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Enhanced Charge Trapping Response of the In Doped TiO_2 TF Device

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Abstract:

Indium (In) doped TiO_2 TF and undoped TiO_2 TF capacitive memory device has been fabricated through e-beam deposition technique. In metal was used as dopant source. A comparative study of frequency dependent impedance – voltage characteristics were measured to analysis charge trapping behavior of the devices. Large interface states density was found in In doped device (6.62 x 10^{12} $cm^{-2}eV^{-1}$) compared to undoped devices (2.80 x 10^{12} $cm^{-2}eV^{-1}$) at 2MHz operating frequency.A high impedance value was recorded in the doped device of 50.87 KΩ and 7.32 KΩ compared to undoped device of 42.1 KΩ and 6.87 KΩat 200 KHz and 2MHz frequency, respectively. Function of trap/defect states have been explained and it has been explicated that the introduction of defect states due to the In doping into TiO_2 thin film, enhanced the trap states and charge trapping capability of the In doped device, which can be proposed for the fabrication of nonvolatile memory devices.

Keyword: Thin Film, interface trap states, capacitive memory

1. Introduction

These days, capacitive memory device is turning into an essential section of research intrigue. The dielectric properties of TiO_2 have been gotten an extraordinary consideration for applications in the telecommunications industry in view of its typical high dielectric constant and low dielectric loss [1, 2]. Recently, electric pulse induced reversible (EPIR) resistance change effect was perceived in oxide materials such as binary oxides [3]. There is an exceptional change in resistance amongst high and low resistance. In this way TiO_2 based MOS devices turns into a reason for use of these materials in non-volatile memory applications.Among a lot of transition metal oxide, TiO_2 exhibits remarkable charge trapping phenomena as capacitive memory[4] which depends upon its crystal structure, surface area, size, charge distribution etc. Efforts have been made to enhance the charge storing of TiO_2 by increasing the roughness of the surface relative to simple TiO_2 thin film (TF).In addition to that the band gap reduction of TiO_2, again leads to alteration in vital semiconductor parameters. S. In et. al[5] and G. Liu et. al [6] showed non-metal ions like B an N produces band gap smaller than the threshold (1.23-2.5 eV) value. This recommends low dimensional structures with energy gap higher than ~3.0 eV might be a superior beginning for doping. There is no give an account of the enhanced charge trapping of the In doped TiO_2 capacitive memory, without degradation of device performance.

In this paper we have inspected the charge storing behaviour of In doped TiO_2 TF and undoped n- TiO_2 TF MOS structure in association with the function of interface trap state density (Dit) inside the insulator substrate interface by performing frequency dependent C-V measurement as a function of gate bias. Frequency dependent impedance measurement revels enhanced charge trapping of the In doped TiO_2 capacitive memory, without degradation of device performance.To investigate the aforementioned interests, relevant device fabrication and operation mechanism have been discussed. Undoped samples were doped with varying In content of 1.45 at% and the samples were termed as In doped TiO_2 TF device during entire experimental work.

2. Experiments

Fabrication of Undoped and In doped TiO_2 device

A 200 nm thickness of TiO_2 TF was deposited on n-type Si <100> substrate (35 ohm-cm) from 99.999% vastly pure TiO_2 (MTI, USA) source inside the chamber of an e-beam evaporator (Hind High Vacuum Co. (p) Ltd., 15F6). Before starting the fabrication process several pieces of (1cm × 1cm) n-type Si substrate were prepared from the n type <100> silicon wafer of 2” diameter. Then the wafers are cleaned with wet cleaning technique. The first step in the ex situ cleaning process was to ultrasonically degrease the wafer in trichloroethylene, acetone and methanol,DI water for 3-5 minutes followed by standard cleaning-1 (RCA-1) process. Once more, cleaned Si wafers were dipped into the diluted HF (arrangement comprising of Hydrofluoric acid (HF) and DI water, ($HF:H_2O$) in a 1:50 volume ratio) for few seconds to remove the native oxide on Si wafer. The source and substrate were held in inversely perpendicular position to synthesize desired TiO_2 TF. The opposite separation distance between the source material to be evaporated and the substrate was kept at 25 cm for the deposition of TiO_2 TF. After that the entire deposition was carried out inside a high vacuum chamber, to permit the evaporated source material to reach the substrate without responding with or disseminating against different gas-phase atoms in the chamber, and decrease the incorporation of impurities from the residual gas at a base pressure of 2×10^{-5} mbar. A constant high deposition rate of 1.2 Å s^{-1} was maintained, during TF deposition, which was monitored by a quartz crystal.Then the TiO_2 TF was doped with Indium. Indium (In) metal films of thickness 5 nm was developed using 99.999% pure In (MTI, USA) in the same e-beam evaporator. Then all the samples were annealed in open air condition at 950 ˚C for 1 hour inside the tube furnace (GSL-1700X, MTI, USA) using even heating and cooling ramp of 4 ˚C/min to diffuse the In into the TiO2 TF. Metal contacts of Gold (Au) were deposited through evaporation technique using aluminium mask whose hole diameters are of size 1.5 mm shown in Fig. 1 (a-b).

