MOSAIC TARGET DC SPUTTERING TO SYNTHESIZE $(TA_2O_5)_X$ WITH $(TIO_2)_{1-X}$ MIXED OXIDE AS HIGH K DIELECTRIC

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Abstract: High dielectric mixed oxide of $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ thin film is prepared by dc reactive sputtering. Mosaic target consist of 3" diameter circular disc of Tantalum metal on which Titanium metal and its small pieces of different areas can be fixed to deposit mixed oxide of films of varying composition. P-type single crystal silicon with 100 crystal orientation is used as substrate. Oxygen is used as reactive gas along with argon. The thickness of deposited film is in the range of 300±10 nm after heating at 6000C. Agilent make 4284 A model L-C-R meter along with Karlsuss make wafer probe station is used for C-V measurement. Maximum dielectric constant of 34.28 is achieved for mixed oxide of $(Ta_2O_5)_{87.5}$ with $(TiO_2)_{12.5}$ which is promising to replace SiO_2 as gate dielectric layer in Microelectronics devices.

***IndexTerms* – dielectric, mixed oxide, sputtering, thin film.**

I. INTRODUCTION

The term high-K dielectric refers to a material with high dielectric constant largely used in semiconductor industry which replaces the silicon dioxide gate dielectric. The implementation of high-K gate dielectric is one of several strategies developed to allow further miniaturization of microelectronic components referred to as Moore's Law [1]. The dielectric constant is the ratio of the permittivity of a substance to the permittivity of free space. Dielectric constant, also called relative permittivity indicates the extent to which a substance concentrates the electrostatic lines of flux. As the dielectric constant increases, the electric flux density increases, this enables the materials to hold large quantities of charge.

The success of the semiconductor industry relies on the continuous performance improvements of integrated circuits [2]. As device dimensions of individual MOSFETs are reduced to achieve higher densities and faster switching speeds, it is necessary to scale device dimensions proportionally in order to achieve level of their performance. The scaling limit of SiO_2 in MOSFETs as gate oxide layer is the exponential increase of direct tunneling current as function of the SiO_2 thickness. In order to reduce direct tunneling, make the physical thickness of the gate dielectric larger, but keep the capacitance the same as an equivalent SiO_2 film. The application of this principle is to increase the dielectric constant to values larger than the SiO_2 and thereby continue Moore's law scaling [3, 4].

II. EXPRIMENTAL

The experimental work is aimed at the preparation of $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ mixed oxide thin films. There is enhanced dielectric constant of Ta_2O_5 through TiO_2 substitution as alternative to the conventional SiO_2 gate dielectric of MOSFETs.

Substrate

The substrate material used for deposition of mixed oxide $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ thin films is P type single crystal silicon with 100 crystal orientation having a doping concentration in the range of 0.2 x 10^{15} to 2.2 x10^{15} boron atoms /cm^3.The 4″ wafers are cut down into small pieces of rectangular or square shape before deposit the mixed oxide $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ thin films. For MOS configuration aluminum electrodes were deposited on the dielectric films using a mechanical mask. For MIM configuration, Platinum coated substrates have been used and on the top of the dielectric layer, aluminum electrodes have been deposited using thermal evaporation process.

Cleaning procedure

First the samples are subjected to ultrasonication for removing the contaminants like dust particles, then cleaned in Piranha solution which is a warm mixture of sulphuric acid and hydrogen peroxide in 1:3 ratio to remove any organic residues left on the substrate and to make it hydrophilic. Then the samples are rinsed in De Ionized water and then dipped in 5% HF solution to remove any native SiO_2 present on the samples. Finally the samples are rinsed in De Ionized water and then flushed with dry air prior to loading in the deposition chamber.

Sputtering system

DC reactive magnetron sputtering system has been used for obtaining the mixed oxide thin films. The target material used is a Mosaic target, which is a combination of 3" diameter circular disc of Tantalum and small Titanium pieces having different areas of 99.99% purity. Argon gas (99.99% pure) and Oxygen (99.999% pure) are used as sputtering and reactive gas respectively. The sputtering chamber is evacuated to a base pressure of 1.0× 10^{-5}m-bar using a diffusion pump and rotary pump combination. The partial pressures of the two gases have been controlled by using mass flow controllers. The substrate to target distance is 6 cm.

III. RESULT AND DISCUSSION

Before the deposition of mixed oxide thin films, the process parameters have been optimized for deposition of Tantalum oxide films at different current densities and different thicknesses at a base vacuum of 1.0×10^{-5}m-bar, Oxygen partial pressure of 6×10^{-4}m-bar and sputtering pressure of 4×10^{-3} m-bar. The film is heated at 600ºC to reduce the defects. The area of MOS capacitor is $13278.57\times10^{-10}m^2$. The metal contact used is aluminum.
K is the Dielectric constant, calculated by using the following relation

$$K = \frac{Coxtox}{A\varepsilon 0} \qquad (1)$$

Where,
C_{ox}- Maximum oxide capacitance,
t_{ox}- Thickness of the oxide film,
A - Area of the MOS capacitor or dot
ϵ_o- Permittivity of free space and its value is 8.85×10^{-12} F/m

Table 1 Optimization of process parameters of tantalum oxide

Current density (mA/cm^2)	Thickness (nm)	Capacity (Cox) (pf)	Deposition time (min)	Dielectric Constant (K)
1.5	70	994	35	6.0
	214	990	105	17.1
	310	924	150	24.41
	600	488	290	26.61
2.0	82	2012	30	14.0
2.5	55	1401	15	6.5

