

# Contents

<b>Chinese Abstract</b> .....	i
<b>English Abstract</b> .....	iii
<b>Acknowledgement</b> .....	v
<b>Contents</b> .....	vi
<b>Figure Captions</b> .....	viii
<b>Chapter 1 Introduction</b>	
1.1 General Background .....	1
1.2 SONOS Nonvolatile Memory Devices .....	2
1.3 Nanocrystal Nonvolatile Memory Devices .....	4
1.4 Organization of This Thesis .....	8
<b>Chapter 2 Basics principle of nonvolatile memory</b>	
2.1 Introduction .....	15
2.2 Basic Program/Erase Mechanisms .....	17
2.3 Basic Reliability of Nonvolatile Memory .....	21
2.4 Basic Physical Characteristic of Nanocrystal NVM .....	22
<b>Chapter 3 Nonvolatile Zr-Germaniumlicide Memory</b>	
3.1 Motivation .....	34
3.2 Sample Structure & Thermal process .....	34
<b>Chapter 4 Experiment Results and Discussions</b>	
4.1 Introduction .....	49
4.2 Ge/Zr double layer structure .....	49
4.3 Ge-Zr cosputtering layer structure .....	51
4.4 Ge single layer .....	53
4.5 Zr single layer .....	54
<b>Chapter 5 Conclusions</b>	
5.1 Conclusions .....	78

**References** -----79

**Vita** -----84



# Figure Captions

## Chapter 1

Figure 1-1 The structure of the conventional floating gate nonvolatile memory device.

Continuous poly-Si floating gate is used as the charge storage element.

Figure 1-2 The development of the gate stack of SONOS EEPROM memory devices.

The optimization of nitride and oxide films has been the main focus in recent years

Figure 1-3 The energy band diagrams of the write/erase operation for a SONOS device.

Figure 1-4 The structure of the SONOS nonvolatile memory device. The nitride layer is used as the charge-trapping element.

Figure 1-5 The structure of the nanocrystal nonvolatile memory device. The semiconductor nanocrystals or metal nano-dots are used as the charge storage element instead of the continuous poly-Si floating gate.

Figure 1-6 Band diagram illustration of different approaches for improving the  $I_{g, \text{write/erase}}/I_{g, \text{retention}}$  ratio.

## Chapter 2

Figure 2-1 I–V curves of an FG device when there is no charge stored in the FG (curve A) and when a negative charge  $\bar{Q}$  is stored in the FG (curve B).

Figure 2-2 Energy band diagrams of a dual-channel SONOS transistor under (a) positive and (b) negative gate bias. ● electrons, ○ holes.

Figure 2-3 (a) Schematic cross-section of nanocrystal memory device structure; (b) illustration of write process: inversion-layer electron tunnels into the nanocrystal; (c) illustration of erase process: accumulation layer hole

tunnels into the nanocrystal, electron in nanocrystal can tunnel back to the channel.

Figure 2-4 SONOS ideal energy band diagram.

Figure 2-5 Fourth approaches to programming methods, described by Hu and White.

Figure 2-6 Schematic cross section of MOSFET. The energy- distribution function at point  $(X_1, Y_1)$  is also shown.

Figure 2-7 (a) Positive gate voltage applied when use Fowler-Nordheim tunneling to program (b) Energy band representation of Fowler-Nordheim tunneling. Electron in poly-Si conduction band tunnel through the triangular energy barrier.

Figure 2-8 (a) Positive gate voltage and Positive drain voltage applied when use hot carrier injection to program (b) Energy band representation of hot carrier injection

Figure 2-9 (a) Negative gate voltage and negative drain voltage applied when use hot hole injection to erase. (b) Energy band representation of hot hole injection to erase.

### Chapter 3

Figure 3-1(a) Sample structure of structure 1 (b) Sample structure of structure 2.

Figure 3-2 The thermal process flow of structure 1

Figure 3-3 The thermal process flow of structure 2

Figure 3-4(a) Sample structure of structure 3 (b) Sample structure of structure 4.

Figure 3-5 The thermal process flow of structure 3

Figure 3-6 The thermal process flow of structure 4

Figure 3-7(a) Sample structure of structure 5 (b) Sample structure of structure 6

Figure 3-8 The thermal process flow of structure 5

Figure 3-9 The thermal process flow of structure 6

Figure 3-10(a) Sample structure of structure 7 (b) Sample structure of structure 8

Figure 3-11 The thermal process flow of structure 7

Figure 3-12 The thermal process flow of structure 8

## **Chapter 4**

Figure 4-1 The capacitance voltage (C-V) hysteresis of structure 1 for standard under  $\pm 10\text{V}$  bidirectional voltage sweeping.

Figure 4-2 The capacitance voltage (C-V) hysteresis of structure 1 after thermal treatment (RTA 500C N2 30S) under  $\pm 5\text{V}$  and  $\pm 10\text{V}$  bidirectional voltage sweeping.

