Cd Content effects on the Performance of the MgZnO/CdZnO/ZnO Hetero structure

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Abstract: In this paper, we propose the performance improvement by inducing an increase in electric current by using a CdZnO space layer in the MgZnO/ZnOheterostructure. The polarization effect on 2DEG(two dimensional electric gas) in the MgZnO/CdZnO/ZnOheterostructure was theoretically investigated as a function of Cd content, and carrier confinement in this structure was found to be superior to that of the conventional MgZnO/ZnO HEMT(high electron mobility transistor) structure. Based on this, the performance change was observed by changing the Cd content of the space layer in the SILVACO simulation. As the Cd content increased, the electron density increased. As a result, it can be seen that the saturation drain current is proportional to the Cd content increase in the space layer.

Keywords: 2DEG, ZnO, MgZnO, CdZnO, HEMT

1. Introduction

In the development of integrated circuits made of compound semiconductors, one of the problems is the leakage current of the gate, which decreases the reliability of devices and circuits as well as power consumption [1]. This problem can be improved by using HEMT because the gate leakage current can be reduced by the Schottky barrier height and conduction band discontinuity in the heterojunction structure.

Recently, a lot of research has been done on high-electron mobility-transistor applications because many of the physical properties of ZnO among II-VI semiconductor-related oxides are similar to those of III-V GaN [2]. These include MgZnO/ZnO [3-6], MgZnO/MgO/ZnO [7, 8], and BeMgZnO/ZnO [9-11] heterostructures. ZnO-related HEMT structures have great potential for high-frequency and high-power device applications because of their large conduction band offsets and their potential to form high-density two-dimensional electron gases (2DEGs).

In particular, for a modified ZnMgO/MgO/ZnO structural system using a thin MgO interfacial layer between MgZnO and ZnO layers, Meng et al. [12] showed an increase in 2DEG sheet density and an improvement in electron mobility. This means that systems using thin interfacial layers in ZnMgO/ZnO structures are important for increasing the 2DEG sheet density.

In this paper, we theoretically investigated the polarization effect on 2DEG in aMgZnO/CdZnO/ZnOheterostructure using a thin CdZnOspace layer. Analyzing the polarization effect on the MgZnO/CdZnO/ZnOheterostructure will be useful for the design of advanced electronic devices based on ZnO-based HEMT systems. Numerical results were obtained using the Silvaco simulation software package. The simulation results show that the Cd content in the space layer affects the performance of the MgZnO/CdZnO/ZnO HEMT.

2. MgZnO/CdZnO/ZnOHeterostructure

Figure 1 displays the structure of MgZnO/CdZnO/ZnO HEMT. The structure consists of an n-doped ($n = 1.0 \times 10^{18} cm^{-3}$) MgZnO layer, a CdZnO channel layer with an undopedZnO spacer, and a thick ZnO substrate, which is the basis for migration from the gate contact to the substrate. A spacer layer was inserted to improve mobility and reduce alloy scattering. And it is assumed that the layer is grown on the ZnO substrate.

