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Annealing characteristics of ultra-thin high-K HfO_2 gate dielectrics*

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Ultra-thin HfO_2 gate-dielectric films were fabricated by ion-beam sputtering a sintered HfO_2 target and subsequently annealed at different temperatures and atmospheres. We have studied the capacitance-voltage, current-voltage, and breakdown characteristics of the gate dielectrics. The results show that electrical characteristics of HfO_2 gate dielectric are related to the annealing temperature. With increase annealing temperature, the largest value of capacitance decreases, the equivalent oxide thickness increases, the leakage current reduces, and the breakdown voltage decreases.

Keywords: annealing characteristics, high-K, HfO_2 gate dielectrics
PACC: 7360, 7755

1. Introduction

With the rapid progress of microelectronics technology, the metal-oxide-semiconductor field effect transistor (MOSFET) devices are scaled down to below 100 nm. At the same time, the gate oxide thickness is required to be below 2 nm. Among all the materials for MOS devices, the gate oxide is one of the important materials. SiO_2 has been used as a gate dielectric since MOSFET devices were first introduced due to its simplicity in processing, insulating properties, and compatibility with the substrate. However, SiO_2 should be replaced by other materials due to its excessive leakage and poor reliability when used as a gate dielectric with less than 2 nm thickness. Thus, high dielectric constant (K) gate dielectrics are studied to find an alternative for SiO_2. High-K dielectric materials such as CeO_2, Y_2O_3, Ta_2O_5, HfO_2, ZrO_2, TiO_2, Al_2O_3, $SrTiO_3$(STO), and $BaSrTiO_3$(BST) have been studied.[1−8] The basic idea of using high-K materials is to increase the film thickness so as to reduce the tunnelling leakage current and improve the reliability while scaling up the capacitance equivalent-oxide thickness(EOT) below the direct tunnelling limit of SiO_2. However, CeO_2, Y_2O_3, and Al_2O_3 do not provide significant advantages over SiO_2 because of their relatively low dielectric constant, and some ultrahigh-K dielectrics such as STO and BST have been predicted to cause poor short channel effects. In addition, most of the high-K dielectrics are thermally unstable and may form silicides or low-K interface layers when directly contacted with silicon. While HfO_2 is a promising candidate due to its thermodynamic stability on silicon, high dielectric constant (∼25), and relatively large band gap (5.68 eV).

In this paper, ultra-thin HfO_2 gate dielectric films are fabricated, and their capacitance-voltage (C–V), current-voltage (I–V), and breakdown characteristics at different annealing temperatures are studied. The results obtained are analysed and discussed.

2. Experiment

In our experiment, HfO_2 capacitor samples have been fabricated using the following process. p-type (100) silicon substrates with a 5–8Ωcm resistivity were cleaned using a H_2SO_4:H_2O_2 (2:1) solution and HF dip. Then thin HfO_2 layers were deposited at room temperature by ion-beam sputtering a sintered HfO_2 target. They were subsequently annealed at various temperatures and atmospheres. After annealing, Pt top electrodes were deposited by sputtering. The area of the capacitors was measured to be 5×10^{-5}cm^2. The C–V and I–V curves were measured using HP4156B

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semiconductor parameter analyser and Keithley 590 C–V analyser. The flatband voltage V_{FB} and the EOT for capacitors were extracted from C–V curves.

3. Results and analysis

Figure 1 shows the C–V curves of HfO_2 gate dielectrics at different annealing temperatures: 400, 600 and 800°C. The largest value of the measured capacitance density in accumulation is C_{max}/A=11.6fF/μm^2. The EOT is about 2.9 nm. Comparing the capacitances of the samples annealed at various temperatures, the capacitance of the sample annealed at 400°C is the highest. In addition, with increasing annealing temperature, the largest value of the capacitance decreases, the EOT increases.

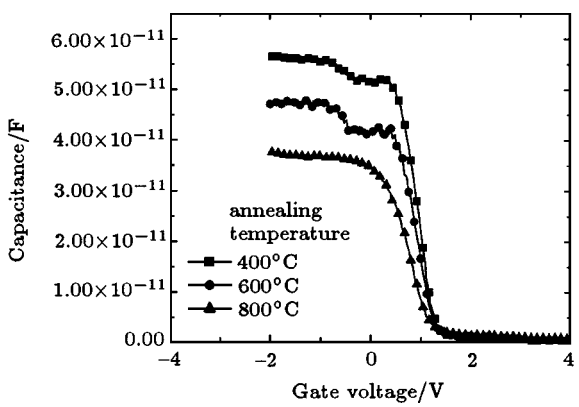


Fig.1. C–V curves of HfO_2 measured on samples annealed at 400, 600 and 800°C.

