High-k Dielectric Materials for ultra-wide band gap transistor

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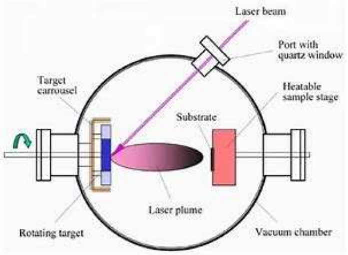
Abstract

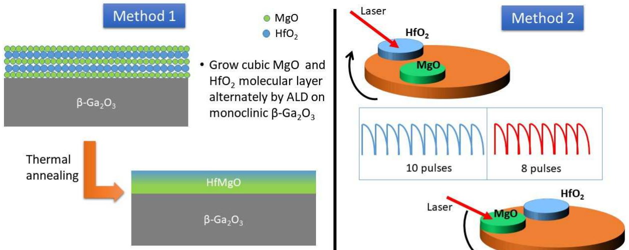
The search for high-k dielectric material suitable for Ga_2O_3 transistors was the focus in this fellowship. High-k dielectric materials with larger band gaps than Ga_2O_3 were investigated. Thin films were prepared by pulsed laser deposition (PLD) and atomic layer deposition (ALD). Selected high-k materials are MgO, HfO_2 and Y_2O_3. Among these, MgO and HfO_2 can be deposited by both techniques. Y_2O_3 can only be prepared by PLD. Difficulties were encountered during thin film growth of MgO due to depleted precursor for ALD and poor target quality for PLD. Preliminary results for HfO_2 and Y_2O_3 from PLD have shown encouraging signs of potential. C-V measurements were conducted to extract effective dielectric constant of the thin films through metal-insulator-metal test structures. Future research on those materials needs to cover material composition, in-depth C-V measurement, surface roughness, etc. in order to find suitable dielectric materials for Ga_2O_3 applications.

Fabrication

Pulsed laser deposition (PLD) is used to deposit the thin film up to 500 nm to provide high quality dielectric material needed by the transistor. Two methods have been adopted to achieve dielectric alloys.



Structure of PLD



- Grow cubic MgO and HfO_2 molecular layer alternately by ALD on monoclinic β-Ga_2O_3
- Achieve MgO alloy by post deposition thermal annealing
- Sequential PLD: Alternating 10 pulses on HfO_2 target; 8 pulses on MgO target in O_2/Ar environment

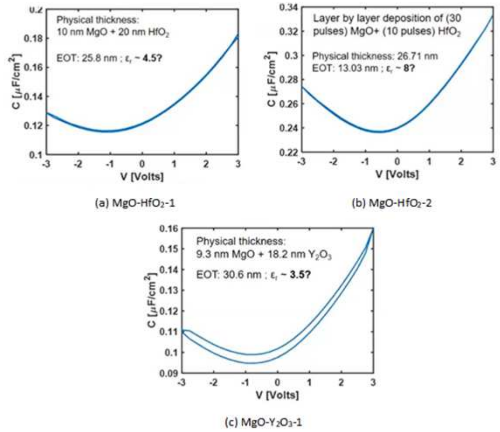
* Other elements such as N, Y and Si can also be introduced to form alloy by the same propose methods.

Adopted methods

Results

From the Result 1, a stack or alloy with other dielectric materials certainly improves dielectric quality by mitigating leakage. All have shown to be stable insulating state during voltage sweep. However when MgO stacks with HfO_2 (MgO-HfO_2-1) and Y_2O_3 (MgO-Y_2O_3-1) with similar thicknesses, the effective dielectric constant is still very low (~4.5 and ~3.5). this indicates although additional dielectric material helps to improve the performance of overall stack, MgO is of poor quality given that HfO_2 and Y_2O_3 were tested and met the reasonable dielectric constant range reported elsewhere [4]. It's worth noting that sequential PLD to deposit MgO and HfO_2 with overall thickness about 267.1 Å followed by oven annealing at 600 °C has significant impact on the dielectric constant (MgO-HfO_2-2). It's believed that the possibly alloyed $Mg_xHf_yO_2$ has been formed during the process and thus the poor quality of MgO in this alloy exhibits less impact on the effective dielectric constant of the film.

Preliminary C-V measurements on all these samples have been conducted. HfO_2-Y_2O_3-2 demonstrated low capacitance (10^{-12} *F*) in C-V or high current (μA range) in I-V which implied serious current leakage in the film. Even with 600 °C annealing, the film properties did not improve likely due to the low deposition temperature. Therefore, the effective dielectric constant was not evaluated on HfO_2-Y_2O_3-3 sample. Result 2 summarizes the C-V measurement of HfO_2-Y_2O_3-1 and HfO_2-Y_2O_3-2 with convincing dielectric behavior. Both films have effective dielectric constant more than 10. With more HfO_2 deposition pulses in each loop, sample HfO_2-Y_2O_3-1 has higher effective dielectric constant. Given the current Al_2O_3 results, it appears that Al_2O_3 prepared by plasma ALD has significant leakage occurred beyond 1V. The effective dielectric constant for Al_2O_3 from the AFRL ALD chamber is about 7.

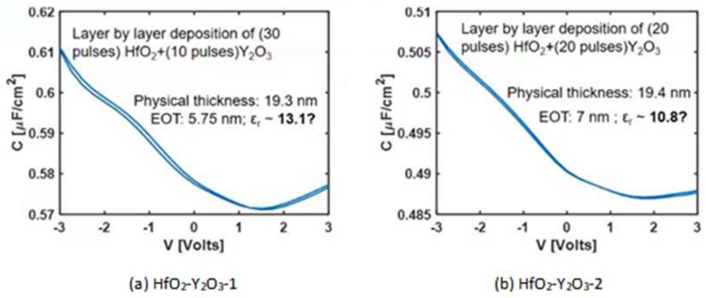


(a) MgO-HfO_2-1

(b) MgO-HfO_2-2

(c) MgO-Y_2O_3-1

Result 1: MgO based dielectric materials



(a) HfO_2-Y_2O_3-1

(b) HfO_2-Y_2O_3-2

Result 2: HfO_2 and Y_2O_3 oxide stack

Conclusion

PLD is a reliable deposition method to prepare oxide thin films. It consistently provides high quality films through laser ablation in a high vacuum chamber with precisely controlled O_2 environment. Although ALD allows conformal coverage of thin films using completely different concepts, the film quality often varies and subsequent post deposition annealing is necessary to ensure the integrity of the thin film.

The results from HfO_2 and Y_2O_3 prepared by PLD have given a good understanding about the potential for both materials and deposition conditions that are needed to prepare high quality films. They have exhibited expected dielectric constant ranges that were reported in literature. Therefore more research can be continued on a HfO_2 based dielectric layer. It's worth noting that thick HfO_2 based ferroelectric material [6,7] by PLD could also have applications in UWBG transistors.

Acknowledgement

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