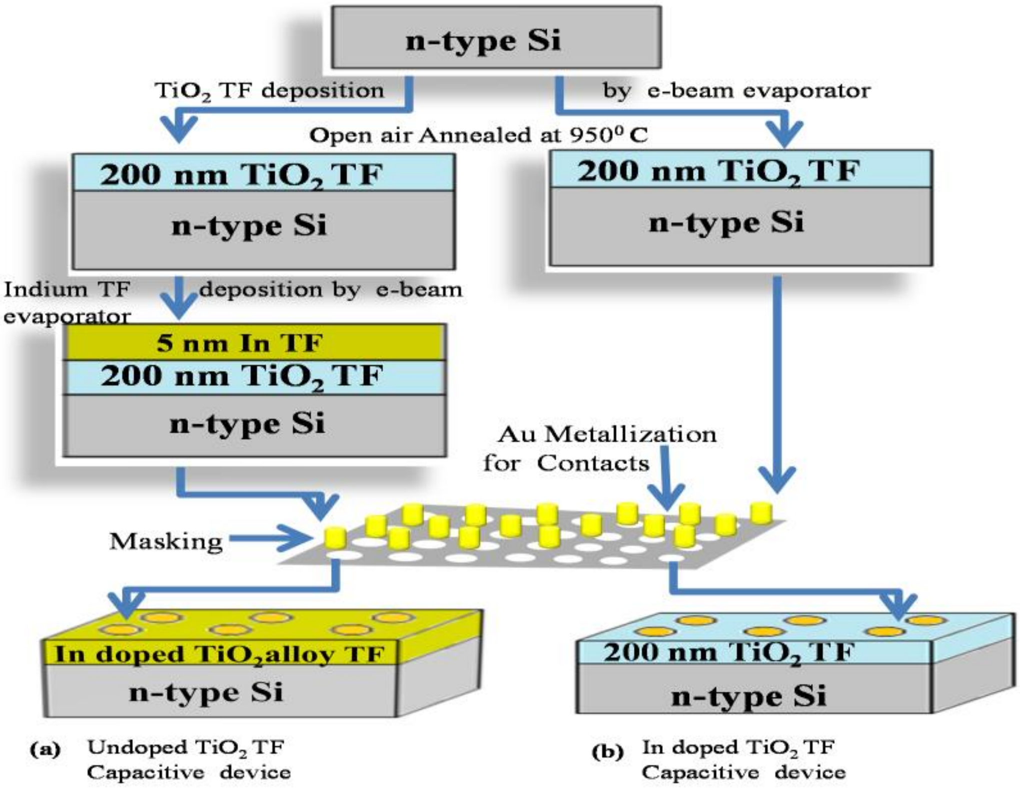

Fig: 1 Schematic diagram of fabrication steps: (a) undoped TiO_2 TF Capacitive device (b) In_5 doped TiO_2 TF Capacitive device

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The frequency dependent capacitance as a function of gate bias were measured by Agilent (E4980A) LCR meter using Au top contact for both of the In doped and undoped TiO_2 TF devices. Impedance –voltage measurement was also performed to explore the various charges trapping related behaviour using aforementioned instrument.

3 Results and Discussion

3.1. Device Impedance

Frequency dependent impedance measurement was carried out at an applied electrode voltage ranging from +10 V to -10 V for both In doped TiO_2 TF and TiO_2 TF based devices under room temperain open air condition.

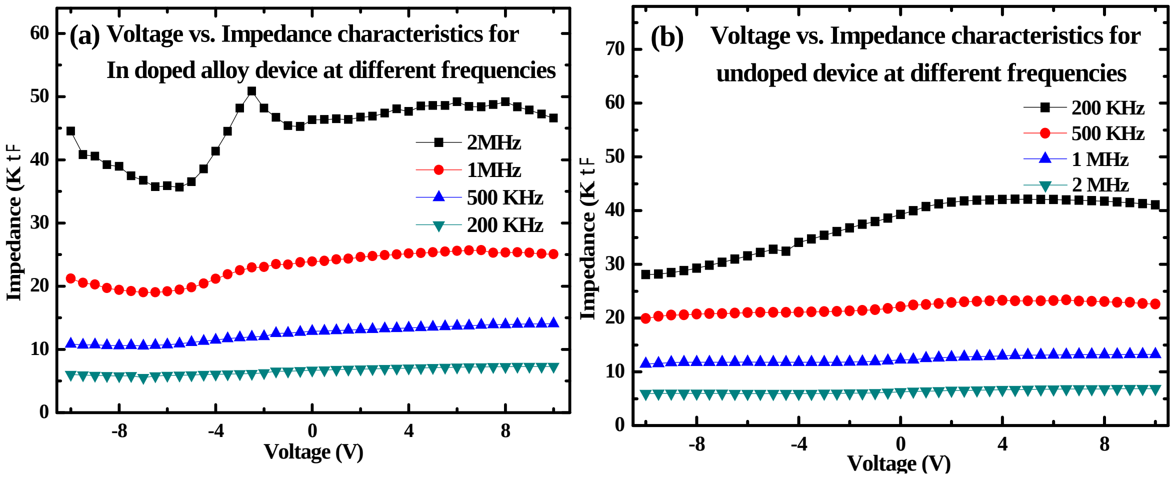

Figure 2 Frequency dependent impedance for (**a**) In doped TiO_2 TF and (**b**) Undoped TiO_2 TF devices..

