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The Electrical Properties of High Quality Stacked CdTe/Photo-Enhanced-Native-Oxide for HgCdTe Passivation

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A novel surface treatment method for obtaining high quality CdTe/HgCdTe interface is proposed. By stacking photo-enhanced-native-oxide and CdTe films, we successfully passivated the HgCdTe. This technique is advantageous because photo native oxides could form excellent interface and adhere to HgCdTe substrate well. By using this novel technique, we have fabricated the metal(Au)/CdTe/photo-enhanced-native-oxide/HgCdTe substrate structured metal-insulator-semiconductor(MIS) capacitors. From the MIS capacitance-voltage(C-V) measurement, we found that the flat band voltage of such a MIS capacitor is about -0.2V with a fixed oxide charges of $1x10^{10}$ cm^{-2}. For comparison, conventional metal/CdTe/HgCdTe structured MIS capacitors were also fabricated. We found that capacitors with the photo-enhanced-native-oxide layer have a much lower leakage current. Such a drastic leakage current reduction is due to the good interface property between the photo-enhanced-native-oxide and the HgCdTe substrate.

Introduction

HgCdTe[1] is the most important semiconductor material for infrared (IR) photo detector application. Compared with other semiconductor IR materials, such as InSb[2], HgCdTe can be used for both IR windows(i.e. 3-5 μm and 8-12 μm wavelength regions) in atmosphere by changing the composition ratio of Hg and Cd. In order to obtain a feasible IR detector, it is necessary to have a high quality surface passivation layer with a low interface trap density, near flat band condition and a high IR transmission rate. Among the passivation materials, wider bandgap II-VI compounds [3], such as ZnS, native sulfide and native oxide are normally used for HgCdTe since they can provide barriers to both majority and minority carriers close to the surface. It is also possible to use lattice matched CdTe[4] to passivate HgCdTe. Recently, deposition of CdTe on HgCdTe surface emerged as a very promising method for passivation of HgCdTe photo detector. By using molecular beam epitaxy(MBE)[5] and metal organic chemical vapor deposition(MOCVD)[6], it becomes possible to grow high quality CdTe on top of HgCdTe. Previously by using MOCVD, Bahir et.al.,[6] reported the "direct" (in situ) growth of CdTe on top of HgCdTe in a single run, and "indirect" growth of CdTe on a previously grown HgCdTe samples. It was found that directly grown CdTe layers lead to low fixed interface charge and the indirectly grown samples are still aceptable although not as good as the directly grown samples. For practical application, direct growth of CdTe is not always possible because additional technological steps for HgCdTe are sometimes required before the growth of the passivation layer. In such cases, indirect growth of CdTe must be used and the HgCdTe surface preparation procedure must be taken into consideration. It is well known that HgCdTe tends to deviate from stoichimoetry. Thus, at high passivation temperature, indirect passivation of HgCdTe always results in poor interfacial properties, particularly for p-type HgCdTe. Since the charges of surface charge could enhance the bending of the surface potential, either an inversion or accumulation layer at the interface could degrade the performance of the HgCdTe photo diode by inducing leakage current. To overcome this problem, we propose a novel stacked photo-enhance-native oxide/CdTe[7,8] method for the surface passivation of HgCdTe. In this method, a thin layer of native oxide was first grown by direct photo chemical vapor deposition at a low temperature. CdTe layer was subsequently sputtered onto the native-oxide layer to complete the passivation of HgCdTe.

Experiment

In the experiment, a photo-enhanced-native-oxide layer was first grown on the HgCdTe epilayer, at a low temperature, in a photo chemical reactor using a deuterium(D_2) lamp as the light source. The $Hg_{0.8}Cd_{0.2}Te$ epilayer used in this study were grown by liquid phase epitaxy on CdTe substrate. The $Hg_{0.8}Cd_{0.2}Te$ epi-layers were p-type with a hole concentration of $1x10^{16}$ cm^{-3}. Prior to loading the $Hg_{0.8}Cd_{0.2}Te$ wafers into the a vacuum chamber ($8x10^{-6}$ Torr), they were

etched in a methanol solution with 1/8% bromine and rinsed in a pure methanol solution. During oxidation, oxygen gas is introduced into the chamber to raise the pressure to 10 Torr. Since D_2 lamp radiates strong vacuum ultra violet(VUV) and ultra violet(UV) light in the wavelength region from 130nm to 200 nm, it can effectively dissociate the introduced oxygen molecule(O_2) into the excited atoms such as $O(^3p)$ and $O(^1d)$. The excited oxygen atoms move through the $Hg_{0.8}Cd_{0.2}Te$ film so that the oxidation process occurs at the interface to form a thin layer of photo-enhanced native oxide. During oxidation, the HgCdTe wafer is exposed to VUV and UV light for 2 hours and the oxidation temperature is fixed at 50 °C. After oxidation, CdTe layer is deposited on top of the native oxide layer by sputtering, with an rf power of 20 Watt, to complete the passivation.

Results and Discussion

To study the electrical properties of the passivation layer, an Au metal layer with an area of $3x10^2$ cm^2 was evaporated on the top of CdTe as the gate electrode. The high frequency(1MHz) capacitance-voltage(C-V) characteristics of the fabricated stacked Au/CdTe/photo-enhanced-native-oxide/HgCdTe MIS capacitors measured at 77 K is shown in Fig.1.

