Contributed paper

OPTO-ELECTRONICS REVIEW 7 (4), 357–360 (1999)

Surface passivation of $Hg_{0.8}Cd_{0.2}Te$ grown by MBE

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We have investigated on the surface passivation of HgCdTe with various surface treatment method;.chemical oxidation, photochemical oxidation, and sulfur treatment. The density of fast state, slow state and fixed charge are analyzed by C–V method. We confirm that the sulfur treatment is the best surface passivation condition showing low density of the fast states and the fixed charge.

Keywords: MBE growth, HgCdTe MIS structure, passivation.

1. Introduction

HgCdTe is very important semiconducting material in the application of the mid- and long-wavelength infrared (IR) photodetector. However, its extremely sensitive surface still makes it difficult to develop and fabricate HgCdTe-based devices. In recent, therefore, the passivation of surface in HgCdTe are widely studied to enhance the device quality [1–3].

As is well known, the bandgap energy of HgCdTe with Cd fraction of 0.2-0.3 is between 0.1-0.25 eV at 77 K. Even though the amount of surface potential with band bending is small, hence, it is often the order of bandgap energy. So, accumulation, depletion and inversion are easily caused in devices and these limit the device performance.

Surface passivation of HgCdTe is very difficult because of the compound nature of the material, the difference in the chemical properties of the constituents, and the electrically active defects formed near interface region during the passivating process.

Because the surface of HgCdTe is very sensitive to temperature, passivation treatments and deposition processes are limited to near room temperature [4–6]. Also, electrolytic growth such as anodic sulfidization process gives rise to a substantial depletion of Hg in the semiconductor near surface [7,8].

In this paper, we report on the results of surface passivation which does not cause above problems at the semiconductor/insulator interface during a passivation process. For this, we have done the three kinds of passivation process; chemical oxidation, photochemical oxidation, and sulfur treatment.

2. Experiment

The n-type HgCdTe with Cd fraction of 0.2 and 2.5 μm-thick species used in this study were grown by MBE. The carrier concentrations of our samples are 8×10^{16} and 6×10^{16} cm^{-3}, the mobility is about 40000 cm^2/Vs at 77 K.

These epilayers were chemically etched in the mixed solution of HBr, H_2O_2, and H_2O for 10 s. In the process of surface treatment, we used three types of treatment methods as followes. One is the chemical oxidation process. In this methods the species were immersed in solution of H_2O_2 for 10–30 min. Another treatment method is photochemical oxidation method, in which treatment the species is exposed by UV source (10 W) under the O_2 atmosphere at 45°C for 3 hours [9]. And the third method was sulfur-treatment in a solution of $(NH_4)_2S_x$ for 20 min. This method is very effective to passivate the surface of GaAs [10,11].

To characterize the electrical properties, metal-insulator-semiconductor (MIS) structure were fabricated on surface-treated HgCdTe layer. The ZnS as an

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insulating layer was deposited with a thickness of 450 nm on HgCdTe layer by thermal evaporation method. The 500 nm-thick Al was evaporated on ZnS/HgCdTe as a gate metal. The diameter of gate was 300 μm. The capacitance-voltage (C–V) relations were measured as a function of the gate voltage at a frequency of 1 MHz at 100 K.

3. Results and discussion

Figure 1 shows the C–V results of the MIS structure which is surface treated by chemical oxidation treatment for 10 min. In this figure the line with thick solid points is experimental result, and slight solid- and dotted-line are ideal C–V curves. The capacitance is normalised by the insulator capacitance (C_i). This C–V result is obtained from the voltage range of –20 ~ 20 V. It is relatively high voltage region.

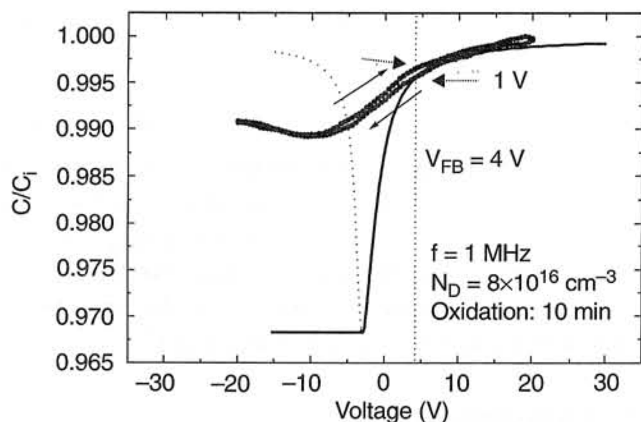

Fig. 1. C–V result of chemically oxidized sample for 10 min (solid points: experimental, thin line: ideal).