Figure 4-3 The capacitance voltage (C-V) hysteresis of structure 2 after thermal treatment (RTA 500C N2 30S) under  $\pm 5\text{V}$  and  $\pm 10\text{V}$  bidirectional voltage sweeping.

Figure 4-4 The capacitance voltage (C-V) hysteresis of structure 2 after thermal treatment (RTA 600C N2 30S) under  $\pm 5\text{V}$  and  $\pm 10\text{V}$  bidirectional voltage sweeping.

Figure 4-5 The retention hysteresis of structure 1 after thermal treatment (RTA 500C N2 30S)

Figure 4-6 The leakage current character of structure 1 after thermal treatment (RTA 500C N2 30S)

Figure 4-7 The retention hysteresis of structure 2 after thermal treatment (RTA 600C N2 30S)

Figure 4-8 The leakage current character of structure 2 after thermal treatment (RTA 600C N2 30S)

Figure 4-9 The endurance character of structure 2 after thermal treatment (RTA

600C N2 30S)

Figure 4-10 The transmission electron microscope (TEM) diagrams of standard structure 1

Figure 4-11 The transmission electron microscope (TEM) diagrams of structure 1 after thermal treatment after thermal treatment (RTA 500C N2 30S)

Figure 4-12 The X-ray photoelectron spectroscopy (XPS) analysis of structure 1 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient and structure 2 after RTA treatment at the condition 600C for 30sec in nitrogen ambient for Ge 3d spectra.

Figure 4-13 The X-ray photoelectron spectroscopy (XPS) analysis of structure 1 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient and structure 2 after RTA treatment at the condition 600C for 30sec in nitrogen ambient for Zr 3d spectra.

Figure 4-14 The capacitance voltage (C-V) hysteresis of structure 3 for standard under  $\pm 5V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-15 The capacitance voltage (C-V) hysteresis of structure 3 after thermal treatment (RTA 500C N2 30S) under  $\pm 5V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-16 The capacitance voltage (C-V) hysteresis of structure 4 after thermal treatment (RTA 500C N2 30S) under  $\pm 5V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-17 The retention hysteresis of structure 3 for standard

Figure 4-18 The leakage current character of structure 3 for standard

Figure 4-19 The retention hysteresis of structure 3 with after thermal treatment (RTA 500C N2 30S)

Figure 4-20 The leakage current character of structure 3 after thermal treatment (RTA

500C N2 30S)

Figure 4-21 The retention hysteresis of structure 4 after thermal treatment (RTA 500C N2 30S)

Figure 4-22 The leakage current character of structure 4 after thermal treatment (RTA 500C N2 30S)

Figure 4-23 The endurance character of structure 3 for standard

Figure 4-24 The endurance character of structure 3 after thermal treatment (RTA 500C N2 30S)

Figure 4-25 The endurance character of structure 4 after thermal treatment (RTA 500C N2 30S)

Figure 4-26 The transmission electron microscope (TEM) diagrams of structure 3 for standard

Figure 4-27 The transmission electron microscope (TEM) diagrams of structure 3 after thermal treatment (RTA 500C N2 30S)

Figure 4-28 The X-ray photoelectron spectroscopy (XPS) analysis of structure 3 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient for Ge 3d spectra

Figure 4-29 The X-ray photoelectron spectroscopy (XPS) analysis of structure 3 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient for Zr 3d spectra

Figure 4-30 The capacitance voltage (C-V) hysteresis of of sample 5 for standard under  $\pm 5V$   $\pm 7V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-31 The capacitance voltage (C-V) hysteresis of structure 5 after thermal treatment (RTA 500C N2 30S) under  $\pm 7V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-32 The capacitance voltage (C-V) hysteresis of structure 6 after thermal

treatment (RTA 500C N2 30S) under  $\pm 5V, \pm 7V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-33 The transmission electron microscope (TEM) diagrams

of structure 6 after thermal treatment (RTA 500C N2 30S)

Figure 4-34 The X-ray photoelectron spectroscopy (XPS) analysis of structure 5 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient for Ge 3d spectra

Figure 4-35 The capacitance voltage (C-V) hysteresis of of structure 7 for standard under  $\pm 5V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-36 The capacitance voltage (C-V) hysteresis of structure 7 after thermal treatment (RTA 500C N2 30S) under  $\pm 7V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-37 The capacitance voltage (C-V) hysteresis of structure 8 after thermal treatment (RTA 500C N2 30S) under  $\pm 7V$  and  $\pm 10V$  bidirectional voltage sweeping.

Figure 4-38 The X-ray photoelectron spectroscopy (XPS) analysis of structure 7 for standard, after RTA treatment at the condition 500C for 30sec in nitrogen ambient for Zr 3d spectra