Impact of Post-Annealing at 80°C on Oxide Fixed Charges in Au/CdTe/HgCdTe MIS Structures

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Abstract: ***The effect of hydrogen post-annealing on the interface characteristics of Au/CdTe/HgCdTe Metal-Insulator-Semiconductor (MIS) structures was investigated through capacitance-voltage (C-V) measurements at 77 K and 1 MHz. CdTe was employed as a passivation layer for HgCdTe (MCT) owing to its lattice compatibility, wide bandgap, and infrared transparency. Five MIS structures were fabricated with varying post-annealing durations (0, 2, 4, 5, and 6 hours) in hydrogen atmosphere at 80°C. The results revealed a significant reduction in oxide fixed charge density after post-annealing, decreasing from approximately -2.56 × 10^{14} ions/cm² for the unannealed sample to about -1.64 × 10^{11} ions/cm² after 6 hours of annealing. The reduction in fixed charges indicates improved interface quality due to hydrogen passivation of dangling bonds and defects at the CdTe/HgCdTe interface. The study confirms that hydrogen post-annealing is an effective technique for enhancing the electrical performance of HgCdTe-based MIS devices.***

Keywords: HgCdTe (MCT), CdTe Passivation, MIS Structure, Hydrogen Annealing, Oxide Fixed Charges Capacitance–Voltage (C–V) Analysis, Infrared Detectors, Interface States, Semiconductor Devices and Thin Films.

1. Introduction

Passivation of HgCdTe is a critical step, specially for small area devices used for imaging applications (1-3) In fact passivation of MCT surface has been a major challenge in the optimisation (4-5)of MCT devices The fabrication of stable high performance MCT infrared devices is critically dependent particularly difficult in view of the complex chemistry and temperature sensitivity of upon the control of surface electrical properties (6)Surface passivation of MCT is this material. During the previous decade, various materials like ZnS (7- 11) SiO_2 , (12-17) and SiN_4 have been used for passivation of MCT photodiodes. In this project, CdTe is used as a passivating material for MCT photodiodes. It (CdTe) was expected to be a better choice than ZnS, SiO2 or $Si3N_4$ (18) , since it is a wide gap material, nearly lattice matched and chemically compatible to MCT. Also it is transparent to IR radiation, not hygroscopic and mechanically harder than MCT . The role of a passivant is to reduce the number of dangling bonds thus reducing the generation centres, recombination centres, and traps at the interface and in the case of MCT,CdTe was considered a suitable choice. In this study we describe the detailed study of the various.MIS structures which were fabricated by employing different combinations of pre- and post-annealing treatments in hydrogen atmosphere in presence of UV photons and their interface parameters have been studied by the analyses of CV measurements carried out at 77K at a frequency of 1 MHz. To understand the MIS structure of Au/CdTe/MCT system from its C-V analyses we take the Si/SiO_2, MOS structure as an analogy since this is known to be one of the best understood MIS structures and has been investigated in great depth with a lot of information and data available along with the physical interpretations .In our case the various characterisations and calculations have been made on similar lines as for the Si/SiO_2 system, with relevant modifications made for various parameters in the equations and formulae established for the Si/SiO_2 system. The oxide fixed charges of the Si/SiO_2 structures, however, would be termed insulator fixed charges for the MCT/CdTe heterojunction of our investigations. For simplicity and to avoid confusion in the equations and formulae used, we will continue to use the term "oxide fixed charges" instead of “insulator fixed charges.

