Memory Characteristics of MOS Capacitors Embedded with Ge Nanocrystals in HfO₂ Layers by Ion Implantation

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Abstract: Ge nanocrystals(NCs)-embedded MOS capacitors are characterized in this work using capacitance-voltage measurement. High-k dielectrics HfO₂ are employed for the gate material in the MOS capacitors, and the C-V curves obtained from O₂- and NH₃-annealed HfO₂ films are analyzed.

Key Words: nano-floating gate, Ge NCs, HfO₂, nitridation

1. Introduction

Nano-floating gate memory (NFGM) has attracted attention and has widely investigated for replacing conventional flash memory devices which employ continuous floating gates [1]. Si nanocrystals(NCs) usually have been investigated for NFGM and recently many studies pay attention to Ge NCs which have smaller band gap than Si NCs [2]. There has been many attempts to replace SiO₂ with higher dielectric constant materials such as HfO₂, ZrO₂, and Al₂O₃. However, in many cases high-k materials have problems with reliability and there have been many trials to improve the film stability including the annealing process [3]. In this work, HfO₂ is employed for a high-k gate material and implantation method is used to form Ge NCs in the gate material.

2. Experiment

Tetrakis Ethyle Methyle Amino Hafnium (TEMAH) and O₂ were utilized as the precursors of 20 nm HfO₂ deposition on (100) p-type Si substrates with the atomic layer deposition (ALD) method. The films were then implanted at room temperature with ⁷⁷Ge⁺ ions at 17 keV with a dose of 1x 10¹⁶ cm⁻² for the NFGM. The dose of ions and the kinetic energy of ions were determined using a TRIM(transport of ions in matter) simulation Code. The Ge-embedded HfO₂ films in the MOS capacitors were annealed in O₂ and NH₃ gas ambient for 10 min at 800 °C, and Ti/Au electrodes were then formed using thermal evaporator system. The high frequency (1 MHz) capacitance-voltage (C-V) measurements were conducted using a HP 4285A LCR meter at room temperature.

3. Results and discussion

Several studies show that the annealing of the films in O₂ ambient will improve stoichiometry. However, as a result of this study, the annealing may not reduce the number of traps in the films causing leakage current. Figure 1 shows C-V curves obtained from the films annealed in O₂ ambient for 10 min at 800 °C. The counterclockwise C-V curves present memory windows related with the traps of HfO₂ film.

![C-V curves of MOS capacitors](image)

Figure 1: C-V curves of MOS capacitors without Ge NCs in HfO₂ gate material annealed in O₂ ambient for 10 min at 800 °C

Recently, the physical characteristics associated with the nitridation of HfO₂-based high-k gate dielectrics have been actively investigated since nitridation can improve scalability, lower leakage, and higher breakdown fields even though the role of N diffused to HfO₂ material is not clearly clarified yet. C-V curves obtained from the HfO₂ films annealed in NH₃ ambient for 10 min at 800 °C don’t represent memory effects (Fig. 2), in contrast to the C-V curves taken from the films annealed in O₂ ambient.
Figure 2. C-V curves of MOS capacitors without Ge NCs in HfO₂ gate material annealed in NH₃ ambient for 10 min at 800 °C.

To form Ge NCs within the HfO₂ films after the Ge implantation into these films, annealing process is needed and in this study the same annealing condition as the abovementioned HfO₂ film annealing was used. The implantation followed by annealing for forming Ge NCs from the implanted Ge ions in HfO₂ is a simpler fabrication of NFGM compared with NCs formation by other deposition methods. Also, the distribution can be controlled well adjusting implantation energy and ion dose.

Figure 3 shows the high frequency C-V curves obtained from the MOS capacitors with Ge NCs embedded in HfO₂ and represents counterclockwise hysteresis with a 3.5 V memory window when the bias voltage was varied from -10 to 10 V, while there is little memory window in a curve taken from the MOS capacitors without Ge NCs. This result reveals that Ge NCs also act well as charge storage in HfO₂ films when the films are treated with NH₃ gas annealing.

4. Conclusion

MOS capacitors with HfO₂ gate material annealed in NH₃ ambient characteristics were compared between with and without Ge NCs and C-V results show that Ge NCs are related with memory effect for NFGM.

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References