The I–V characteristics of HfO_2 gate dielectrics annealed at 400, 600 and 800°C are shown in Fig.2. The leakage current of the sample annealed at 800°C is the lowest, about 3.09×10^{-6}A/cm^2 at –1.5 V gate voltage. From Fig.2 we can see that the leakage current reduces as the annealing temperature increases.

Figure 3 shows the breakdown characteristic of HfO_2 gate dielectrics annealed at 400, 600 and 800°C. The breakdown voltage of this gate dielectric exceeds 20 V. This value is sufficiently high, showing that the quality of the HfO_2 gate dielectric is very good. However, with increasing annealing temperature, the breakdown voltage decreases.

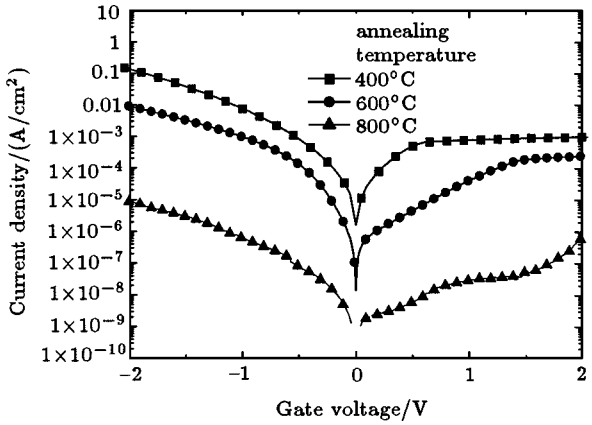


Fig.2. I–V curves of HfO_2 measured on samples annealed at 400, 600 and 800°C.

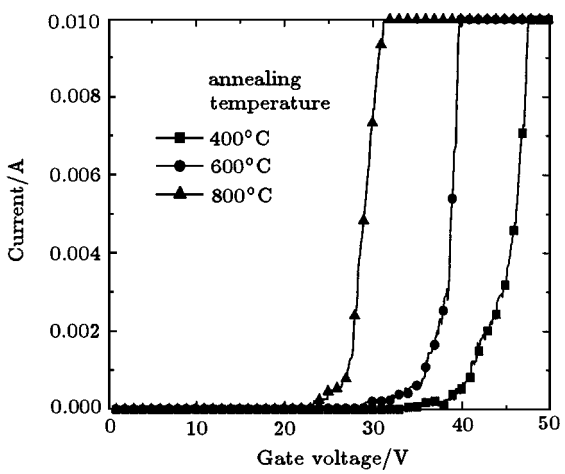


Fig.3. Breakdown characteristics curve of HfO_2 measured on samples annealed at 400, 600 and 800°C.

4. Conclusion

In summary, we have fabricated ultra-thin HfO_2 gate dielectrics by ion-beam sputtering a sintered HfO_2 target. The EOT measured by the C–V method is about 2.9 nm. All the samples annealed at different temperatures in N_2 atmosphere have good electrical characteristics. With increasing annealing temperature, the EOT of the samples increases, the leakage current reduces, and the breakdown voltage also decreases.

References

[1] Gusev E P, Carier E, Buchanan D A, Gribelyuk M, Copel M, Okorn-Schmidt H and Emic C D 2001 *Microelectron. Eng.* **59** 341

[2] Qi W J, Nieh R, Lee B H, Kang L, Jeon Y and Lee J C 2000 *Appl. Phys. Lett.* **77** 3269

[3] Wilk G D and Wallace R M 1999 *Appl. Phys. Lett.* **74** 2854

[4] Kevin X Z and Carlton M O 1995 *IEEE Trans. Electron Devices* **42** 2181

[5] Wilk G D, Wallace R M and Anthony J M 2001 *Appl. Phys. Rev.* **89** 5243

[6] Zhang J C, Hao Y and Zhu Z W 2001 *Acta Phys. Sin.* **50** 1586 (in Chinese)

[7] Wang S W, Lu W, Wang H, Wang D, Wang M and Shen X C 2001 *Acta Phys. Sin.* **50** 2465 (in Chinese)

[8] Cheng S H, Ning Z Y, Kang J, Ma C L and Ye C 2000 *Acta Phys. Sin.* **49** 2041 (in Chinese)