2. Experimental Procedure

All the MCT crystals used for the fabrication of MIS structures were pre-characterised Pre-characterisation means the characterisation on MCT wafer before processing it for the fabrication of MIS structure. The characterisation of MCT wafers has been done in a Hall measurements set up using Van der Pauw configuration. In order to carry out Hall characterisation, the contacts on MCT crystals were made by depositing gold dots and gold wires were soldered to these contacts through Indium bumps. The characterisations on MCT samples were made at liquid nitrogen temperature. To confirm the effectiveness of CdTe as a suitable passivant for MCT surfaces, the CdTe-MCT (HgCdTe) interface needs to be analysed For this purpose we fabricated Five MIS structures and studied their interface characteristics. All five MIS samples Here, the polished MCT wafers were pre-characterised to confirm their smoothness and stoichiometry after which thin films of CdTe were deposited for passivation of the MCT surface. Four of the p-MCT (x ~ 0.2) wafers with CdTe on one face which were subjected to post- annealing in hydrogen atmosphere at 80°C for durations of 2h, 4h, 5h, and 6h were labelled as sample 2, 3, 4 and 5 respectively. Once this post -(after CdTe deposition)- annealing had been carried out, through an Al mask and back contacts also of gold deposited on the other MCT face by electroless deposition of gold chloride. One sample of this series which was however, not subjected to has been labelled as sample 1. The samples bracketed as series A were all those which ty annealing and the metal (gold) gates were deposited directly after CdTe deposition had not been given any pre-(before CdTe deposition) annealing treatment The C-V analyses of all the above prepared MIS samples in series All the measurements were performed at liquid Nitrogen temperature (77K) and at a A has been done to study the effect of hydrogen annealing on interface characteristics frequency of 1MHz.

3. Experimental Results

The MCT crystals used for fabrication of MES the MIS The pre-characterisation of MCT alderatenate the contacts on MCT vstals were made by and Ardened to these contacts through it The characion of Teemade Sound Nitrogen temperature The parameters obtained from ial care concentration resistivity and Halling of these MCT wafersdorfabrication of MIS capacitors The MCT wafer surface with gold contacts on it for Hall measurement was made as back wer for MIS structures

In order to prepare the MIS structures, p-type MCT crystals were anted to extensive chemo-mechanical polishing till the surfaces were scratch free and dun with mirror like finish. Surface conditions were monitored after each step by microscope and a Gaertner ellipsometer operated at 6328A To study the effect of hydrogen annealing on MCT/CdTe interface, we prepared Metal-Insulator-Semiconductor ncture on p-type MCT wafer with x-0.2. The polished MCT crystal were subjected to amal is hydrogen atmosphere before and after deposition of CdTe The MIS capacitors were thus fabricated after employing the various post-annealing conditions as described for series A, B, C, D and E. For each sample metal gates of gold were deposited using a natal mask by thermal evaporation. A gold back contact was made on the other face of MCT crystal by electroless deposition of gold chloride The MIS structure viz. CdTe-CdTe-Au was now ready for C-V analyses The C-V curves of the 24 samples fabricated in five The corresponding interface series A.B.C.D and E are shown in figs 5.6 to 5.10 parameters obtained for each C-V curve are also given below each figure. The pre-characterisation data, ellipsometery data thickness of insulating (CdTe) film and conditions employed in pre and post annealing for each sample are given on Samples No.1 -5 substrate temperature 80° C and hydrogen atmosphere 1 mbar.

