Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 360–361

E-6-3
Influence of the Ferroelectric Polarization on the Properties of the Two-Dimensional Electron Gas in $Pb(Zr_{0.53}Ti_{0.47})O_3/Al_xGa_{1-x}N/GaN$ Structures

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1. Introduction

Due to its strong piezoelectric effect and large conduction-band offset, a modulation-doped $Al_xGa_{1-x}N/GaN$ heterostructure produces the two-dimensional electron gas (2DEG) with high mobility and high density at the heterointerface, which makes $Al_xGa_{1-x}N/GaN$ heterostructures as the most promising candidates in heterostructure field effect transistors for high-frequency, high-temperature, and high-power applications. On the other hand, much effort has been made on integrating ferroelectrics into semiconductor technologies, among which metal-ferroelectric-semiconductor (MFS) field effect transistor looks as one of the most promising devices to achieve this goal. In this study, MFS structures based on modulation-doped $Al_{0.22}Ga_{0.78}N/GaN$ heterostructures were developed. Their electrical behaviors were investigated by means of high-frequency capacitance-voltage (C-V) measurements.

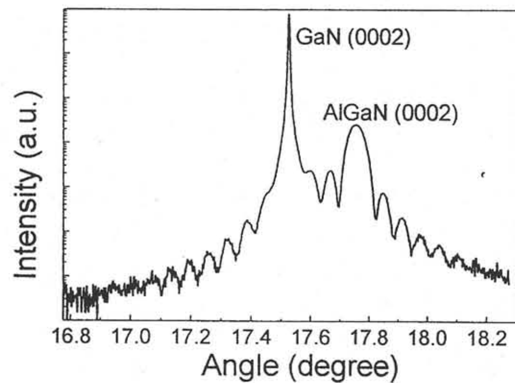

Fig. 1. High-reolution X-ray diffraction spectrum with the $\omega/2\theta$ scanning of the modulation-doped $Al_{0.22}Ga_{0.78}N/GaN$ heterostructure with 75-nm-thick Si-doped $Al_{0.22}Ga_{0.78}N$ layer and 3-nm-thick $Al_{0.22}Ga_{0.78}N$ spacer.

2. Experiments and results

Modulation-doped $Al_{0.22}Ga_{0.78}N/GaN$ heterostructures with various thickness of the Si-doped $Al_{0.22}Ga_{0.78}N$ layer and the unintentionally doped $Al_{0.22}Ga_{0.78}N$ spacer were grown using metal organic chemical vapor deposition (MOCVD). Fig. 1 shows the high-resolution X-ray diffraction spectrum of one $Al_{0.22}Ga_{0.78}N/GaN$ heterostructure. The mobility and sheet concentration of the two dimensional electron gas (2DEG) in the heterostructures were determented by means of Hall measurements. The $Pb(Zr_{0.53}Ti_{0.47})O_3$ (PZT) film was deposited on the heterostructures by means of pulsed laser deposition (PLD) system.

The C-V properties of the $Al_{0.22}Ga_{0.78}N/GaN$ MFS structure with the 75-nm-thick Si-doped $Al_{0.22}Ga_{0.78}N$ layer and 3-nm-thick $Al_{0.22}Ga_{0.78}N$ spacer were measured using HP4194A impedance analyzer. Fig. 2 shows the high-frequency C-V spectrum under 1 MHz. When the applied bias is positive (> 0.7 V), the capacitance of the MFS structure is determined by the PZT film. When the applied bias is swept to negative, the negative voltage was applied on the $Al_{0.22}Ga_{0.78}N$ layer and the capacitance decrease rapidly. There is a capacitance "shoulder" observed near -10 V in the depletion of the 2DEG at the heterointerface.

From Fig.2, the 2DEG sheet density is calculated to be 5.6×10^{12} cm^{-2}. However, it is 1.56×10^{13} cm^{-2} determined from the Hall measurement in the same heterostructure without the PZT film. This indicates that the 2DEG density decreases significantly in the heterostructure under –10 V bias. This can be explained quite well based on the existence of the negative ferroelectric polarization charges at the $PZT/Al_{0.22}Ga_{0.78}N$ interface.