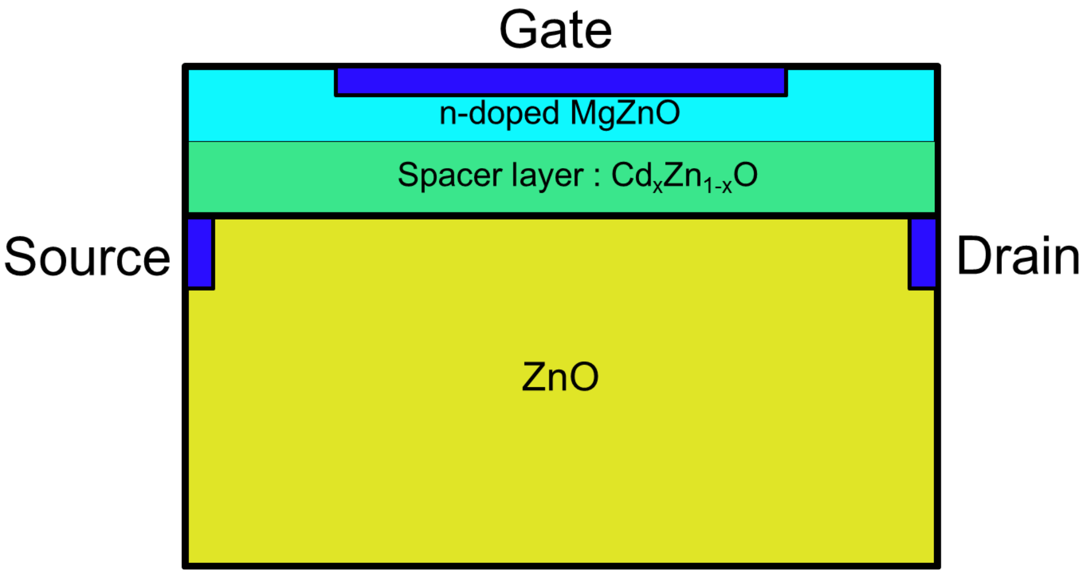

Figure 1. MgZnO/CdZnO/ZnO HEMT

4. Simulation and Validation

The proposed HEMT was tested using SILVACO, simulation software, where the thickness of the CdZnO spacer layer was fixed at 2 nm and the thickness of the MgZnO cap layer was fixed at 35 nm. A self-consistent solution was calculated at zero applied voltage (V = 0 V). A Schottky barrier height of 0.7 eV was used for the metal-semiconductor interface. We also considered the Zn-face for the MgZnO/CdZnO/ZnO HEMT structure.

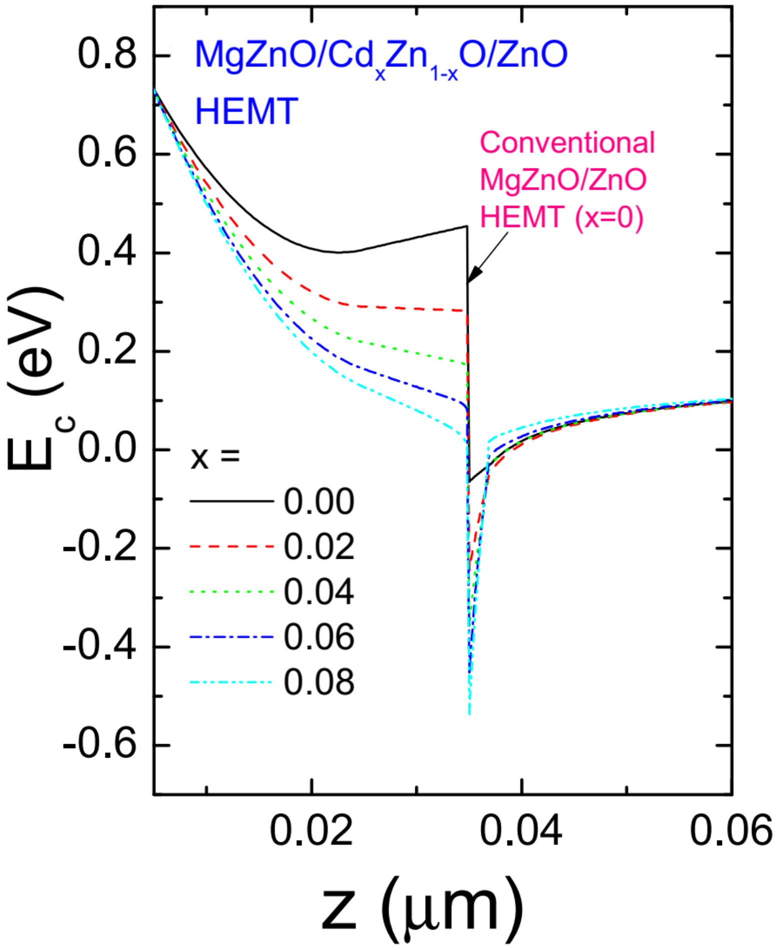

Figure 2. Conduction band

Figure 2 shows the conduction band edge profiles of theMgZnO/CdxZn1-xO/ZnO HEMT structures with several Cd contents. We observe that the bending of the conduction band in the interface between MgZnO andCdZnOgradully becomes sharper with increasing Cd content (x). As a result, the carrierconfinement in the MgZnO/CdZnO/ZnO HEMT structure is expected to be superior to thatin the conventional MgZnO/ZnO HEMT structure.

