ALD La-doped ZrO$_2$ for BEOl compatible decoupling capacitors

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As transistor dimension and power supply voltage continues to scale down, and as more functionality is integrated to the chip, signal-to-noise ratio becomes more significant. On-chip decoupling capacitors are usually implemented to reduce power supply noise. To minimize chip area, high-k material based capacitors placed between BEOl metal layers have been successfully employed to decouple induced voltage fluctuations in the power grids of high-performance processor chips. The challenge of the semiconductor processing is to meet the BEOl thermal budget of 400°C while maintaining optimal electrical performance such as low leakage current, high breakdown voltage, good reliability, and all at a high capacitance density. Typical high-k materials used for decoupling capacitors are Ta$_2$O$_5$, HfO$_2$ or ZrO$_2$ based high-k dielectrics, deposited by atomic layer deposition to guarantee excellent thickness and composition control. One of the most promising materials for these capacitors is ZrO$_2$, due to its high-k value. ZrO$_2$ is often used in combination with Al$_2$O$_3$ to further reduce leakage currents and improve the reliability at the expense of reducing the capacitance density.

In this paper, La$_2$O$_3$ (which has a higher-k value than Al$_2$O$_3$) is studied as dopant material of ZrO$_2$ to improve the reliability. A uniform growth was realized by a combination of ZrCl$_3$/H$_2$O and La(THD)$_3$O$_3$ ALD processes at 300°C on 300 mm wafers. The main issue of uniformity optimization is tuning the O$_2$ pulse time due to decomposition effects in the used hot wall cross flow reactor. The effect of La on the electrical performance is studied by comparing thickness series of mixed oxides (MO) and laminate structures (LAM) which are integrated as MIM capacitors with PVD TiN electrodes directly between the Cu layers of the BEOl$^1$ (Fig.1). The electrical characterization performed with high statistic shows a good uniformity of capacitance (Fig. 2) and leakage current (Jg). As the capacitance density decreases, the leakage current slightly increases but breakdown voltage is significantly improved with enhanced La-concentration determined by XPS (Fig 3.). An influence of structural properties is ruled out as the films are fully crystallized independently from the material setup. Additionally, polarity asymmetry of capacitance and leakage current as well as the incorporation of fixed charges for La-doped and undoped ZrO$_2$ are compared. The reason for observed differences between these two material systems will be explained in terms of leakage current mechanisms and interface properties.

![Fig.1: TEM of integrated decoupling capacitor in BEOl.](image1)

![Fig. 2: Full map of C0 in fF/µm$^2$ of ZrO$_2$ mixed oxide with 2.8at% La.](image2)

![Fig. 3: Jg @ 1.2 V versus C$_0$ of La-doped ZrO$_2$.](image3)