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Ultra High Density HfO_2-Nanodot Memory for Flash Memory Scaling

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Abstract

We have developed a simple technique for forming ultra high density HfO_2 dots with diameter < 3 nm and density > $5x10^{12}$ cm^{-2}. Advantages of our method are that the density and diameter are controllable and the dots are well separated with average space 3 nm between dots. We propose that the ultra high density dots are suitable for charge storage node in the future 45 and 32 nm generation Flash memory.

1. Introduction

For further scaling of flash memory technology, discrete charge trap memories with nanocrystals or nano-dots have been studied widely [1]. The reliability problems of thinner tunnel oxide is partly compensated with discrete trap layers as well as lower gate stack structure decreases the electric filed coupling interference with neighbor gates. Most of the reported nano-particle densities are up to lower $10^{12}cm^{-2}$. For the case of $1x10^{12}$ cm^{-2} density, average 5 particles locate along a 50 nm gate span. For large scale flash memory, this density is not enough due to a large variation of nano-particle numbers in gate regions.

In this paper, we fabricated the mid-10^{12} cm^{-2} density HfO_2 dot and confirmed the program and erase flash memory operation into HfO_2 dots. Charge hopping between HfO_2 dots is suppressed comparing with lateral charge migration in the planar HfO_2 trapping layer.

2. Preparation of HfO_2 nanodots

High density HfO_2 dots were formed with self-agglomeration of HfO_2 thin layers. HfO_2 layer is well known to form nanocrystals with high temperature annealing above 800C. HfSiO films shows phase separation into HfO_2 nanocycrystals and SiO_2 layers with high-temperature annealing, too. We used these characteristics to make high-density and very small nanodots of HfO_2. First, 0.5-2nm thick HfO_2 thin layers were deposited by metal-organic chemical vapor deposition (MOCVD) on SiO_2 layers. With the rapid thermal annealing (RTA) above 1000C, HfO_2 thin layer starts to agglomerate to form nanodots. Then CVD SiO_2 were deposited to fill the space between nanodots (Fig.1). TEM observation of nanodots (Fig.2) confirms that the average 2-nm-diameter nanodots are formed (Fig.3) and its sheet density is as large as $6x10^{12}cm^{-2}$. This number is roughly one order of magnitude larger than conventional Si nanocrystals. We found that the diameter and the density of nanodots depend on the thickness of the initial HfO_2 thin layer (Fig.4). Below 1 nm HfO_2 layer thickness, high density HfO_2 dot can be formed with the RTA. During the RTA process, nascent HfO_2 small nanodot does not have enough time to collide with each others to form larger dots. For the 2 nm HfO_2 layer, self-agglomeration is not occurred and a planar film was observed by TEM (Fig.5).

These densities are much larger than the HfO_2 dot density in HfSiO phase separation, too [2]. This is the advantage of the use of self-agglomeration. We can expect that the HfO_2 nanodots are capable for well defined flash-memory operation with several tens nm gate length. In Fig. 2 b), we compare the gate feature sizes of 45/32 nm with a plane-view TEM. The number of nanodots in the gate areas is enough for stable operation even with the scattering nature of the nanodot formation.

3. Flash memory operation

We fabricated the MONOS-type flash memory with HfO_2 nanodot charge traps (Fig.6). Fig. 7 shows the channel hot electron programming and hot hole erasing characteristics of this device. 2-bit/cell operation is confirmed. Microseconds' programming speed and 100 μs erasing speed are obtained. Fig.8 shows the advantage of nanodots over the planar trapping layer. In the previous work, the lateral migration of the trapped electrons is very prominent in the HfO_2 layer (Fig. 8 a)) [3]. With the nanodot formation, this lateral migration or charge hopping are suppressed effectively (Fig.8 b)). High density HfO_2 nanodot memory is one of very promising candidates for further scaling of flash memory beyond 45 nm.

4. Summary

Ultra high density HfO_2 nanodots up to Mid-10^{12} cm^{-2} density were fabricated adopting self-agglomeration of HfO_2 thin layer with RTA. The program and erase operations of HfO_2 nanodot charge traps were confirmed. With the nanodot formation, the lateral migration of trapped charge is suppressed effectively. Ultra high density HfO_2 dots memory is very promising to further scaling of flash memory technology.

References

[1] S. Tiwari et al., *IEDM Tech. Dig.*, 521 (1995).
[2] Y.H. Lin et al., *IEDM Tech. Dig*., 759 (2004).
[3] T. Sugizaki et al., *Symp. On VLSI Technol*., 27 (2003).

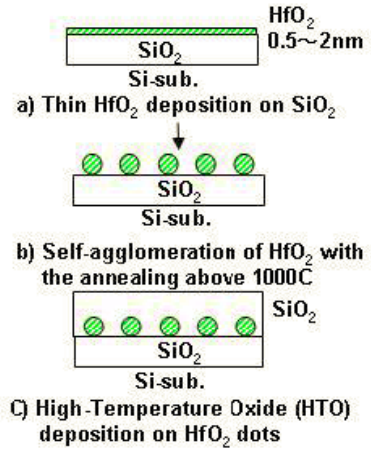
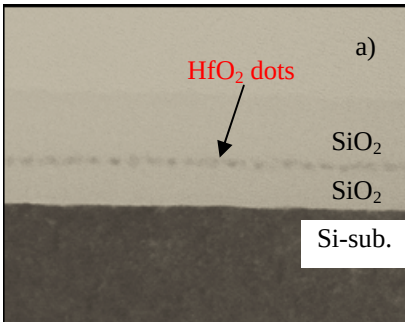


Fig.1 HfO_2 nanocrystal formation with self-agglomeration.