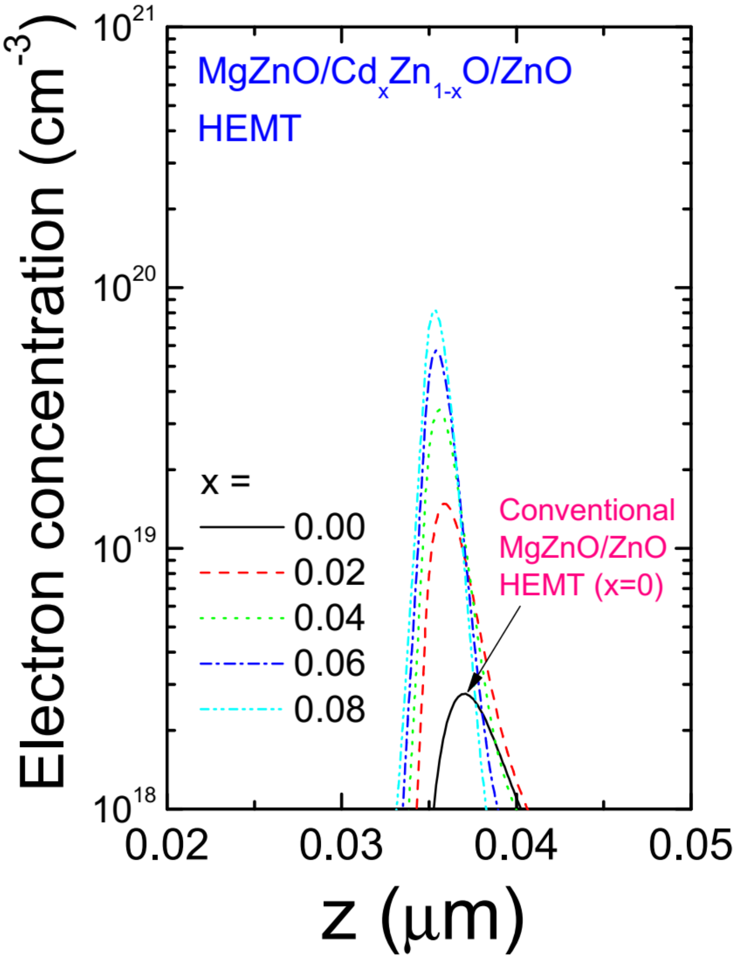

Figure3. Electronic density

Figure 3 shows the electron density of MgZnO/CdxZn1-xO/ZnO HEMT structures with different Cd contents. The peak positions of the electron density correspond to the positions of the CdZnO channels, z=0.037nm. For the MgZnO/CdZnO/ZnO HEMT structure, the electron density is much larger than that for the conventional MgZnO/ZnO HEMT (x=0) structure.

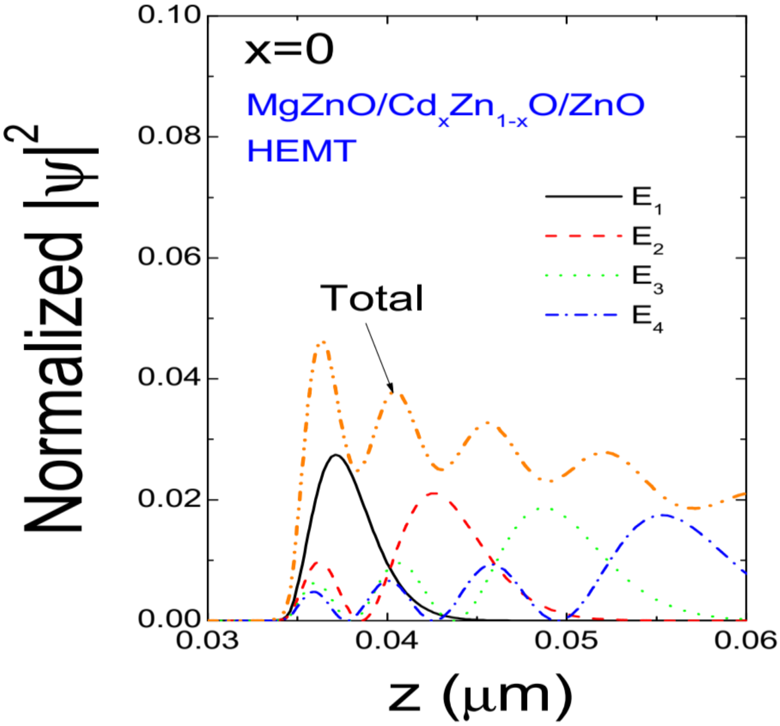

Figure4. Normalized wave functions (MgZnO/ZnO)

Figure 4 shows the squares of the normalized wavefunctions for the first four subbands in conventional MgZnO/ZnOwhich means the graph of x=0 and Figure 5 shows those of the MgZnO/CdxZn1-x/ZnO HEMT structure (x = 0.06).