4. Discussion

For this series a set of experiments was carried out to evaluate the passivation properties of insulator (CdTe) on semiconductor (HgCdTe) During this series five samples (MIS structures) were fabricated by employing different post-annealing durations. The post-annealing has been done after depositing CdTe on cleaned HgCdTe crystal. The MCT/CdTe structures fabricated were subjected to post-annealing in H_2 atmosphere at substrate temperature of 80°C for different durations, depending upon the post-annealing time the MIS structures fabricated in current series were labelled as samples 1,2,3,4 and 5. Sample 1 was prepared without any annealing while sample 2,4,5 and 6 were made after post-annealing has increased to 4hours, the oxide fixed charges reduced to -186E11 ions/cm² Further increase in post-annealing duration, up to Shours and 6hours lydrogen atmosphere shows a further reduction in the value of oxide fixed charges which goes down to the level of about 1.689E11 ions/cm² and -1.636E11 ions/cm² Respectively From fig. 5.30 it is observed that the oxide fixed charges initially shows a sharp decrease from without annealing to 2hours post-annealing after that there is a very small decrease in oxide fixed charges from 2hours post-annealing to 6hour post- annealing. For series A, it is seen that the sample 1 and sample 3 are prepared MCT wafers having same characterisation data, which was measured using Hall characterisation data, which was measured using Hall measurement set up at 77K. The carrier concentration and mobility of both samples 1 and 3 have same values 3.22E16 cm³ and 189cm²eV¹ respectively Sample 1 is fabricated without any annealing and sample 3 is made after post-annealing of 4 hours in hydrogen atmosphere at a temperature of 80°C.Comparing the data obtained from C-V curve of sample 1 and sample 3, it is observed that the oxide fixed charge for sample 1 is -2.56E14ions/cm² and it reduces to the ~ -1.86E11 ions/cm² for sample 3.The post-annealing of MCT/CdTe interface in hydrogen atmosphere plays an important role in the reduction of oxide fixed charges. In all, four experiments were conducted to see the effect of hydrogen post-annealing on interface characteristics of MIS structures. It has been found that the use of post-annealing produced better interfaces than as grown MIS structure i.e. without post-annealing. It was however confirmed that for the unannealed sample the oxide fixed charges are quite high as compared to other samples that are post -annealed in hydrogen for different durations. The other possible reason for high population of oxide charges in sample 1 could be due to some drawback in the polishing of MCT wafer After polishing the crystal, the value of delta A as recorded through ellipsometer 145 which is a little bit low as compared to the ideal value for Aie 148º which indicates post-annealing has increased to 4hours, the oxide fixed charges reduced to -186E11 ions/cm² Further increase in post-annealing duration, up to 5ours and 6hours hydrogen atmosphere shows a further reduction in the value of oxide fixed charges which goes down to the level of about 1.689E11 ions/cm² and -1.636E11 ions/cm² Respectively . 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These samples have improved delta and closer to ideal value of delta as compared to sample 1.From the data obtained for all samples in series A after analysing the C-V measurements at a frequency of 1MHz and at a temperature of 77K. observed that the oxide fixed it was charges have negative value whereas the flat band voltage shift has a positive value For sample 1 the flat band shift is 0.46381V while for samples 2.3.4 and 5 it is 0.3884 V, 0.3779V. 0.3820V and 0.3798V respectively. 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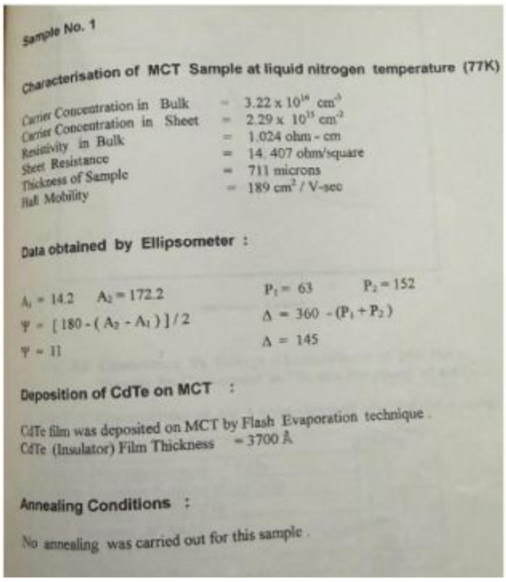
The threshold voltage shows an increase in value with increase in post-annealing duration. Sample 1 has a threshold voltage of 2.81V while for samples 2 ,3,4 and 5 the threshold voltages values are 4.315V, 4.253V, 4.6397V and 4.7198V respectively. The effect of hydrogen post-annealing on interfaces indicates an improvement of interface parameters of MIS structures. This could be attributed to the fact that the hydrogen neutralises the dangling bonds present on the surface of insulator (CdTe) film and improved the quality of film. The improvement in the quality of CdTe deposited films was also confirmed, when the Flash evaporated CdTe thin films annealed in hydrogen atmosphere at substrate temperature of 80°C showed an increase both in the resistivity (17-18) as well as band gap.

Sample 1



Sample No. 1

Characterisation of MCT Sample at liquid nitrogen temperature (77K)

Carrier Concentration in Bulk = 3.22×10^{16} cm^{-3}
Carrier Concentration in Sheet = 2.29×10^{15} cm^{-2}
Resistivity in Bulk = 1.024 ohm - cm
Sheet Resistance = 14. 407 ohm/square
Thickness of Sample = 711 microns
Hall Mobility = 189 cm^2 / V-sec

Data obtained by Ellipsometer :

$A_1 = 14.2$ $A_2 = 172.2$ $P_1 = 63$ $P_2 = 152$
$\Psi = [180 - (A_2 - A_1)]/2$ $\Delta = 360 - (P_1 + P_2)$
$\Psi = 11$ $\Delta = 145$

Deposition of CdTe on MCT :

CdTe film was deposited on MCT by Flash Evaporation technique.
CdTe (Insulator) Film Thickness = 3700 Å

Annealing Conditions :

No annealing was carried out for this sample.

