Silicon nitride layers obtained by ECR PECVD

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Abstract— **It has been found that good quality silicon nitride films can be deposited at room temperature, with an alternate electron cyclotron resonance (ECR) plasma source, called multipolar ECR. The effects of several deposition conditions on physical and electrical properties were studied in order to optimise the deposition process. The layers were characterised by a refractive index of 1.97, dielectric constant of 7.1, Si/N ratio values of around 0.78 and very low hydrogen content (under 1%). The lowest oxygen contamination (2%) was obtained for the highest nitrogen flow. A decrease in refractive index was observed at high pressure, probably because of insufficient energy to dissociate the nitrogen molecules. The density of interface charge was estimated to be in the range of 3-11·10^{11} cm^{-2} and the breakdown field was calculated to be around 12 MV/cm.**

Keywords **— silicon nitride, PECVD, Poole-Frenkel, room temperature.**

I. INTRODUCTION

The demand for high mobility TFTs realised on temperature unstable substrates is increasing [1]. These devices require thin, low-temperature, high-quality gate dielectrics.

Plasma-enhanced chemical vapour deposition (PECVD) with radio-frequency excitation is the most known method used for obtaining TFTs materials at temperatures of 300^{o}C. However, the rf-PECVD dielectrics contain a large amount of hydrogen (20-30%) and have high defect densities due to the high-energy ions impinging on the film surface during the film growth.

Multipolar ECR plasma enhanced deposition [2] was chosen for our research because it is a low process pressure, with low electron and ion energy [3], and high electronic density [4]. Because of the ECR plasmas characteristics ("soft" and "dense") [5] we believe that the deposition temperature can be lowered, without degrading the film quality or increasing the concentration of unwanted hydrogen bonds.

The influence of different deposition parameters on film quality was investigated in order to find the optimal deposition conditions.

II. EXPERIMENTAL DETAILS

The deposition system, equipped with a MPDR-300 plasma source has been described elsewhere [6]. N_2 was admitted directly into the quartz dome. SiH_4 was introduced through a dispersive ring downstream from the plasma.

3-inch (100)-oriented n-type Si wafers having a resistivity of 1-10 Ω*cm were used for the experiments. The wafer preparation included a 10 minute dip in 100% fuming HNO_3, a 10 minute dip in boiling 69% HNO_3, followed by a 1% HF etch in order to remove the native oxide.

The silicon nitride layers were obtained at floating temperature, without external heating. Due to plasma heating, the substrate temperature, measured by a thermocouple reached a maximum of 60^{o}C. During the experiments, the flow rate of 2% SiH_4-in-helium was maintained at a constant value of 5 sccm and the microwave power was adjusted at 400 Watts. The total pressure was in the range of 5-23 mTorr and the flow rate of nitrogen varied between 30 and 110 sccm. Silicon nitride films with thickness of 30-50 nm were deposited. The refractive index was measured with an automatic PLASMOS elipsometer and the atomic composition was detected by X-ray photoelectron spectroscopy (XPS).

MNS capacitors with aluminum gate electrodes were manufactured in order to measure the electrical properties of the SiO_2 layers. All samples were subjected to an aluminium-sintering step for 5 minutes, at 400°C in wet N_2 ambient. The CV and IV curves were obtained with an MDC system and an HP 4156.

III. Results and Discussion

A. Film composition

In figure 1 the refractive index of the layers and the nitrogen atomic concentration are plotted versus pressure The refractive index decreases with increasing the pressure as a result of less nitrogen incorporation in the layers. Apparently, at high pressures, due to more collisions, the energy provided by the plasma is insufficient for ionizing the nitrogen molecules [7]; and oxygen atoms, originating from leaks, saturate instead the silicon bonds.

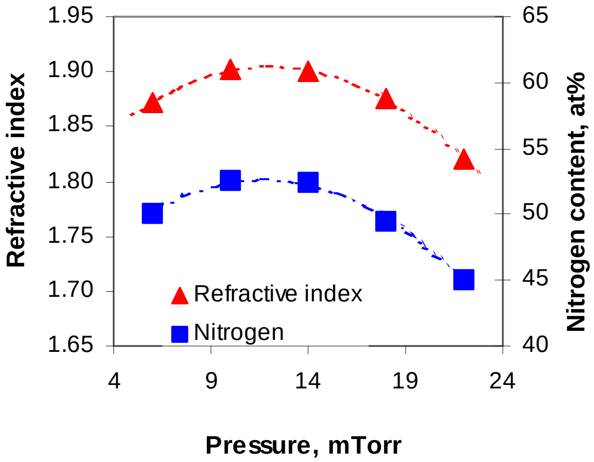

Figure 1 Refractive index and nitrogen atomic concentration versus pressure for nitrides deposited with 30 sccm N_2.

A typical depth profile of an ECR layer is shown in figure 2 and as it can be seen the concentration of nitrogen, silicon and oxygen does not vary with the film thickness.

The refractive index increased until 1.97 and the oxygen contamination decreased from 5% until 2%, when the nitrogen flow rose from 30 sccm to 110 sccm. This decline in oxygen content is due a reduction of oxygen partial pressure, proving that the oxygen originates from the system leaks. Improving the base pressure can furthermore diminish the oxygen contamination [8].