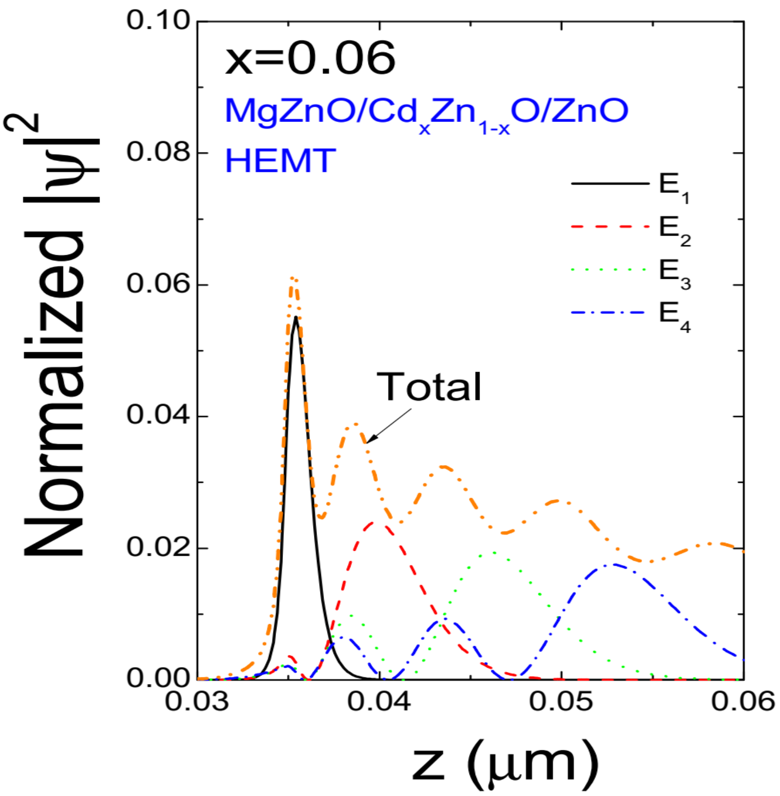

Figure5. Normalized wave functions (MgZnO/CdZnO/ZnO)

In Figures 4 and 5, the total value given as the sum of squares of the normalized wavefunctions for the four subbands is also plotted. Since the depth of the doped MgZnO is 35nm and CdZnO is 2nm, it shows a peak value around 37nm (0.037um). The difference in piezoelectric and natural polarization between the MgZnO and CdZnO layers induces a positive charge at the interface between the two materials. Electrons are attracted to this positive charge and tend to accumulate at the interface, forming conductive channels. The electrons appeared to occupy mainly the ground subband. These properties make that the peak shape of the total value in the interface of the CdZnO/ZnO is sharper than that in the interface of the MgZnO/ZnO and the higher peak value results in the more carrier confinement.

