Enhanced Dielectric Properties of HfO_2 Thin Films Produced Via Novel Catalytic Atomic Layer Deposition Process

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Optimized high-κ dielectric materials are widely utilized as gate oxides and dielectric barriers in compound semiconductor devices such as GaN HEMT and MEMS [1]. Monolithic high-κ dielectric materials have inherent performance tradeoffs demonstrated by hafnium oxide (HfO_2) which has a high dielectric constant but a low breakdown voltage and high leakage current limiting overall efficacy as a dielectric barrier [2]. Composite materials such as $HfAlO_x$ can improve dielectric performance by combining the high dielectric constant of HfO_2 with the wider band gap and higher breakdown voltage of aluminum oxide (Al_2O_3) unlocking capabilities for next generation dielectric materials [2]. Atomic layer deposition (ALD) exploits precise control over self-limiting surface chemistry allowing for discreet nanolayers that can be tailored to optimize bulk film dielectric performance with a level of control that is not possible via other deposition techniques (CVD and PVD). This work demonstrates HfO_2 thin films deposited via ALD with enhanced dielectric properties achieved through the addition of a novel catalytic conversion step known as a CRISP Process. HfO_2 deposited via the CRISP process has 29% higher GPC, 7% higher density, more ideal stoichiometry, 44% less carbon impurity and larger crystal grains when compared to films growth with O_3 alone. In pursuit of high performing dielectric materials several compositions of ALD deposited nanolaminates were studied through the incorporation of small amounts of Al_2O_3 into bulk HfO_2. Discreet nanolayer formation is demonstrated via cross sectional scanning electron microscopy (SEM) shown in Figure 1. With varying amounts of Al_2O_3, dielectric constant, κ, can be increased from 16.2 to 19.2, the dielectric strength (breakdown voltage) can be increased from 6.9 to 7.8 MV/cm, and the leakage current density can be reduced from $3.3x10^{-9}$ to $8.1x10^{-12}$ J at 60Vm. Work is ongoing to tune layer composition for the best overall performance. In the future, full characterization in GaN HEMT devices is planned for both the HfO_2 – O_3 and HfO_2 – CRISP processes.

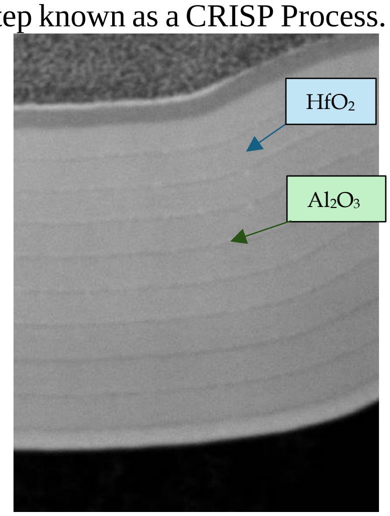

Figure 1: SEM image of $HfAlO_x$ nanolaminate showing HfO_2 layers (thick) and Al_2O_3 layers (thin)

[1] S. Kol, et al., Acta Physica Polonica A 136, 6, (2019), pp. 873-881
[2] A.M. Mumlyakov et. al.,Journal of Alloys and Compounds V858 (2021), 157713

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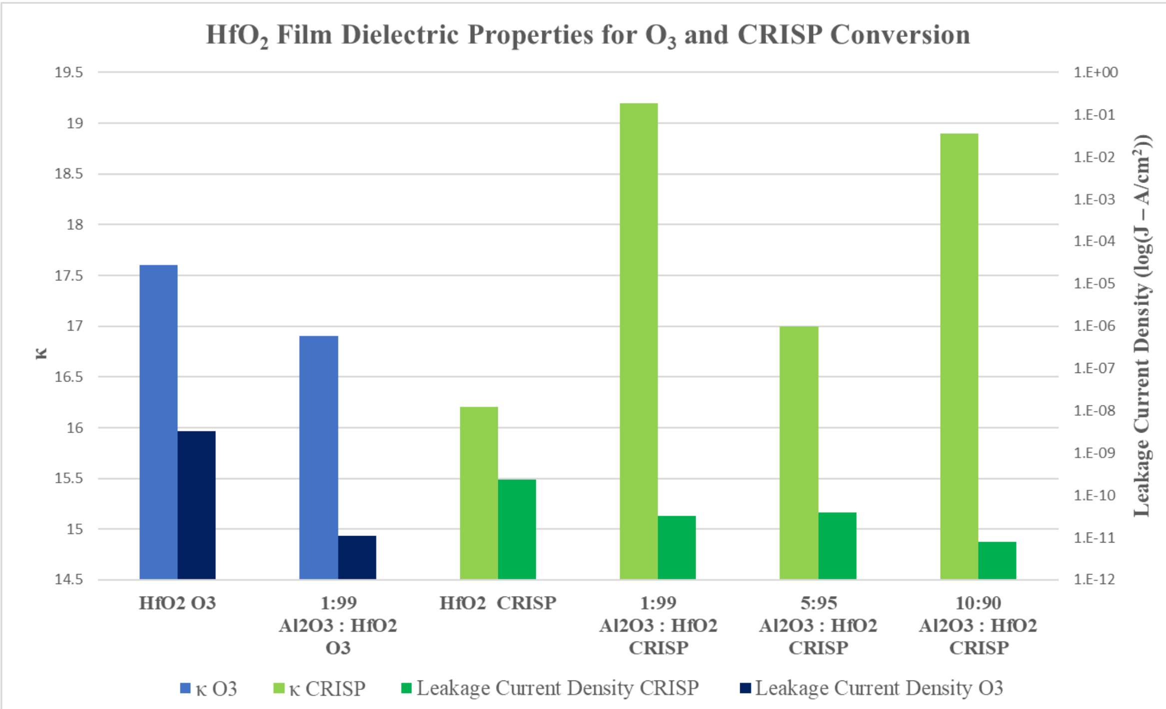

Figure 2: Dielectric properties of studied $HfAlO_x$ thin film compositions. Dielectric constant κ at 10^6 Hz is displayed on the left axis in light blue for O_3 conversion and light green for CRISP conversion. Leakage current density at 60V is displayed on the right axis in dark blue for O_3 conversion and in dark green for CRISP conversion.