The hysteresis width in this case is about 1 V and the flat band voltage shift (ΔV_{FB}) is about 4 V, respectively. We think this shift was caused by interface negative charges (O^- ions) which are introduced during chemical treatment process of sample.

As we see in this figure, depletion region is built up near interface when bias is 1 V. It means that fixed oxide charge was much formed in the insulator. Also, narrow hysteresis width means that the density of slow states is less under 1 V bias.

Figure 2 shows the C–V results of the MIS structure which is surface-treated by chemical oxidation treatment for 20 min. As shown in Fig. 2 the hysteresis width (about 0.2 V) is narrower than that of 10 min-treated sample. This result means the density of slow states near interface was reduced than that of before case.

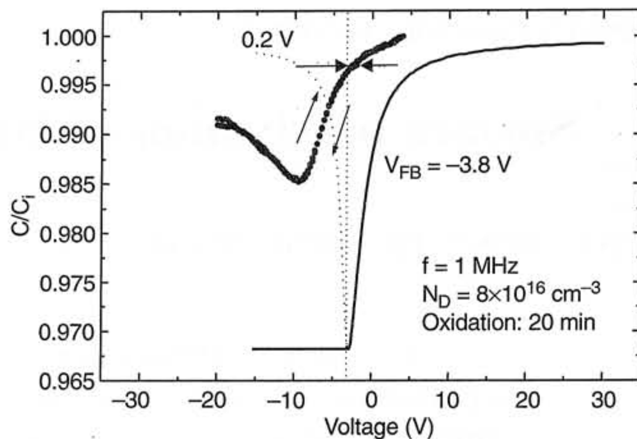

Fig. 2. C–V result of chemically oxidized sample for 20 min (solid points: experimental, thin line: ideal).

The density of fast states can be estimated from difference of slopes in the depletion region between experimental C–V curve and the theoretical curve assuming no fast states [12]. As we can see in Fig. 2, the slope of experimental C–V curve is very similar with theory in depletion region. This result means the density of fast states in this sample is very low.

For this reason we think oxygen ions are contribute the formation of stable compounds like as $HgTeO_3$, TeO_2, and $CdTeO_3$, therefore density of mobile ion by oxygen is reduced. The C–V results from the sample of which surface is chemically oxidized for 30 min are shown in Fig. 3. As seen in this figure, the flat band voltage is much shifted from Fig. 1 and Fig. 2. This reason may be attributed to the creation of positive charge by contaminants while the surface is exposed in the solution of H_2O_2 for long time. The difference in minimum capaitances (C_{min}) between experimental value and theoretical is larger than in the case of 10 min treated and 20 min treated.

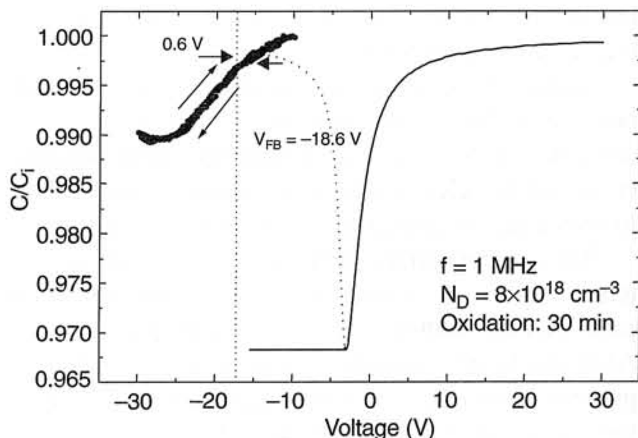

Fig. 3. C–V result of chemically oxidized sample for 30 min (solid points: experimental, thin line: ideal).

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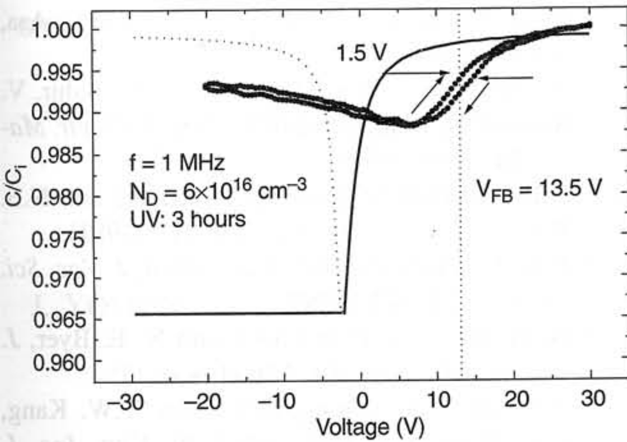

Fig. 4. C–V result of photochemically oxidized sample for 3 hours (solid points: experimental, thin line: ideal).

