前處理對二氧化鉿閘極介電層特性的影響

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摘 要

本論文研究前處理對二氧化鉿閘極介電層特性的影響，我們利用材料分析研究二氧化鉿薄膜物性，量測二氧化鉿電容和場效電晶體研究二氧化鉿薄膜電性，最後利用載子分離的方法釐清了二氧化鉿薄膜的崩潰機制。

材料分析的結果顯示剛沈積的二氧化鉿薄膜呈非晶相，經過溫度高於 600℃的退火後會發生結晶化，RTO 前處理的試片退火後呈現接近完美的複晶晶相，SC1 前處理試片的結晶情況則比較混亂，此外介面層在經過退火後厚度增加。

由二氧化鉿電容的穿隧機制分析結果發現，SC1 前處理未退火試片和 RTO 前處理的三種試片的漏電流機制完全相同，低電場的時候是 Ohmic 穿隧，高電場是 Fowler-Nordheim 穿隧。SC1 前處理退火後的試片則呈現完全不同的 Frenkel-Poole 穿隧機制。配合第三章的晶相觀察以及本章 CET 的測量結果，似乎漏電機制主要取決於二氧化鉿的晶相，和介面層厚度沒有關聯。我們推論因為介面層厚度都不厚，載子很容易以直接穿隧方式穿透介面層。未退火的二氧化鉿因為是非晶相，缺陷密度較低，故低電場是 Ohmic 機制，高電場是

Fowler-Nordheim 機制。RTO 前處理退火後試片因為接近理想的複晶晶相，缺陷密度仍低，故漏電流因介面層增後而微幅降低。SC1 前處理退火後的試片則因為結晶相混亂，形成大量缺陷，因此載子是以 Frenkel-Poole 機制穿透二氧化鉿，造成較大的漏電流。由 C-V 量測觀察到遲滯現象，藉由改變偏壓範圍指出遲滯現象主要是來自於負偏壓時發生電洞捕捉造成的。

雖然退火後會造成等效氧化層厚度增加，但是驅動電流仍然隨著退火溫度上升而增加。這是因為退火後較厚的介面層減少了聲子散射和庫侖散射的影響導致較高的遷移率，至於 RTO 前處理試片的遷移率高於 SC1 前處理試片的遷移率也是基於相同的原因。二氧化鉿薄膜的正偏壓溫度相關不穩定測試顯示臨界電壓偏移主要是來自於二氧化鉿中的本體缺陷而非界面缺陷。

SC1 前處理未退火的二氧化鉿薄膜較 RTO 前處理未退火的二氧化鉿薄膜有較高的崩潰電場和崩潰時間，而經過退火後則相反。利用載子分離的方法指出負偏壓下二氧化鉿薄膜的漏電流主要為電洞電流和發生崩潰時為二氧化鉿崩潰。此外，介電層的崩潰主要和介面層厚度和二氧化鉿薄膜品質有關，介面層厚度雖有影響，但不是首要因素。

考慮所有的要素後，SC1 前處理因為具有較薄的等效氧化層厚度和可接受的電性，因此或許是較佳的選擇，而其高於 1.3V 的十年工作期限操作電壓滿足了下一世代的需求。

Impacts of Pre-treatments on the Properties Of HfO_2 Gate Dielectric

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ABSTRACT

In this thesis, we study the impacts of pre-treatments on the properties of HfO_2 gate dielectric. We study the physical properties of HfO_2 film by material analysis, and study the electrical properties of HfO_2 film by measurement of the MOS capacitor (MOSCAP) and MOSFET devices. Using carrier-separation technique, the breakdown mechanisms of HfO_2 film can be further determined.

Material analyses show that the as-deposited HfO_2 film is amorphous. After annealing at temperatures higher than 600°C, the film is crystallized. The HfO_2 films on RTO-treatment substrate show perfect polycrystalline structure while those on SC1-treatment substrate shows disordered polycrystalline structure. The thickness of interfacial layer increases after annealing.

Electrical analyses on MOSCAP structure show that the as-deposited SC1-treatment sample and all of the RTO-treatment samples have identical leakage mechanisms : Ohmic tunneling at low field and Fowler-Nordheim tunneling at high field. The annealed SC1-treatment samples shows totally different mechanism : Frenkel-Poole tunneling at

any field. Since the leakage mechanisms do not correlated to the interfacial layer thickness, it is believed that carriers tunnel through the interfacial layer easily. It is thus postulated that the as-deposited HfO_2 films on both SC1- and RTO-treatment substrates and the annealed HfO_2 films on RTO-treatment substrate have low defects density so that the Fowler-Nordheim tunneling dominates leakage current at high field. On the other hand, the annealed HfO_2 films on SC1-treatment substrate have high defects density, therefore, the Frenkel-Poole tunneling results in high leakage current. This postulation is consistent with the observation of micro-structure. Hysteresis phenomenon was observed during capacitance-voltage measurement. Voltage swept measurement with various voltage ranges indicate that the hysteresis phenomenon arises from hole-trapping under negative gate bias.

Although thermal annealing increases the effective oxide thickness (EOT), the driving current increases with the increase of annealing temperature. This observation is explained by the higher mobility due to thicker interfacial layer because phonon scattering and coulomb scattering becomes less significant as the interfacial layer becomes thick. Due to the same reason, the mobilities of the RTO-treatment samples are higher than those of the SC1-treatment samples. Positive biased temperature stress on HfO_2 gate dielectric shows that the threshold voltage instability is primarily dominated by the HfO_2 bulk trapped charges rather than interface charges.

Before post-deposition annealing, the breakdown field and the time dependent dielectric breakdown performance of the SC1-treatment sample are better than those of the RTO-treatment sample. The results are opposite after annealing. Carrier-separation technique indicates that hole is the dominant carrier for leakage current and breakdown occurs mainly in the HfO_2 under negative gate bias. Therefore, the dielectric breakdown depends on the quality of HfO_2 film mainly and the interfacial layer thickness plays minor role.

Considering all of the evaluated factors, SC-1 treatment might be a better choice because thinner EOT and acceptable electrical performance. The projected operation voltage for 10-year lifetime is higher than 1.3V and is fulfill the requirement for next generation.