Characterization and Metrology of novel materials involved in advanced CMOS processes

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Scaling down the size of CMOS transistors require huge efforts on research and development of new materials, process and structures. This continued acceleration of feature size reduction drives physicochemical characterization and metrology solutions for such developments.

In the frame of front end of line (FEOL) developments ultra thin silicon oxynitride films now replaces thicker silicon oxide layers as gate dielectrics in advanced integrated circuits. This change is mainly driven by an increase in gate capacitance, which translates into increased current driving capability, and by a decrease of boron diffusion from the p^+ gate to the substrate , which causes excessive and uncontrollable threshold voltage shifts and insufficient reliability.

The transition from silicon oxide to silicon oxynitride remains a key metrology challenge. Physical oxynitride thickness, nitrogen content and nitrogen depth profile need to be accurately determined using a non destructive metrology technique. Spectroscopic ellipsometry is the most relevant technique to monitor the film thickness but does not provide any information about the nitrogen content. Non-contact electrical measurements are sensitive to both the physical thickness and the nitrogen content but do not seem so accurate. To overcome these issues X-Ray Photoelectron Spectroscopy (XPS) is nowadays expected as an in or at-line metrology tool to monitor both the silicon oxynitride and the nitrogen content

In the near future; 2004 according to the last ITRS roadmap [1], high K materials thin films will be used instead of silicon oxynitride layers as gate dielectrics for low power devices. Many candidate materials are currently investigated like rare earth oxides, yttrium oxide, nanolaminate ZrO_2-Al_2O_3 and HfO_2, which has been recently highlighted due to its relatively high dielectric constant and thermodynamic compatibility of the interface with single crystal and poly silicon. However most vapor phase grown high K thin films appear to have interfacial layers at the Si-interface that reduces the overall gate capacitance. In addition Si diffusion into the high K film also occurs, which alters the dielectric properties of the high K layer.

Characterization and, in the near future, metrology of the film and interfacial layers in the high K gate stack is mandatory to develop these processes and for future process control. Standard characterization techniques like XPS, SIMS, ToF-SIMS, RBS, ERDA, XRD, TEM are currently used to determine the important physical parameters [2]. Non-conventional characterization techniques like Attenuated Total Reflection (ATR) infrared spectroscopy and Medium Energy Ion Scattering (MEIS) allow to precisely investigating the various interfacial layers (Figure 1).

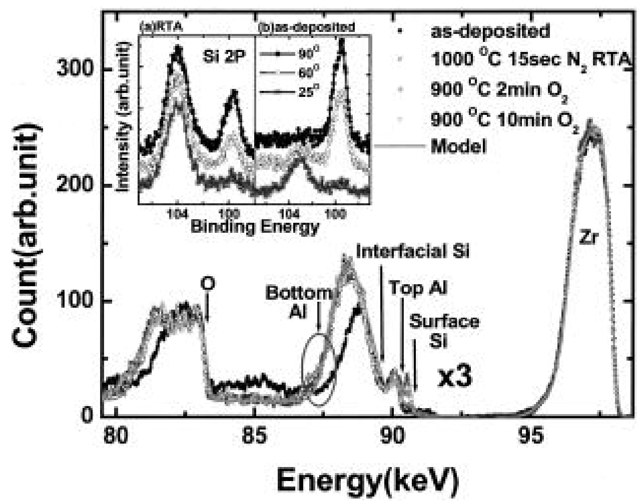

Figure 1: Ion Scattering spectra of nanolaminate ZrO_2-Al_2O_3 films. The growth a 1.5nm thick is confirmed by MEIS and XPS (insert) [3]

With increasing clock frequency and the decreasing size of devices, the resistance capacitance (RC) delay time becomes a significant problem because it limits the overall performance of ultra large-scale integration. Recently copper interconnect lines and low k interlayer dielectrics have been used, instead of the traditional aluminum lines and SiO_2 dielectrics, to reduce the RC delay time.

To lower the effective dielectric constant of the low K layer nanometer-size pores are introduced into the film. As the structure of porous low k dielectrics strongly influences the physical and electrical properties of the interlayer material, characterization of this pore structure is critical to understand the material properties and to improve the fabrication processes.

Only few experimental techniques are currently available to characterize the pore size distribution in porous low K films. They include positron annihilation lifetime (PALS), ellipsometric porosimetry, small angle X-Ray scattering (SAXS). Among these few techniques only ellipsometric porosimetry and SAXS are good candidates as new metrology tools. Nevertheless they are not mature enough to be used as an “at-line” metrology tool.

In this presentation characterization and metrology issues induced by the use of new materials and new process structures are discussed. Emphasis is given on characterization of high K and low K materials thin films, as well as the metrology of ultra thin copper diffusion barrier and copper seed layers.

References

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