Table 1 shows the optimized process parameters for value of dielectric constant K=24.41 condition for reasonable thickness. So we selected this condition for deposition of $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ mixed oxide thin films by adding small Titanium pieces of different known areas and measured the dielectric constant K as shown in Table 2

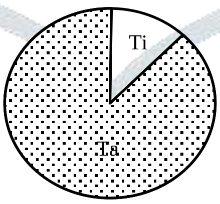

Figure 1 Mosaic Target of 87.5% of Ta and 12.5% of Ti 3" diameter disc

Figure 1 shows the mosaic target configuration for which maximum dielectric constant achieved for MOS structure is 34.28 and for MIM structure is 38 as table 3 when Titanium is 12.5% and Tantalum is 87.5%.The reason for maximum capacitance in MIM structure is that, it is just a parallel plate capacitor with two metal plates and oxide layer between them. Where as in MOS structure, the resultant capacitor is the series combination of both oxide capacitance and the semiconductor depletion capacitance.

Table 2 Dielectric constant variation as per composition of Ta and Ti

Sample no	Tantalum (%)	Titanium (%)	Dielectric Constant
1	100	0	24.41
2	96.875	3.125	32
3	87.5	12.5	34.28
4	81.25	18.75	26.8
5	75	25	26.7
6	62.5	37.5	25.5
7	0	100	10

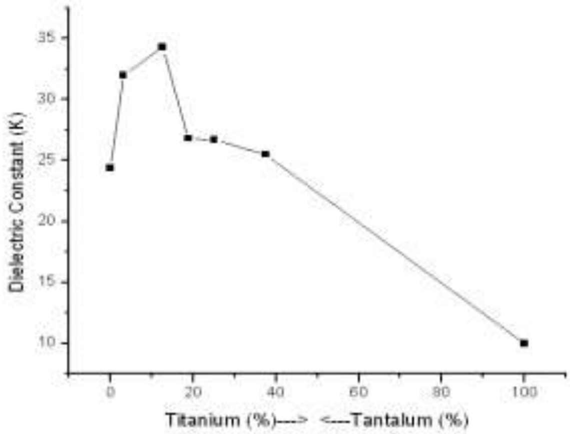

Figure 2 Mixed oxide composition vs Dielectric constant K

Table 3 Dielectric constant of MOS and MIM structure

MOS	MIM
34.28	38

For performing the Capacitance – Voltage measurements Agilent make 4284 A L–C–R meter having operating frequency range from 20 Hz to 1MHz is used along with a KarlSUSS make PM8 model probe station. Lab view program is used to interface L–C–R meter and set program parameters. The probe station is having a vacuum chuck to hold the sample firmly to avoid displacing of the sample while probing and also to provide proper electrical contact at the back side of the wafer. For performing the bi directional HFCV scan on MOS capacitor small AC voltage signal of 5mV amplitude is super imposed onto a DC voltage, which is swept from accumulation region to inversion region and again from inversion to accumulation. The range of the DC voltage as well as the DC voltage step value is varied between different samples to get the best possible curves.

The bi directional C–V curves for our sample number 3 with AC voltage = 5mV, frequency = 1 MHz is shown in the Figure 3. The bi directional C−V scan performed on samples have a finite hysteresis and among the factors which cause the hysteresis in the bi directional C−V the fixed charges (either positive or negative) which are close to the oxide interface. Maximum dielectric constant K is 34.28 in case of MOS structure can be observed for the condition of $(TiO_2)_{12.5}(Ta_2O_5)_{87.5}$ after heating at 600^0C and film thickness of 300 nm.

Literature survey briefs about the Raman scattering and XRD studies of $(Ta_2O_5)_x$ with $(TiO_2)_{1-x}$ mixed oxide thin films. There is some kind of phase structure appearing when a small quantity of TiO_2 is mixed into Ta_2O_5 which enhances the dielectric constant K [9].

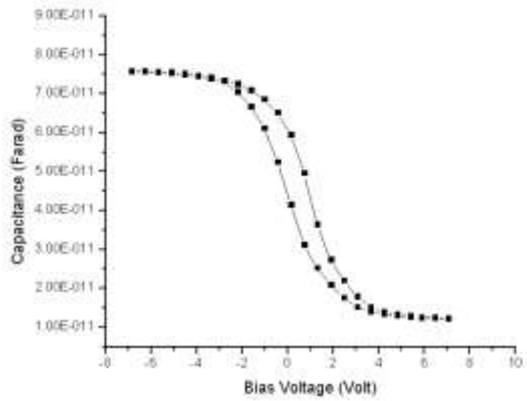

Figure 3 Bi directional C-V scan of $(TiO_2)_{12.5}$ with $(Ta_2O_5)_{87.5}$ mixed thin film

IV. CONCLUSION

In conclusion, mixed oxide thin films of Ta and Ti can be deposited by DC reactive magnetron sputtering from mosaic target. We have shown the maximum dielectric constant of $(Ta_2O_5)_{87.5}$ with $(TiO_2)_{12.5}$ mixed oxide thin film which can be replace SiO_2 as gate oxide layer in MOSFET device. This mixed oxide found stable at 600^0C temperature indicates the compatibility with the fabrication process of MOSFET device.

Further research on fabrication of device and electrical property of $(Ta_2O_5)_{87.5}$ with $(TiO_2)_{12.5}$ mixed oxide thin film should be of significant interest.

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