The maximum impedance for In doped TiO_2 TF devices were measured from impedance-voltage characteristics shown in Fig 2 (a) was about 50.87 KΩ at 200 KHz reduced to 7.32 KΩ at 2MHz . As compared to doped device, fig 6.b indicates relatively lower impedance of 42.1 KΩ at 200 KHz and 6.87 KΩ at 2 MHz. As reported in the previous work that the TiO_2 lattice structure was modified due to the formation of Ti-O-In compounds by the partial substitution of O atoms by In atoms when it was doped with In metal [7]. Again, In dopant ions substitute the Ti ions in the lattice of the TiO_2 TF to form the $In_xTi_yO_2$ alloy interface layer which have large numbers of dangling bonds and hence huge trap states at Au/$In_xTi_yO_2$ interface. Thuspresence of oxygen defect states increased the concentration of traps states in the metal/dielectric and dielectric/substrate interface which trap the excited carriers during device operation and thereby reduce the electron-hole recombination probability of the material. Also presence of defect states further impeded the movement of charge carriers within lattice structure. Thus corresponding carrier mobility was attenuated and therefore showed the high impedance of the In doped device.

The interface trap level density (Dit) can be obtained by using maximum conductance value from the measurement through conduction method [8]. The following equation was used:

$$D_{it} = (2.5/A*q)*(Gp/\omega)_{max} \qquad [1]$$

Where A is the area of the device, ω is the angular frequency, Gp is the maximum measured conductance value .The frequency varying interface trap density have been observed for both doped and undoped devices.

Fig 3 shows the calculated Dit for undoped device varies from 2.46x 10^{12} $cm^{-2}eV^{-1}$ to 2.80 x 10^{12} $cm^{-2}eV^{-1}$ which has negligible frequency variation compared to the In doped device (~2. 75x 10^{13} $cm^{-2}eV^{-1}$ to 6.62x 10^{12} $cm^{-2}eV^{-1}$). It is observed from fig.3 that the interface trap density is less in case of undoped device because of the less defect states present in the oxide as the samples were annealed at 950° C for 1 h in open air condition. Therefore the phenomena of almost linear variation in Dit value with the increase in frequency of undoped

device attributed to the fact that In doped material has efficient frequency response of traps at higher frequency.

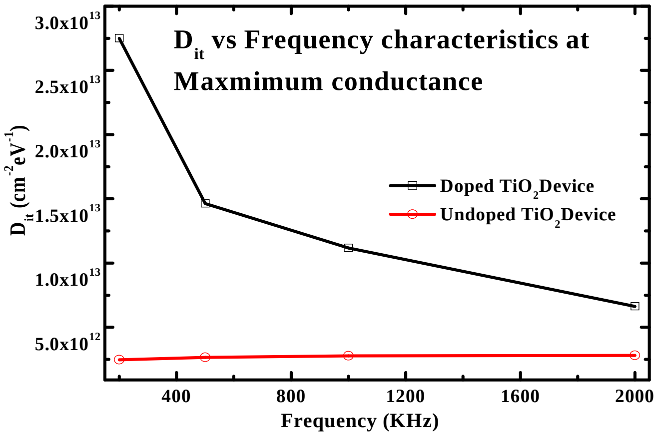

Fig 3 frequency response of Interface trap state density (Dit) for doped and unoped device

Conclusion

A comparative study of frequency dependent impedance –voltage characteristics were measured to analysis charge trapping behavior of the devices. Large interface states density was found in In doped device (6.62 x 10^{12} $cm^{-2}eV^{-1}$) compared to undoped devices (2.80 x 10^{12} $cm^{-2}eV^{-1}$) at 2MHz operating frequency. A high impedance value was recorded in the doped device of 50.87 KΩ and 7.32 KΩ compared to undoped device of 42.1 KΩ and 6.87 KΩ at 200 KHz and 2MHz frequency, respectively. Therefore function of trap/defect states have been detected strongly during device operation for In doped TiO_2 device compared to undoped device. Finally, it has been explicated that the introduction of defect states due to the In doping into TiO_2 thin film, enhanced the trap states and charge trapping capability of the In doped device, which can be proposed for the fabrication of nonvolatile memory devices.

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