Since the higher C_{min} corresponds to higher N_D we think this means the carrier mobility near interface is lower than that of the epilayer inside. In summary, ΔV_{FB} increases linearly as the chemical-oxidation--time increases. When ΔV_{FB} appears in the range of 4 to −18.6 V as oxidation time is varied with 10–30 min. Also, C–V results of all of these species revealed the low frequency characteristics.

Figure 4 shows C–V results of the sample of which epitaxial surface is photo-chemically oxidized for 3 hours before ZnS deposition. As we see clearly in this figure, the inversion layer is formed under 0 V bias unlike above cases. That is, the surface of HgCdTe epitaxial layer is strongly inverted. This result means photo-chemical oxidation treatment is not good in our case.

Figure 5 shows the C–V results of species of which epitaxial surface is sulfur-treated using the solution of $(NH_4)_2S_x$ for 20 min before ZnS deposition. As seen in this figure, the flat-band voltage (2 V) is lower and hysteresis width (3.5 V) is higher than

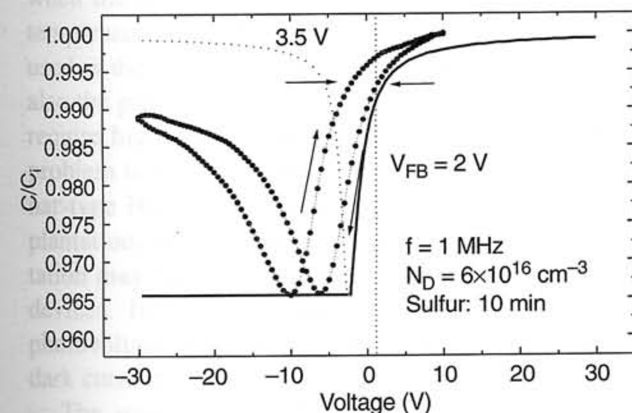

Fig. 5. C–V result of sulfur treatment sample for 20 min (solid points: experimental, thin line: ideal).

other cases. These results mean that density of fixed charge and fast states (~10^{10} $cm^{-2}eV^{-1}$) is very small and the density of slow states is high, respectively. On the other hand, the value of C_{min} of experimental curve well agrees to that of the theoretical curve. For this reason, we attribute to doping concentration did not increase at the surface. Especially, the considerable agreement of C_{min} with the theoretical curve and very low flat-band voltage mean that this sulfur-treatment is very effective method to passivate a surface.

The sulfur can be easily combined with Cd and Hg in the sulfur treated layer [13], and there is no chemical reaction between CdS and HgS. This accounts for the greater thermal stability of sulfide films over oxide films. However, large hysteresis loop means the presence of a high density of slow states near the interface. This result may be bad effect on device performance. So, it requires more optimized condition to decrease the hysteresis width.

Experimental values for the density of slow states and of fixed charge according to the condition of each surface treatments used in this study are summarized in Table 1.

Table 1. The density of slow state and fixed charge of samples used in this work

		Slow state density (cm^{-2})	Fixed charge density (cm^{-2})
Chemical oxidation	10 min	1.16×10^{12}	4.63×10^{12}
	20 min	2.31×10^{11}	4.4×10^{12}
	30 min	6.94×10^{11}	2.2×10^{13}
Photochemical oxidation		1.74×10^{12}	1.56×10^{13}
Sulfur treatment		4.63×10^{12}	2.31×10^{12}

4. Conclusions

In this work, we investigated the passivation of HgCdTe epitaxial layer with various kinds of surface treatment methods. Chemical oxidation, photochemical oxidation, and sulfur treatment methods were done for the surfaces of MBE-grown HgCdTe layers. The passivation effects with these methods were analysed by the C–V measurement. Among the three kinds of surface treatment methods, sulfur treatment method revealed the best C–V results in view of flat-band condition, fast states and C_{min} value. Hysteresis width in C–V curve from sulfur-treated species, however, is larger than other cases. This result means that density of slow states is relatively high.

Acknowledgement

This work was supported in 1999 by the Korea Science and Engineering Foundation through the Quantum-functional Semiconductor Research Center at Dongguk University.

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