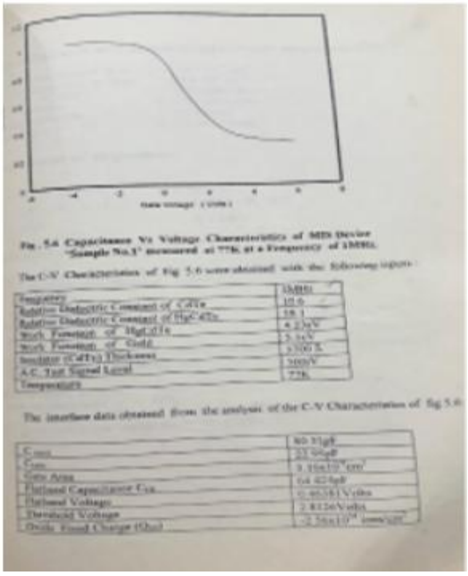


Fig. 5.6 Capacitance Vs Voltage Characteristics of MIS Device "Sample No.1" measured at 77K at a Frequency of 1MHz.

[illegible]

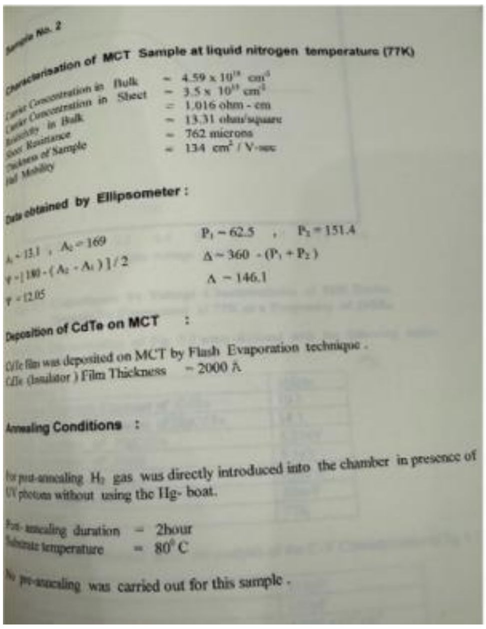
Frequency	1MHz
Relative Dielectric Constant of CdTe	10.6
Relative Dielectric Constant of HgCdTe	18.1
Work Function of HgCdTe	4.23eV
Work Function of Gold	5.1eV
Insulator (CdTe) Thickness	3700 Å
A.C. Test Signal Level	50mV
Temperature	77K

[illegible]

[illegible]	[illegible]

Figure 5.6

Sample 2



Sample No. 2

Characterisation of MCT Sample at liquid nitrogen temperature (77K)

Carrier Concentration in Bulk = 4.59×10^{14} cm^{-3}
Carrier Concentration in Sheet = 3.5×10^{13} cm^{-2}
Resistivity in Bulk = 1.016 ohm - cm
Sheet Resistance = 13.31 ohm/square
Thickness of Sample = 762 microns
Hall Mobility = 134 cm^2 / V-sec

Data obtained by Ellipsometer :

$A_1 = 13.1$, $A_2 = 169$ $P_1 = 62.5$, $P_2 = 151.4$
$\Psi = [180 - (A_2 - A_1)]/2$ $\Delta = 360 - (P_1 + P_2)$
$\Psi = 12.05$ $\Delta = 146.1$

Deposition of CdTe on MCT :

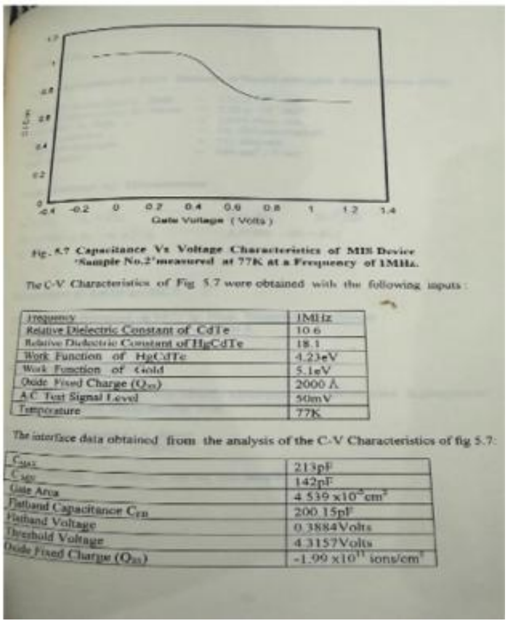
CdTe film was deposited on MCT by Flash Evaporation technique.
CdTe (Insulator) Film Thickness = 2000 Å

Annealing Conditions :

For post-annealing H_2 gas was directly introduced into the chamber in presence of UV photons without using the Hg- boat.