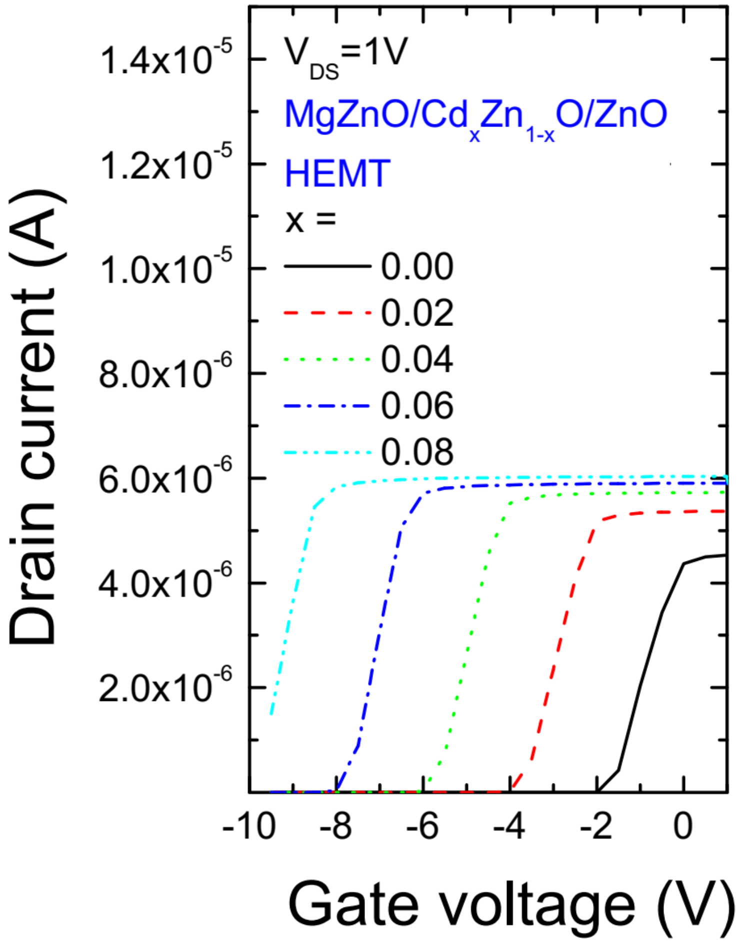

Figure6.I_{DS} vs. V_{GS}

Figure 6 shows the drain current (I_{DS}) versus the gate voltage (V_{GS}) at a drain voltage (V_{DS}) of 1V. For the MgZnO/ZnO HEMT structure, the pinch-off voltage reaches V_{GS} = 0.5V. However, the pinch-off voltage gradually decreases with increasing Cd content in the MgZnO/CdZnO/ZnO HEMT structures.

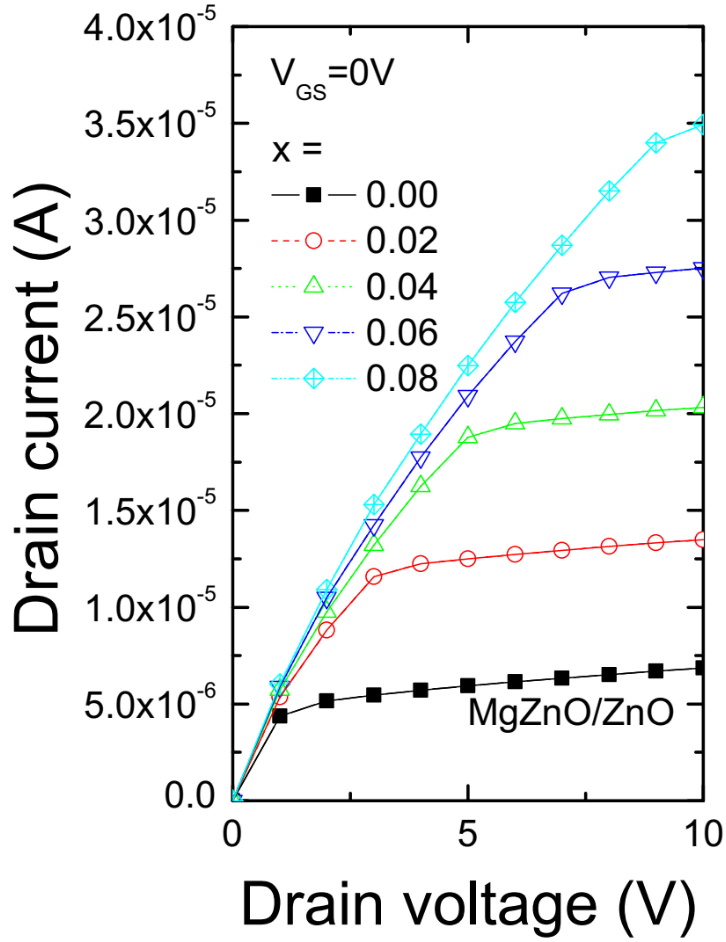

Figure7.I_{DS} vs. V_{DS}

Figure 7 shows the drain current (I_{DS}) versus drain voltage(V_{DS}) at a gate bias(V_{GS}) of 0 V. For MgZnO/CdZnO/ZnO HEMT structures compared to MgZnO/ZnO HEMTs, the saturation drain current increases with increasing Cd content. For the conventional MgZnO/ZnO HEMT structure, the saturation drain current is I_{DS} = 5.6x10^{-5} A at V_{GS} = 5V. For a HEMT structure with x = 0.06, I_{DS} = 2.75x10^{-4} A at V_{GS} = 5V, which is about a factor of 5. This is essentially due to the increase in the electron density in the channel induced by the enhanced polarization charge that occurs when including the CdZnO layer.

5. Conclusion

In this paper, by applying a CdZnO space layer to the MgZnO/ZnO HEMT, the structure showing the performance improvement according to the Cd content was confirmed. The polarization effect for 2DEG in the MgZnO/CdZnO/ZnOheterostructure using a thin CdZnO interfacial layer was theoretically investigated as a function of Cd content and the SILVACO simulation was done for the validation. The carrier confinement of the MgZnO/CdZnO/ZnO HEMT structure was found to be superior to that of the conventional MgZnO/ZnO HEMT structure. The electron density increased with increasing Cd content, as the bending of the conduction band at the interface between CdZnO and ZnO is sharper than at the interface between MgZnO and ZnO. Consequently, for the MgZnO/CdZnO/ZnO HEMT structure, the saturation drain current increases with increasing Cd content.

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