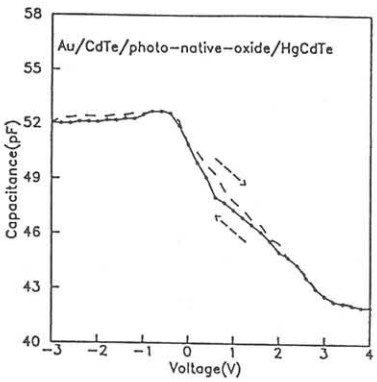

Fig 1. C-V curve of MIS capacitor with stacked CdTe/photo-enhanced-native-oxide on HgCdTe. N_A=1x10^{16}, A=3x10^{-2}cm^2, T=77K, f=1MHz.

For comparison, the ideal C-V[9,10] curve of the narrow band gap HgCdTe based MIS diode is also studied. We consider the unique features of HgCdTe such as non-parabolic conduction band, degeneracy in the occupancy and Fermi-Dirac distribution of free carriers, partially ionized impurities or defects, and constructed the ideal C-V curve of a HgCdTe MIS diode, as also plotted in Fig.1. From Fig.1, we can find that the flat band voltage and the maximum hysteresis are -0.2 V and 0.5 V, respectively, for the fabricated HgCdTe MIS diode. The near flat band condition shown in Fig. 1 implies a low density of the fixed charges in the insulating layers. Based on the flat band voltage, we calculated that the effective oxide charge is about 1x10^{10}cm^{-2}. From the C-V curves shown in Fig.1, we also determined that the distribution of the interface state density is U shaped with a minimum value of 5x10^{11}cm^{-2}eV^{-1} [11]. We summarized the values of V_{FB}, Q_{fix}, and hysteresis in Table 1. The corresponding values of the directly and indirectly CdTe grown on HgCdTe by MOCVD are also listed in Table 1[6]. From Table 1, we can clearly see that the amount of hysteresis of our Au/CdTe/photo-enhanced-native-oxide/HgCdTe MIS diode is much lower than the hysteresis of indirectly grown CdTe/HgCdTe prepared by MOCVD. Such a small hysteresis indicates that the density of slow trap at the interface between the photo-enhanced-native oxide and the HgCdTe epi-layer is low. The V_{FB} and the Q_{Fix} values of our Au/CdTe/photo-enhanced-native-oxide/HgCdTe MIS diode is also small, even smaller than that of the direct CdTe grown sample prepared by MOCVD. For IR detector application, a small V_{FB} is crucial for an HgCdTe MOS diode, since the surface passivation must impose near flat band condition to reduce the tunneling of the electron across the field-induced junctions between the surface or across the pinched-off junction depletion region adjacent to the surface. The small Q_{Fix} also suggests that the quality of our Au/CdTe/photo-enhanced-native- oxide/HgCdTe MIS diode is good.

	V_{FB}	Q_{it}(cm^{-3})	Hysteresis
*Direct growth CdTe/HgCdTe(n)(MOCVD)	0.5V	1x10^{10}	0.1V
Direct growth CdTe/HgCdTe(p)(MOCVD)	-1.5V	5x10^{10}	0.1V
*Indirect growth CdTe/HgCdTe(n)	>-1V		>2V
Stacked CdTe/photo-native-oxide/HgCdTe(p)	-0.2V	1x10^{10}	V_{max}=0.5V

*G. Bahir et al.[6] Appl. Phys. Lett 65(21) p-2725 (1992).
(p):P-type HgCdTe substrate.
(n):n-type HgCdTe substrate.

Table 1. Electrical data for CdTe passivation on HgCdTe.

The amount of leakage current as a function of applied electric field is also studied. For comparison, MIS diode prepared with and without the photo-enhanced-native oxide were both prepared. Figs.2(a) and 2(b) show the current-electric field relationship for sample A and B, where sample A is an Au/CdTe/photo-enhanced-native-oxide/HgCdTe MIS diode and sample B is an Au/CdTe/HgCdTe MIS diode. For both samples, the deposition condition for the CdTe layers were exactly the same.

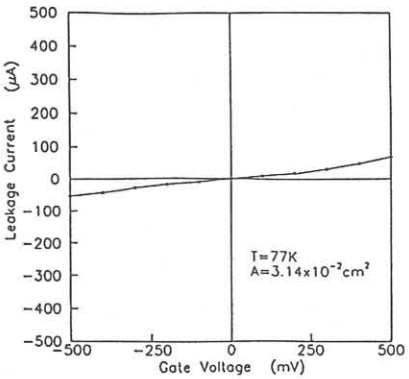

Fig 2(a)

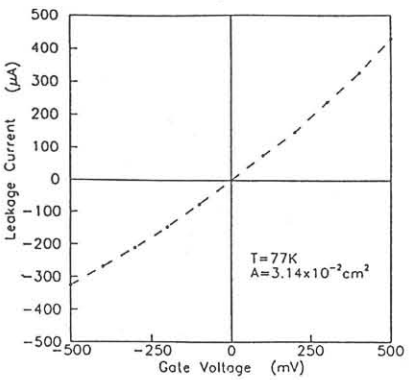

Fig 2(b)

Fig 2(a) The I-V characteristics of the stacked CdTe/photo-enhanced-native oxide /HgCdTe and Fig 2(b) the I-V characteristics of the CdTe/HgCdTe MIS diode with gate areas are $3x10^{-2}$ cm^2.

From Figs.2(a) and 2(b), we can clearly see that the leakage current in sample A is much lower. This leakage current reduction again indicates that by inserting a thin native-oxide layer, one can improve the quality of the HgCdTe based MIS diodes and photo detectors.

In summary, a novel surface treament method is proposed for HgCdTe passivation. By stacking photo-native-oxide and CdTe, we have successfully passivated the HgCdTe and fabricated HgCdTe based MIS diodes with lower interface charges, lower fixed oxide charge, near flat band conditions and low leakage current. These improvements are attributed to the excellent interface between the photo-enhanced-native- oxide and the HgCdTe substrate.

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