Vol 16 No 1, January 2007
1009-1963/2007/16(01)/0245-04
Chinese Physics
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and IOP Publishing Ltd

Fabrication and characteristics of high-K HfO_2 gate dielectrics on n-germanium*

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(Received 28 March 2006; revised manuscript received 21 July 2006)

This paper reports that the high-K HfO_2 gate dielectrics are fabricated on n-germanium substrates by sputtering Hf on Ge and following by a furnace annealing. The impacts of sputtering ambient, annealing ambient and annealing temperature on the electrical properties of high-K HfO_2 gate dielectrics on germanium substrates are investigated. Experimental results indicate that high-K HfO_2 gate dielectrics on germanium substrates with good electrical characteristics are obtained, the electrical properties of high-K HfO_2 gate dielectrics is strongly correlated with sputtering ambient, annealing ambient and annealing temperature.

Keywords: Germanium, high-K, HfO_2
PACC: 7360, 7755

1. Introduction

With the rapid progress of VLSI technology, the scale of Si metal oxide semiconductor (MOS) device is becoming smaller and smaller, the performance of device is becoming higher and higher, but the improvement of Si device is limited. Germanium channel metal oxide semiconductor field effect transistors (MOSFETs) have been considered as one promising option for future high performance CMOS technology because of the high electron and hole mobilities in germanium.[1−9] Compared with Si, pure Ge offers two times higher mobility for electrons and four times higher mobility for holes. The high-K gate dielectrics are well known to have attractive properties for future ultra-scaled MOSFETs. HfO_2 is one of the most attractive high-K gate dielectrics materials because of its thermal stability, high dielectric constant (~ 25), and relatively large band gap (5.68eV).[10−17] In this paper, the high-K HfO_2 gate dielectrics on n-Ge (100) substrates process are experimentally investigated. The high-K HfO_2 gate dielectrics on n-Ge (100) substrates with good electrical characteristics are demonstrated experimentally. The impacts of sputtering ambient, annealing ambient and annealing temperature on the electrical properties of high-K HfO_2 gate dielectrics on n-Ge (100) substrates are investigated.

2. Experiment

The high-K HfO_2 gate dielectrics were formed on n-Ge (100) substrates. The n-type Ge (100) wafers with resistivity $\sim 0.4\Omega$·cm were first wet cleaned by using acetone and dilute-HF and dried with N_2 before gate growth. Afterwards HfO_2 gate dielectrics layers were deposited at room temperature by ion beam sputtering Hf target in O_2 or N_2 ambient. Then they were annealed in O_2 or N_2 ambient under annealing temperatures 500°C or 600°C for 5 minutes. The area of gate electrode is 50 μm×50 μm.

The capacitance–voltage ($C-V$) characteristics of the high-K HfO_2 gate dielectrics samples were measured by using Keithley 590 $C-V$ analyser. The electrical characteristics of samples were measured at room temperature by using Agilent 4156C semiconductor parameter analyser.

3. Results and discussion

3.1. Effect of sputtering ambient on the electrical properties of HfO_2 gate dielectrics on Ge

The high frequency capacitance–voltage(HF $C-V$) characteristics of high-K HfO_2 gate dielectrics grown on n-Ge sputtered in O_2 or N_2 ambient were

*Project supported by the National Natural Science Foundation of China (Grant No 90307006), by the National High Tech. Development Program of China (Grant No 2003AA1Z1370), and by the State Key Development Program for Basic Research of China (Grant No G2000036500).
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showed in Fig.1. The area of gate electrode is $50\mu\text{m}\times50\ \mu\text{m}$. Comparing the HF $C-V$ curves of different sputtering ambient, the $(C-V)$ characteristics of the sample sputtered in N_2 ambient are better than those in O_2 ambient. The largest value of measured capacitance per unit area in accumulation is $C_{\max}/A = 15.2\ \text{fF}/\mu\text{m}^2$. The equivalent oxide thickness (EOT) extracted from the HF $C-V$ curve is 2.5 nm.

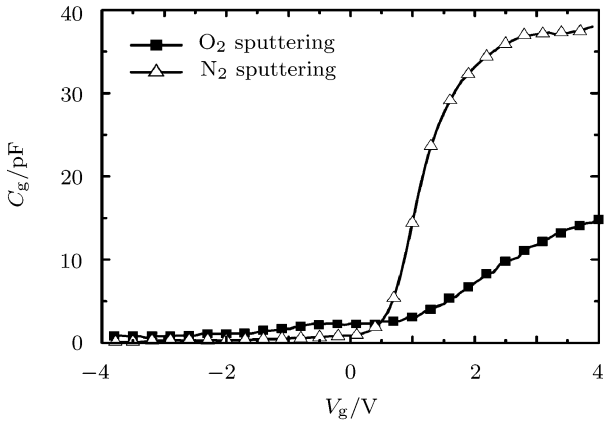


Fig.1. The HF $C-V$ curves of HfO_2 gate dielectrics grown on n-Ge with different sputtering ambient.

