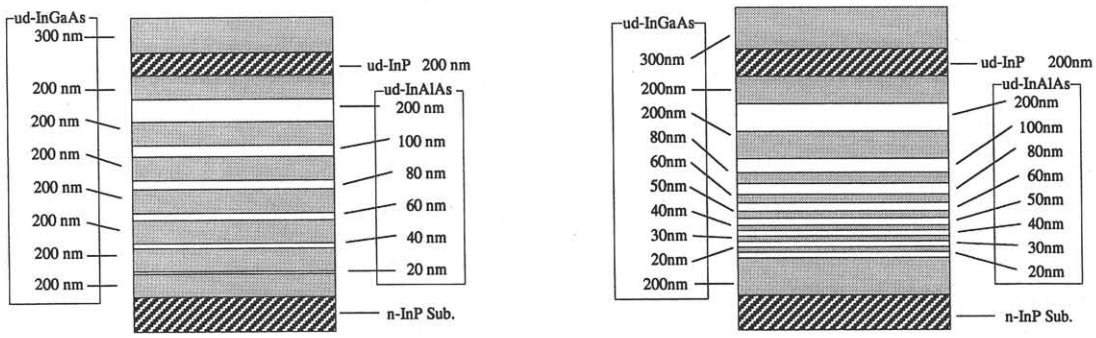


Fig. 2 Measured potential distribution of the GaAs/AlAs MQW structure for V_{ac} of 1, 4, and 7 V.



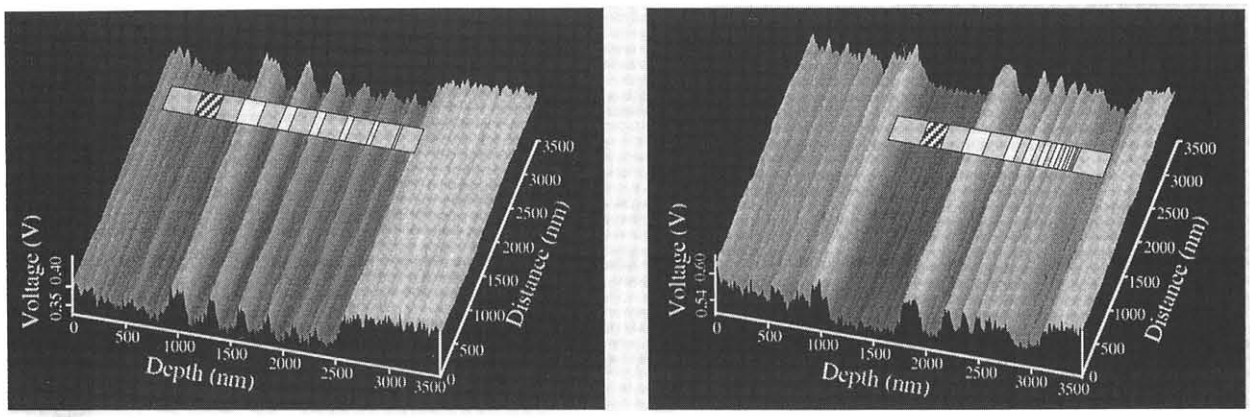
(a) (b)

Fig. 3 Measured topographic image (a) and the corresponding potential image (b) of the GaAs/AlAs MQW structure.



(a) (b)

Fig. 4 InAlAs/InGaAs layer structure used for the measurement . (a) Sample A: the thickness of InAlAs are changed from 200 to 20 nm from the top . (b) Sample B: the thicknesses of both InAlAs and InGaAs are changed from 200 to 20 nm.



(a) (b)

Fig. 5 Measured potential images of the heterostructure; (a) sample A, (b) sample B.