Post-annealing duration = 2hour
Substrate temperature = 80° C

No pre-annealing was carried out for this sample.



Gate Voltage (Volts)

Fig. 5.7 Capacitance Vs Voltage Characteristics of MIS Device 'Sample No.2' measured at 77K at a Frequency of 1MHz.

The C-V Characteristics of Fig 5.7 were obtained with the following inputs:

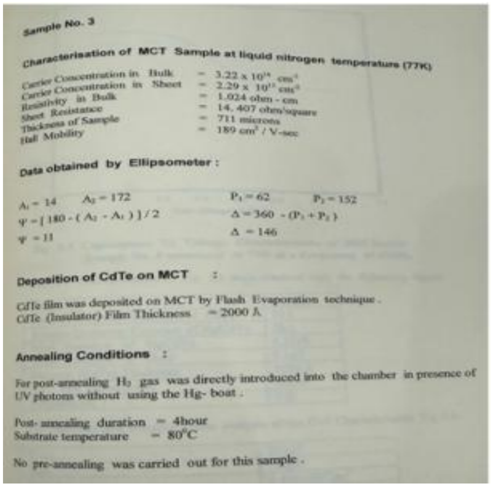
Frequency	1MHz
Relative Dielectric Constant of CdTe	10.6
Relative Dielectric Constant of HgCdTe	18.1
Work Function of HgCdTe	4.23eV
Work Function of Gold	5.1eV
Oxide Fixed Charge (Q_{ss})	2000 Å
A.C Test Signal Level	50mV
Temperature	77K

The interface data obtained from the analysis of the C-V Characteristics of fig 5.7:

C_{MAX}	213pF
C_{MIN}	142pF
Gate Area	4.539×10^{-3} cm^2
Flatband Capacitance C_{FB}	200.15pF
Flatband Voltage	0.3884Volts
Threshold Voltage	4.3157Volts
Oxide Fixed Charge (Q_{SS})	-1.99×10^{11} ions/cm^2

Figure 5.7

Sample 3



Sample No. 3

Characterisation of MCT Sample at liquid nitrogen temperature (77K)

Carrier Concentration in Bulk = 3.22×10^{16} cm^{-3}
Carrier Concentration in Sheet = 2.29×10^{15} cm^{-2}
Resistivity in Bulk = 1.024 ohm - cm
Sheet Resistance = 14. 407 ohm/square
Thickness of Sample = 711 microns
Hall Mobility = 189 cm^2 / V-sec

Data obtained by Ellipsometer :

$A_1 = 14$ $A_2 = 172$ $P_1 = 62$ $P_2 = 152$
$\Psi = [180 - (A_2 - A_1)]/2$ $\Delta = 360 - (P_1 + P_2)$
$\Psi = 11$ $\Delta = 146$

Deposition of CdTe on MCT :

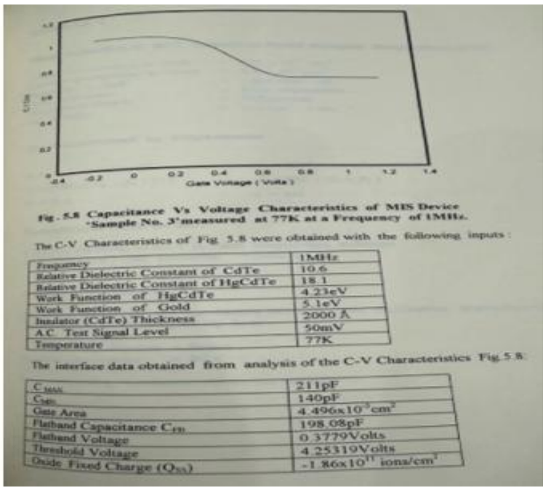
CdTe film was deposited on MCT by Flash Evaporation technique.
CdTe (Insulator) Film Thickness = 2000 Å

Annealing Conditions :

For post-annealing H_2 gas was directly introduced into the chamber in presence of UV photons without using the Hg- boat.