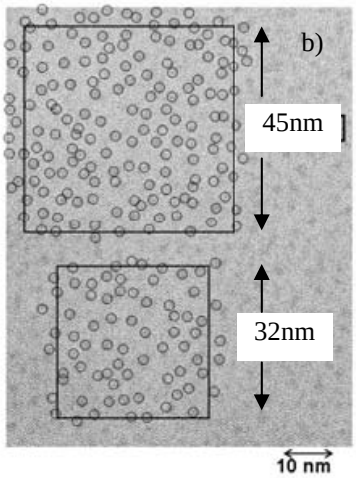


Fig.2 HfO_2 nanodots observation. Thickness of as-deposited HfO_2 film is 0.5nm. a) Cross-sectional TEM image. b) Plane-view TEM photograph. Average sheet density of nanodots is $6x10^{12}cm^{-2}$. HfO_2 dot distribution and gate feature sizes are shown. For the clarity, each dot is marked with an open circle.

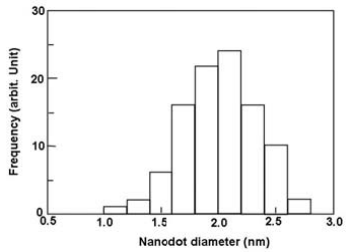


Fig. 3 Histogram of nanodot diameters. Average size is 2nm.

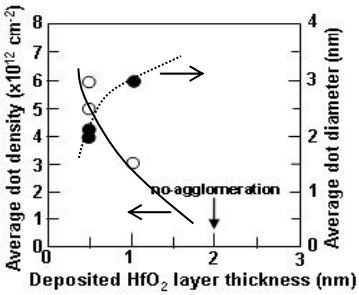


Fig. 4 Average nanodot density and diameter variations with deposited HfO_2 layer thickness. Open circles are average dot densities and closed circles are average dot diameters.

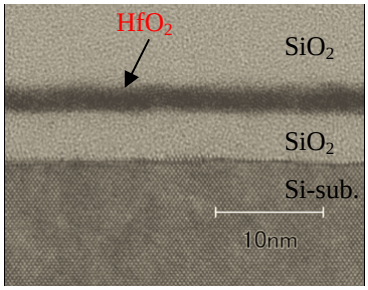


Fig. 5 Cross-sectional TEM observation for HfO_2 layer after RTA. The deposited HfO_2 film thickness is 2-nm.

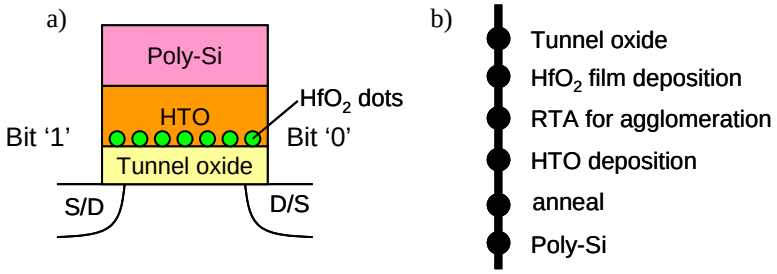


Fig.6 HfO_2 nanodot flash memory structure.
a) Schematic device structure.
b) Process sequence.

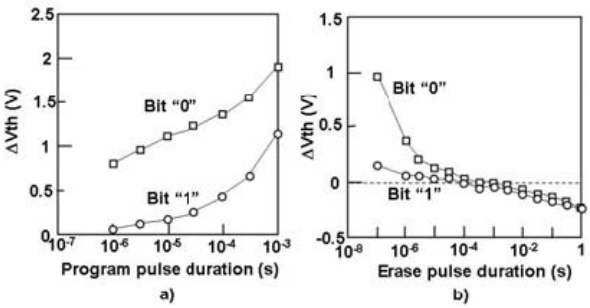


Fig. 7 Program and Erase characteristics of HfO_2 nanodot memory. a) Vth increase with the programming pulse. Vg = 9 V and Vd = 5 V. ΔVth is the Vth difference from the fresh device. b) Vth decrease with the erase pulse. At the beginning, Bit "0" is programmed with 10 μs pulse at Vg = 9 V and Vd = 5 V. The erase pulse condition is Vg = -8 V and Vd = 5 V. ΔVth is the Vth difference from the fresh device.

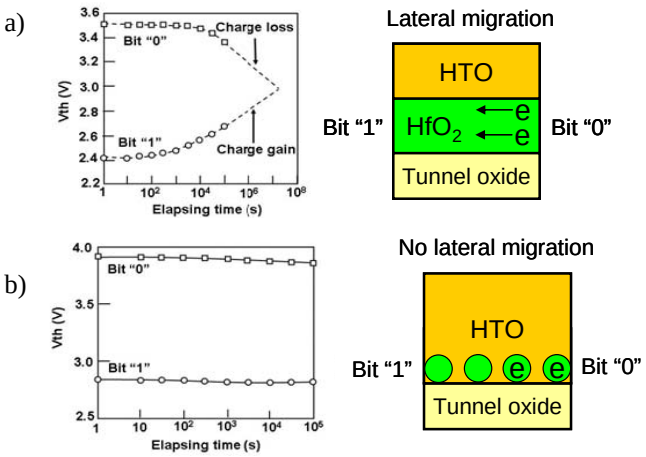


Fig.8 Comparison of charge loss characteristics of 2bit/cell type flash memory at room temperature. Lg = 0.25 μm.: a) Planar HfO_2 trapping layer [3] and b) HfO_2 nanodot trap.