Impact of ECR hydrogen plasma treatment on the properties of silicon oxide and silicon nitride dielectric films

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Introduction

Silicon oxide and silicon nitride are the **main** dielectric materials of microelectronics used as sub-gate dielectrics on CMOS ICs, charge storage layers in memory elements or layers passivating the surface of wafers at the finishing stage of IC manufacture. Their electrical properties are of great importance for the reliable functional operation of microelectronics devices.

However, technological processing during device manufacture may essentially influence the properties of dielectric layers, induce undesirable charge in the structure that could lead to changing operational characteristics of the devices and degradation. Hydrogenation is widely used technique for defect passivation in semiconductor and dielectric layers and at their interfaces. However, hydrogen incorporation into the structure and interaction with the existing defects can lead not only to defect passivation but also to arising new defect levels (see, e.g. [1]).

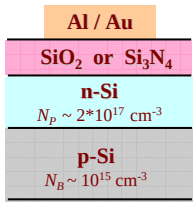
In the present work, the influence of hydrogenation on the properties and induced charge in silicon oxide and silicon nitride dielectric layers is studied. For the effective introduction of hydrogen, an electron-cyclotron resonance (ECR) plasma [2] was used. It is characterized by low operating pressures from 10^{-3} - 10^{-5} torr, a high degree of plasma gas ionization and the possibility of supplying DC bias voltage to the sample.

[1] P.E. Bloechl and J.H. Stathis, Phys. Rev. Lett. 83, 372 (1999).
[2] S.Y. Shapoval, V.T. Petrashov, O.A. Popov *et al*, J. Vac. Sci. Technol. A 9, 3071 (1991).

Samples and technique

MOS structures under study

Al(Au) / SiO_2 / n-Si (epitaxial); d_i=500 A
Al(Au) / Si_3N_4 /n-Si (epitaxial); d_i=800 A



ECR plasma treatment

Components:	H, Ar
Pressure:	10^{-3} torr
Duration:	10 ÷ 60 min
DC bias:	-30V ÷ -120V

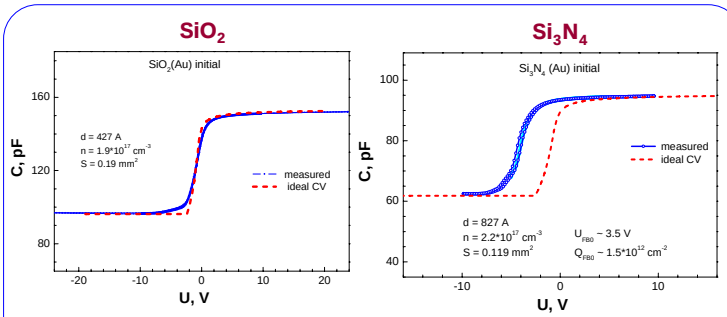
MOS structure characterization by C-V technique

- ✓ the charge trapped in dielectric
- ✓ dielectric/semiconductor interface quality

- simple
- effective
- convenient

Frequency range: 1 kHz – 1 MHz
Equipment: EG&G PAR-410 and Keithley 4200A-SCS

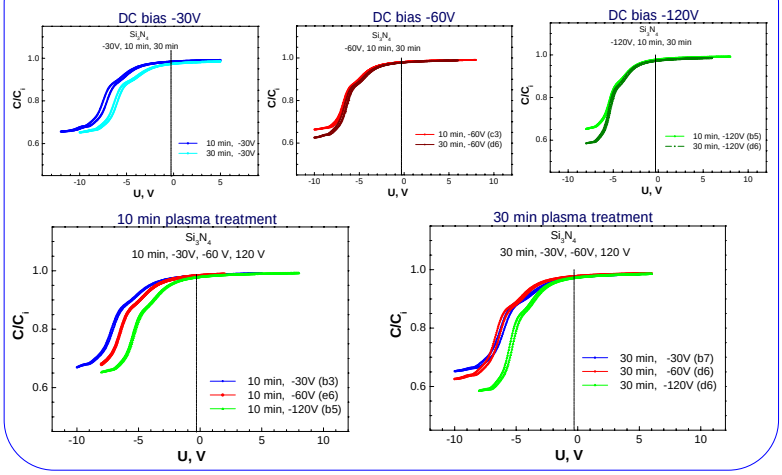
C-V characteristics in un-processed MOS structures