Figure 2 shows the current–voltage $(I-V)$ characteristics of HfO_2 gate dielectrics with different sputtered ambient. From Fig.2, we can see that the leakage current of the sample sputtered in N_2 ambient is lower than that in O_2 ambient. So that, the electrical properties of high-K HfO_2 gate dielectrics grown on n-Ge is strongly correlated sputtering ambient, the electrical characteristics of the sample sputtered in N_2 ambient are better than those in O_2 ambient.

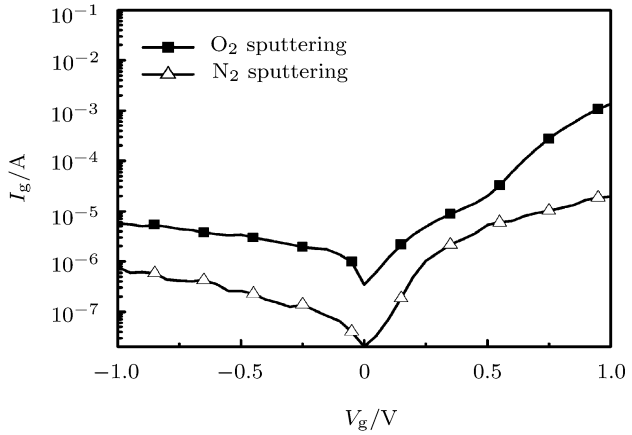


Fig.2. The $I-V$ characteristics of HfO_2 gate dielectrics grown on n-Ge with different sputtering ambient.

3.2. Effect of annealing ambient on the electrical properties of HfO_2 gate dielectrics on Ge

Figure 3 plots the HF $C-V$ curves of high-K HfO_2 gate dielectrics grown on n-Ge by a furnace annealing in O_2 or N_2 ambient under annealing temperatures 600°C. Comparing the HF $C-V$ curves of the two samples, we find that the $C-V$ characteristics of the sample annealed in O_2 ambient are better than those in N_2 ambient.

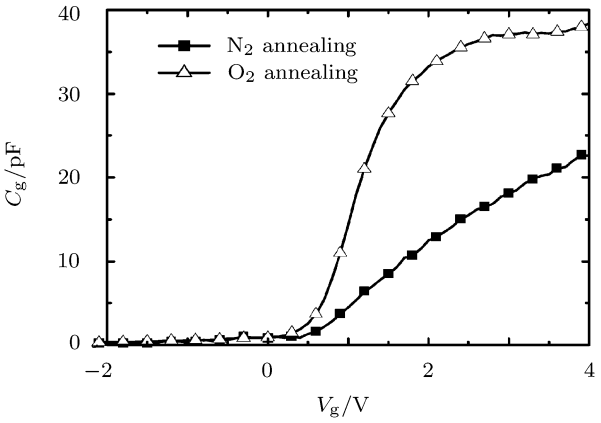


Fig.3. The HF $C-V$ curves of HfO_2 gate dielectrics grown on n-Ge in O_2 or N_2 ambient annealing.

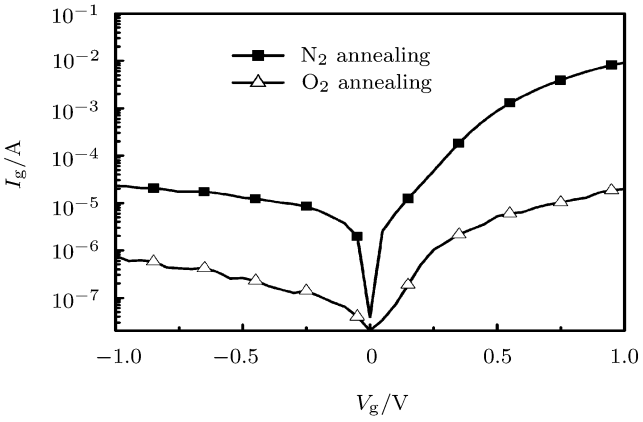


Fig.4. The $I-V$ characteristics of HfO_2 gate dielectrics grown on n-Ge in O_2 or N_2 ambient annealing.