Post-annealing duration = 4hour
Substrate temperature = 80°C

No pre-annealing was carried out for this sample.



Gate Voltage (Volts)

Fig. 5.8 Capacitance Vs Voltage Characteristics of MIS Device 'Sample No. 3' measured at 77K at a Frequency of 1MHz.

The C-V Characteristics of Fig 5.8 were obtained with the following inputs:

Frequency	1MHz
Relative Dielectric Constant of CdTe	10.6
Relative Dielectric Constant of HgCdTe	18.1
Work Function of HgCdTe	4.23eV
Work Function of Gold	5.1eV
Insulator (CdTe) Thickness	2000 Å
A.C Test Signal Level	50mV
Temperature	77K

The interface data obtained from analysis of the C-V Characteristics Fig 5.8

C_{MAX}	211pF
C_{MIN}	140pF
Gate Area	4.496×10^{-3} cm^2
Flatband Capacitance C_{FB}	198.08pF
Flatband Voltage	0.3779Volts
Threshold Voltage	4.25319Volts
Oxide Fixed Charge (Q_{SS})	-1.86×10^{11} ions/cm^2

Figure 5.8

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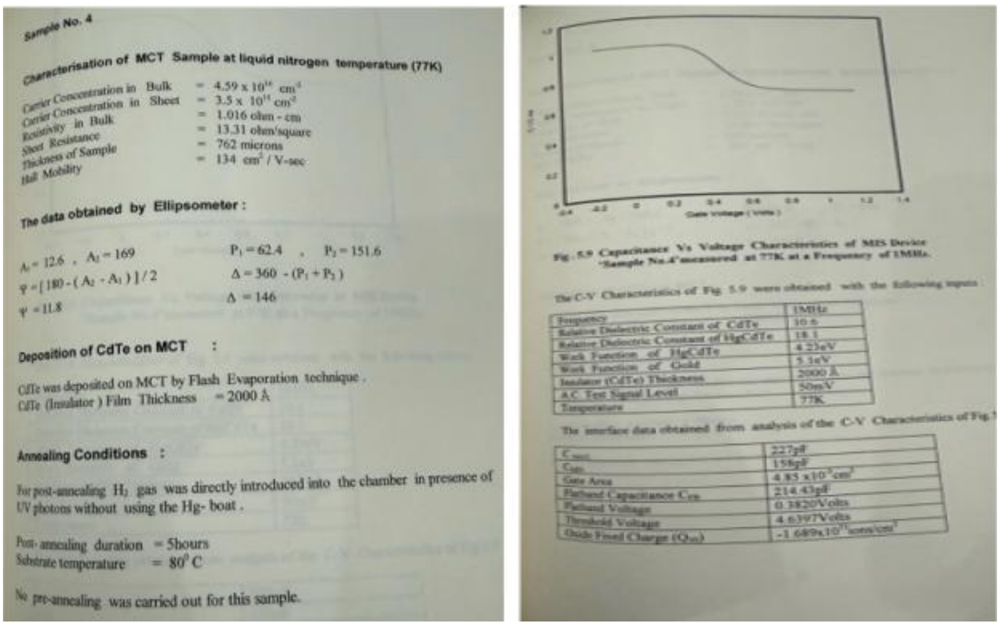
Sample 4



Sample No. 4

Characterisation of MCT Sample at liquid nitrogen temperature (77K)

Carrier Concentration in Bulk = 4.59×10^{14} cm^{-3}
Carrier Concentration in Sheet = 3.5×10^{11} cm^{-2}
Resistivity in Bulk = 1.016 ohm - cm
Sheet Resistance = 13.31 ohm/square
Thickness of Sample = 762 microns
Hall Mobility = 134 cm^2 / V-sec

The data obtained by Ellipsometer :

$A_1 = 12.6$, $A_2 = 169$
$\psi = [180 - (A_2 - A_1)]/2$
$\psi = 11.8$

$P_1 = 62.4$, $P_2 = 151.6$
$\Delta = 360 - (P_1 + P_2)$
$\Delta = 146$

Deposition of CdTe on MCT :

CdTe was deposited on MCT by Flash Evaporation technique .
CdTe (Insulator) Film Thickness = 2000 Å

Annealing Conditions :

For post-annealing H_2 gas was directly introduced into the chamber in presence of UV photons without using the Hg- boat .