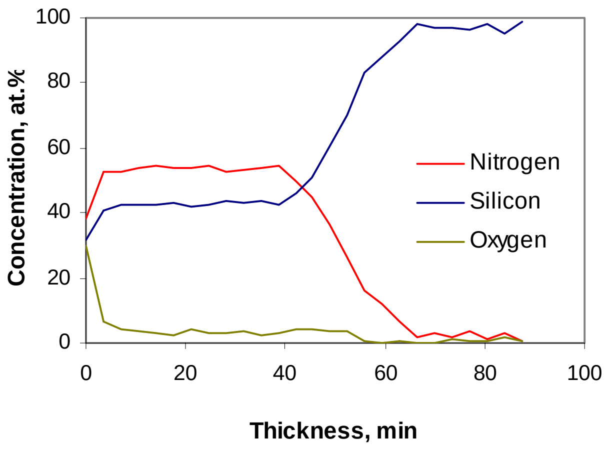

Figure 2 XPS depth profile for a nitride deposited with 55 sccm N_2, at 14 mTorr.

The hydrogen content, measured by elastic recoil detection (ERD) was less than 1%, independent of deposition conditions. These nitrides were deposited at room temperature and did not suffer any annealing process, however they exhibited extremely low hydrogen content, proving that ECR PECVD is a very good method for obtaining films with a low thermal budget and good properties.

B. Electrical properties

High frequency and quasistatic C-V measurements have been investigated in order to determine the SiO_2/Si interface properties.

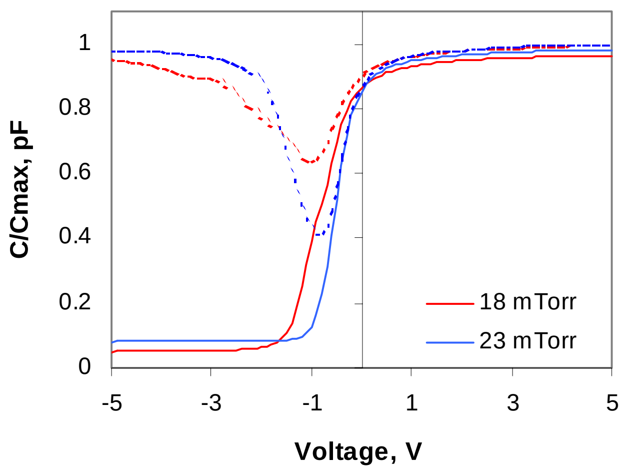

Figure 3 CV curves for two ECR films deposited with 30 sccm N_2 at different pressure.

Figure 3 shows capacitance-voltage characteristics of two silicon nitride layers deposited at different pressure.

As one can see, at higher pressure the flatband voltage shift, the positive charge and the interface trap density are smaller. This is a result of more oxygen incorporation, which relaxes the stressed interface and limits the number of silicon dangling bonds. The positive charge present at the interface varied from $2\cdot10^{11}cm^{-2}$ for high pressure and low nitrogen flows to $1.1\cdot10^{12}cm^{-2}$ for low pressures and high N_2 flows.

Figure 4 presents the current passing through nitride layers deposited at different pressure. It can be observed that while the deposition pressure does not significantly influence the breakdown field, the critical field, defined as the electric field for which the current that passes through the nitride film is higher than $10^{-8}A/cm^2$, increases with amplifying the pressure. This effect can be caused by the amount of oxygen present in the film. It is known that silicon oxide has a higher critical field (6-7 MV/cm) than silicon nitride (4 MV/cm) [9], therefore it is normal for nitrides deposited at higher pressure with more oxygen contamination, to exhibit also a larger critical field.

Nitrogen flow rate does not influence the layers bulk properties.

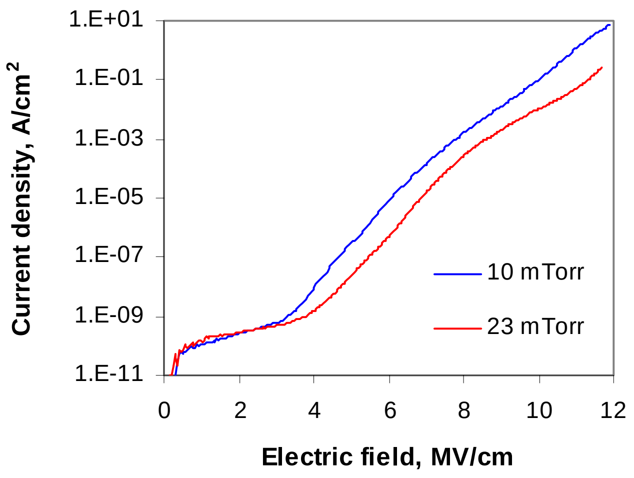

Figure 4 IV curves for two ECR films deposited with 30 sccm N_2 at different pressure.

IV. Conclusions

High electrical quality silicon nitride films with refractive index of 1.97, dielectric constant of 7.1, 2% oxygen content and 1% hydrogen content, critical field of 12 MV/cm, resistivity of 10^{15} Ωcm, and net charge density in the order of $1.1\cdot10^{12}$ cm^{-2} were deposited by a multipolar ECR plasma source at room temperature. In order to optimise the deposition process, the effects of different deposition parameters on film properties were studied. At lower pressure and higher N_2/SiH_4 ratio, we obtained the best silicon nitride films from the physical and electrical point of view. We explained the effects of deposition parameters on the film electrical properties based on film composition.

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