The HF $C-V$ curves of HfO_2 gate dielectrics are showed in Fig.4. From Fig.4, we can see that the leakage current of the sample annealed in O_2 ambient is lower than that in N_2 ambient. The impacts of anneal ambient on the electrical properties of high-K HfO_2 gate dielectrics grown on n-Ge were showed in the Fig.3 and Fig.4. Experimental results indicate

that the electrical properties of high-K HfO_2 gate dielectrics grown on n-Ge annealed in O_2 ambient are better than those in N_2 ambient.

3.3. Effect of annealing temperature on the electrical properties of HfO_2 gate dielectrics on Ge

The HF $C-V$ curves of high-K HfO_2 gate dielectrics grown on n-Ge under annealing temperatures 500°C or 600°C were showed in Fig.5. They were annealed in O_2 ambient under annealing temperatures 500°C or 600°C. The typical HF $C-V$ curves are gained. Comparing capacitances in accumulation of 500°C and 600°C annealing temperatures, we find that the capacitance of the sample annealed at 600° is higher than that at 500°C.

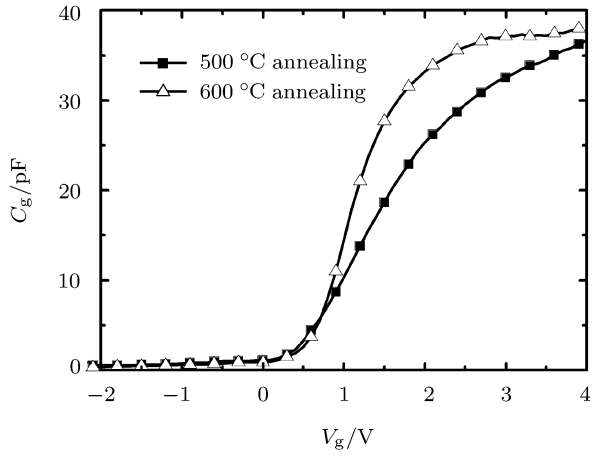


Fig.5. The HF $C-V$ curves of HfO_2 gate dielectrics grown on n-Ge under annealing temperatures 500°C or 600°C.

Figure 6 shows the $I-V$ characteristics of HfO_2 gate dielectrics. From Fig.6, we can see that the leakage current of the sample annealed at 600° is lower than that at 500°C, which is about 7.6×10^{-7}A at -1.0 V gate voltage. So that, the electrical properties of high-K HfO_2 gate dielectrics grown on n-Ge are strongly correlated with annealing temperature, the electrical properties of high-K HfO_2 gate dielectrics grown on n-Ge annealed at 600° are better than those at 500°C.

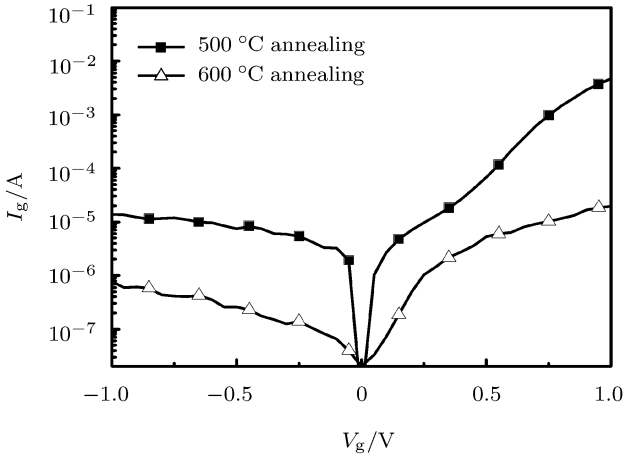


Fig.6. The $I-V$ characteristics of HfO_2 gate dielectrics grown on n-Ge under annealing temperatures 500°C or 600°C.

4. Conclusion

The high-K HfO_2 gate dielectrics were fabricated on germanium substrates by sputtering Hf on Ge and followed by a furnace annealing in O_2 or N_2 ambient under 500°C or 600°C annealing temperature. The high-K HfO_2 gate dielectric on n-Ge (100) substrates with good electrical characteristics is obtained. The EOT extracted from the $C-V$ characteristics is 2.5 nm. The impacts of sputtering ambient, annealing ambient and annealing temperature on the electrical properties of high-K HfO_2 gate dielectrics on germanium substrates were investigated. Experimental results indicate that the electrical characteristic of the sample sputtered in N_2 ambient and annealed in O_2 ambient is better than that of the sample sputtered in O_2 ambient and annealed in N_2 ambient. The electrical characteristic of the sample annealed at 600°C is better than that at 500°C.

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