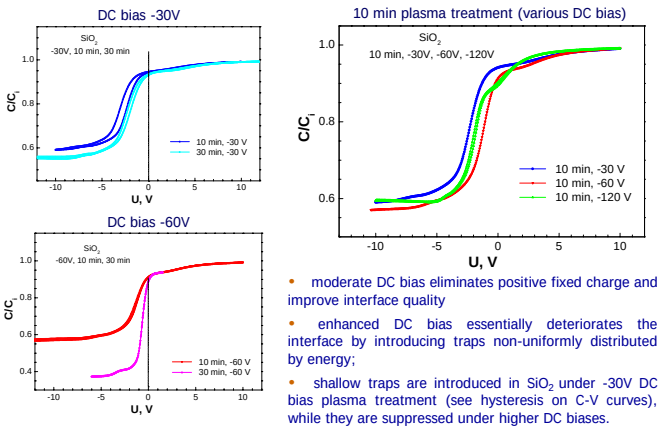
The initial MOS structures on silicon oxide have high enough quality and demonstrated C-V characteristics practically the same as that for the ideal MOS structure

The initial silicon nitride MOS devices contain a significant build-up positive charge up to $(1.5 \div 2.0) \cdot 10^{12}$ cm^{-2}.

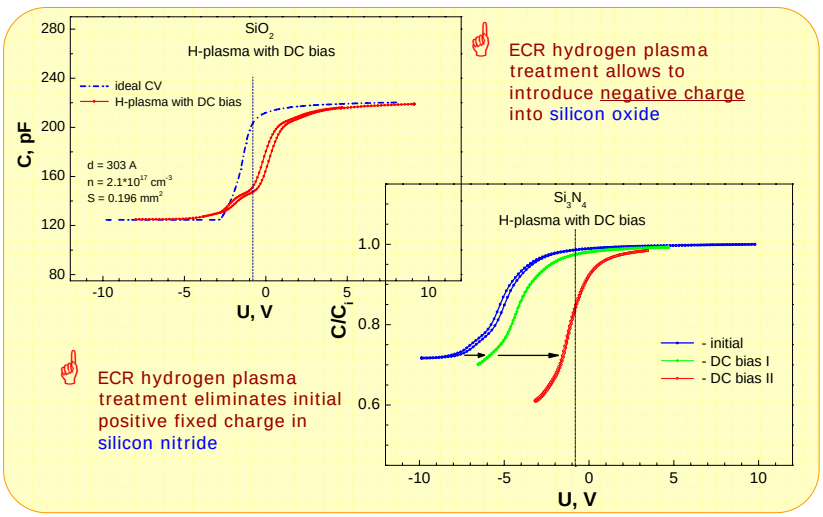
Si_3N_4 MOS: effect of DC bias & treatment duration



SiO_2 MOS: effect of DC bias & treatment duration



- moderate DC bias eliminates positive fixed charge and improve interface quality
- enhanced DC bias essentially deteriorates the interface by introducing traps non-uniformly distributed by energy;
- shallow traps are introduced in SiO_2 under -30V DC bias plasma treatment (see hysteresis on C-V curves), while they are suppressed under higher DC biases.



ECR hydrogen plasma treatment allows to introduce negative charge into silicon oxide

ECR hydrogen plasma treatment eliminates initial positive fixed charge in silicon nitride

Summary

- A comparative analysis of influence of ECR hydrogen plasma treatment on silicon oxide and silicon nitride dielectric layers was carried out
- It was shown that silicon oxide demonstrates higher parameters in the initial state, while silicon nitride is more resistant to processing and irradiations.
- Choosing the appropriate treatment conditions, one can get a possibility to introduce negative charge in silicon oxide and to eliminate the initial fixed charge in silicon-nitride-based structures.
- A modification of dielectric films' properties by ECR hydrogen plasma treatment leads to an improvement of their functional quality and radiation hardness

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