Post-annealing duration = 5hours
Substrate temperature = 80^0 C

No pre-annealing was carried out for this sample.

Fig. 5.9 Capacitance Vs Voltage Characteristics of MIS Device "Sample No.4" measured at 77K at a Frequency of 1MHz.

The C-V Characteristics of Fig. 5.9 were obtained with the following inputs :

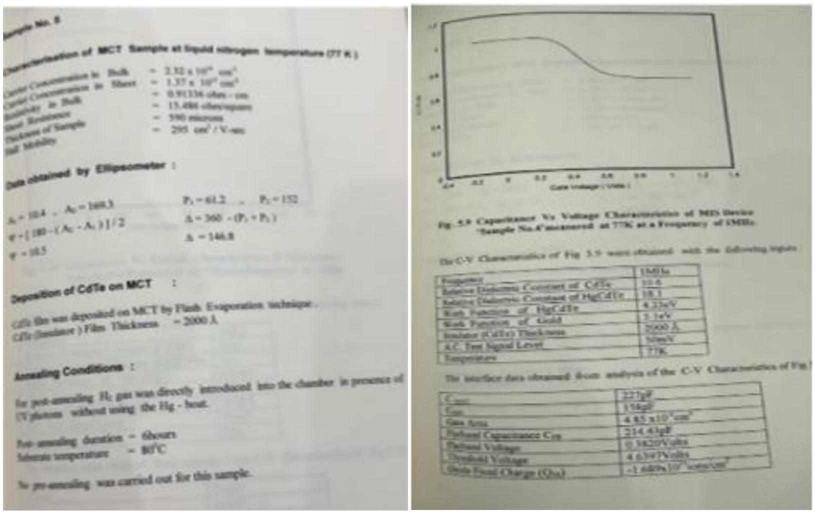
Frequency	1MHz
Relative Dielectric Constant of CdTe	10.6
Relative Dielectric Constant of HgCdTe	18.1
Work Function of HgCdTe	4.23eV
Work Function of Gold	5.1eV
Insulator (CdTe) Thickness	2000 Å
A.C Test Signal Level	50mV
Temperature	77K

The interface data obtained from analysis of the C-V Characteristics of Fig. 5.9

C_{max}	227pF
C_{min}	158pF
Gate Area	$4.85 \times 10^{-3} cm^2$
Flatband Capacitance C_{FB}	214.43pF
Flatband Voltage	0.3820Volts
Threshold Voltage	4.6397Volts
Oxide Fixed Charge (Q_{ss})	-1.689×10^{11} ions/cm^2

Figure 5.9

Sample 5



Characterisation of MCT Sample at liquid nitrogen temperature (77 K)

Data obtained by Ellipsometer :

$\Delta = 360 - (P_1 + P_2)$
$\Delta = 146.8$

Deposition of CdTe on MCT :

CdTe (Insulator) Film Thickness = 2000 Å

Annealing Conditions :

For post-annealing H_2 gas was directly introduced into the chamber in presence of UV photons without using the Hg - boat.

Post-annealing duration = 6hours
Substrate temperature = 80°C

No pre-annealing was carried out for this sample.

Figure 5-10

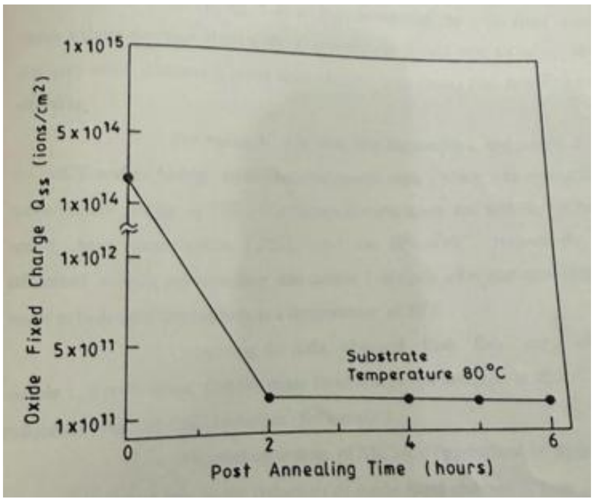


Figure 5.11: Oxide Fixed Charge density as a function of Post annealing duration in hydrogen atmosphere at a temperature of 80 °C

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