Electrical properties of thin films deposited from TMS/O$_2$ in Microwave Multipolar Plasma reactor

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Abstract. Thin films have been deposited from pure Tetramethylsilane and a mixture of Tetramethylsilane and oxygen (TMS/O$_2$). The addition of oxygen proportion to Tetramethylsilane vapors leads to the change in film structure which varies from organic to inorganic character close to SiO$_x$-like film [1]. The electrical characterisation using Metal-Insulating-Metal structure permits the study of current-voltage (I (V)) curves behaviours. The results suggest that the carrier transport in the deposited films is limited by a space charge conduction mechanism.

1. Introduction

Dielectric layers deposited by PECVD technique have been widely employed in the design of ultra large scale integration (ULSI) devices as insulator between metal interlayers [2]. Reduction of dimensions in ULSI technology requires insulator materials with high quality such as: a low dielectric constant [2] and weak electrical current. SiO$_x$ films remains the most insulator material used in microelectronic technology. Moreover, a lot of works have been carried out to deposit SiO$_x$-like films at low temperature using a large variety of precursors such as organosilicon compounds [3-4]. The electrical properties of SiO$_x$-like films elaborated from organosilicon compounds mixed with high proportion of oxygen (O$_2$, N$_2$O) [5] have been found depending on the deposited parameters [6-9]. The effect of the films structure on the electrical properties according to the deposited conditions needs further investigation.

In this work, we have reported the electrical properties evolution of thin films deposited from pure vapor of Tetramethylsilane (TMS) and TMS/oxygen mixture.
2. Experimental details

The thin films were elaborated at ambient temperature in a distributed electronic cyclotron resonance (RCER) plasma reactor of cylindrical geometry. This reactor is equipped with eight magnets arranged alternately with eight antennas cooled by a water circulation. It has been described elsewhere in a several reported works [10][11]. The microwave plasma frequency excitation was 2.45 GHz and the working power explored in this work has been set to 400 W. The eight antennas radiate the same power value transmitted through a waveguide equipped with a high impedance adapter and a power splitter. The films thickness varying in the range of 563-89.6 nm, were deposited from pure TMS vapors and mixed with oxygen proportions on metalized glass substrates. MIM (Metal-Insulator-Metal) structures were obtained by depositing aluminum electrodes on these films using vacuum evaporation technique. Electrical measurements were carried out using a Keithley 6512 electrometer.

3. Results and discussion

The evolution of the charging current as function of the polarization time is shown in Figure 1. Two regimes are observed: the electric current decreases rapidly for short times (transient current regime) and then slowly until reaching a quasi-constant value when the time polarization is important (permanent regime). It’s well known that the first regime is due to a polarization effect and the second regime is due to a conduction mechanism which may be controlled by an interface effect and/or by bulk effect.

![Figure 1. Variation of the charging and discharging current for an applied electric field of about 3.11*10^4 V/cm as a function of the polarization time for films deposited from plasma created in 1 mtorr of TMS vapors and discharge power of 400 watts.](image)

The discharge current represented in figure 1 takes place when the applied electric field is disconnected and the structure MIM electrodes was immediately short-circuited. It can be seen that the charging and the discharging currents are superposition in case of short polarization times. Beyond measuring time of about 20 sec charging and discharging curves start to diverges rapidly (They shift one from the other by two decades for a polarization time of about 3 hours). The current superposition observed for the first regime suggests a presence of dipoles in the films [12]. However, for large applied electric field values, it has been observed that the charging and discharging currents are very distinct even for short times (Figure 2).

Figure 3 shows the evolution of the quasi steady electrical current as a function of the applied electric field square root. This curve shows a nonlinear variation making weak the probability of the presence in the deposited films of Schottky and/or Poiff Frenkel charge transport mechanisms [13,12].
However, as it is shown in figure 4, the electrical current varies with a slope value close to 1 A.cm/V for low values of the applied electric field and with a slope varying from 2 to 3 A.cm/V for the medium and high applied electric field, respectively, suggesting by the way the existence of a space charge conduction mechanism effect in the elaborated films. Indeed, the presence of such conduction mechanism is characterized by an I(V) bilogarithmic curve with a linear variation of the current for low applied voltage values which can be described by the equation 1 (ohmic conduction) :

$$ J = q n \mu \frac{V}{d} $$

where $q$ is the electron charge, $n$ the carrier density, $\mu$ the mobility of the electrons in the films, $d$ the films thickness and $V$ the applied voltage. This ohmic conduction is followed by a quadratic variation of the current given by the equation 2 [14,15],

$$ J = \frac{9}{8} \mu E_0 E \left( \frac{V}{d} \right)^2 $$

Figure 2. Charging and discharging current evolution as a function of the polarization time for a film deposited from pure TMS vapors.

Figure 3. Variation of the electric current as a function of the square root of the applied electric field.
with $\varepsilon_0$ is the vacuum permittivity (8.85 $\times$ 10$^{-12}$ F/m) and $\varepsilon_r$ the films dielectric constant.

On the other hand, it is important to notice that the oxygen introduction in the precursor mixture induces a decrease of the recorded current (reaching more than a decade when the oxygen rate in the precursor is about 90%). The oxygen addition to the TMS vapors improves the electrical properties of the films probably by deceasing defects trapped in the film structure. FTIR results presented elsewhere show that the films produced by plasma using only TMS vapors consist mainly of -CH$_3$ and Si-CH$_3$ groups [1] and the oxygen addition to this vapors leads to the deposition of less organic films, quasi-inorganic when the oxygen ratio in the mixture precursor is over 90% [1].

4. Conclusion

In this study two kinds of films have been deposited, organic films elaborated using only TMS vapors (a-Si:CH) and inorganic films (SiO$_x$ like films) using a high oxygen ratio in the TMS/O$_2$ mixture [1]. The electrical characterization results suggested that conduction is dipolar (for transient regime) and limited by space charge without traps (for permanent regime). The addition of high oxygen proportion could improve the electrical properties by reducing probably defects in the film. In this case the deposited films have inorganic structure close to the thermal oxide (SiO$_x$ like films). Although the recorded I(V) characteristic is consistent with the presence of a space charge mechanism in the films. However to confirm this result, the explored voltage range must be raised at least three decades. Moreover, it will be interesting to carry out a variation study of the electric current as a function of the films thickness.

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