Fig. 3 shows the C-V hysteresis window of 0.2 V with anti-clockwise direction in the same $Al_{0.22}Ga_{0.78}N/GaN$ MFS structure. It is the ferroelectric memory window caused by the polarization difference of the PZT film between the opposite sweeping directions. Due to its buried-channel property, the $Al_{0.22}Ga_{0.78}N/GaN$ MFS structure shows the memory window completely in the range of negative bias, indicating that the $Al_{0.22}Ga_{0.78}N/GaN$ MFS structure can produce C-V

window without the reversal of the ferroelectric polarization. This advantage will possibly weaken the negative effect induced by the fatigue property of the ferroelectric film in the memory performance. We think that the width of the C-V window can increase with decreasing the thickness of the Si-doped $Al_{0.22}Ga_{0.78}N$ layer in modulation-doped $Al_{0.22}Ga_{0.78}N/GaN$ heterostructures.

4. Conclusions

$Al_xGa_{1-x}N/GaN$ based MFS structures were developed by depositing PZT films on modulation-doped $Al_{0.22}Ga_{0.78}N/GaN$ heterostructures. Because the negative ferroelectric polarization charges exists at the $PZT/Al_{0.22}Ga_{0.78}N$ interface under the negative bias, the 2DEG density at the $Al_{0.22}Ga_{0.78}N/GaN$ heterointreface in the MFS structure decreased significantly. Due to the ferroelectric polarization of the PZT film, a ferroelectric C-V memory window of 0.2 V in width is achieved near −10 V bias, indicating that the $Al_{0.22}Ga_{0.78}N/GaN$ MFS structure can make memory performance without the reversal of the ferroelectric polarization.

Acknowledgments

This work was supported by special Funds for Major State Basic Research Projects of China #G20000683, the National Natural Science Foundation of China (No. 69806006, 69976014, 69636010 and 69987001), the National High Technology Research & Development Project of China, and the Research for the Future Program of the Japan Society for the Promotion of Science (Project No. JSPS-RFTF96P00201).

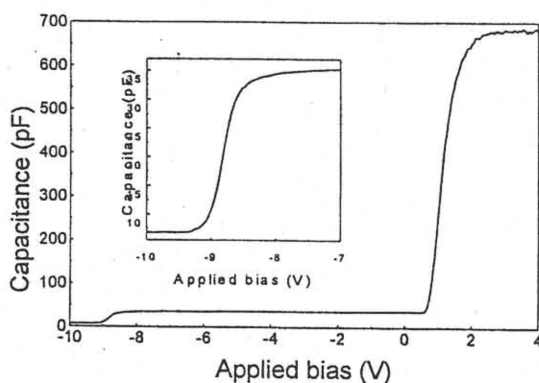

Fig.2 High-frequency C-V plots of the $Al_{0.22}Ga_{0.78}N/$ GaN MFS structure under 1 MHz in the whole range of the scanning voltage. Inlet: the C-V in the negative-voltage range.

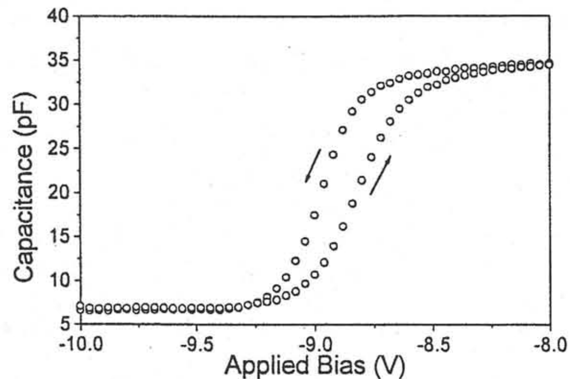

Fig.3 Ferroelectric C-V memory window in the $Al_{0.22}Ga_{0.78}N$ /GaN MFS structure.

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