Inductance Characteristic of Annealed Titanium Dioxide on Silicon Substrate

Chih Chin Yang, Lan Hui Huang, Bo Shum Chen, Jia Liang Ke, and Chung Lun Tsai

Abstract—The control of oxygen flow rate during growth of titanium dioxide by mass flow controller in DC plasma sputtering growth system is studied. The impedance of TiO$_2$ films for inductance effect is influenced by annealing time and oxygen flow rate. As annealing time is increased, the inductance of TiO$_2$ film is the more. The growth condition of optimum and maximum inductance for TiO$_2$ film to serve as sensing device are oxygen flow rate of 15 sccm and large annealing time. The large inductance of TiO$_2$ film will be adopted to fabricate the biosensor to obtain the high sensitivity of sensing in biology.

Keywords—Annealed, Inductance, Silicon substrate, Titanium dioxide.

I. INTRODUCTION

Because the titanium dioxide is with the non-toxic characteristic and well stability in chemical reaction, it will be the material of potential applications in electrochemical field, photovoltaic devices, photo-catalytic, and memory cell capacitors [1]. The silicon based ultra large scale integrated (ULSI) circuits is with a high limitation for the thickness of oxide layer in scale of ULSI circuit, because of gate dielectrics in the metal oxide semiconductor (MOS) or ionic sensing metal oxide semiconductor (ISFET) devices in application of biosensor field. The breakdown voltage of MOSFET will be increased with decreasing the gate oxide thickness. The cause is that the electric field of gate is increased at the same bias at the gate of MOSFET. The leakage current is also important factor with reaching the limit of tunneling thickness of titanium dioxide. Therefore, the physical thickness of oxidation layer must be increased at the gate terminal for the MOSFET device. In this paper, the inductance, so call leakage impedance, is measured and study to improve the leakage current effect of MOSFET when the TiO$_2$ thin film is used as the insulator of MOSFET. The TiO$_2$ thin film were prepared on the silicon substrate of (100) orientation at growth temperature of 500°C using titanium target with purity of 99.99% by using the DC reactive sputtering method with DC power of 80 W. The substrate was separated by a distance of about 10 cm from the centers of the target holder. The titanium target has diameter of 2 inch and 6 mm thick. The growth pressure was at room temperature, about 4.5x10$^{-6}$ Torr. After purging the chamber, the TiO$_2$ films were deposited on the n-type silicon (100) substrates by the reactive DC magnetron sputtering method. Before loading the target and substrate, the substrates was taken into the BOE solvent solution, then the substrate is put into the chamber to growth the TiO$_2$ thin film on silicon substrate. The substrates was taken into the BOE solvent solution, then the substrate is put into the agitator of ultrasonic cleaner and cleaned about 5 minute at first. And then the substrates were rinsed by using the solvent solutions of acetone, methanol and DI water in sequence respectively. After cleaning the substrate, we dried up the silicon wafer by using nitrogen gun. The target of reactive DC magnetic sputter was used titanium element and the oxygen was flowed into chamber to growth the TiO$_2$ thin film on silicon wafer. The oxygen source was arranged with the flow rate into chamber of 5 to 35 sccm in various. The growth time of TiO$_2$ thin film is about 10 minutes. The argon of about 10 sccm in flow rate as plasma is used to bomb the target.

The impedance value of TiO$_2$ thin film is measured in probe station system by using the LCR instrument in sample area of
The inductance of TiO₂ films was also examined by the measurement of LCR meter after TiO₂ films were annealed. We measure the inductance of TiO₂ films which are set into the annealing environment about 30 minutes and one hour. The inductance value of TiO₂ thin film is with some changes as increasing annealing time which we confirmed in this report. The annealing of TiO₂ thin film is completed by the rapid thermal annealing (RTA) system. The annealing temperature of RTA process was arranged at the temperature of 450°C and the annealing time was not including the rise time and fall time for the reach and recover of annealing temperature. In this process, we use RTA system without compensation gas.

III. RESULTS AND DISCUSSION

Fig. 1 shows the films thickness of grown TiO₂ as the function of oxygen flow rate varied from 5, 15, 25, to 35 sccm at growth temperature of 500°C and growth time of ten minutes. It is clear that the film thickness is increased as the oxygen flow rate at fixed argon flow rate. The growth rate is obviously increased when the oxygen flow rate is more than 15 sccm. This suggested that the increased oxygen molecule will result in the more frequency reaction with sputtered titanium ionic. The growth rate of TiO₂ films grown by using the DC sputtering system is more than about 0.16 μm thick per hour.

The inductance of TiO₂ films without heat treatment versus oxygen flow rate in impedance measurement is presented in Fig. 2. The oxygen flow rate is varied from 5 sccm to 35 sccm with increment of 10 sccm. The maximum inductance is occurred at about oxygen flow rate of 15 sccm. When the oxygen flow rate is less than 15 sccm, the inductance of TiO₂ films on surface is slightly decreased. We conclude that the TiO₂ films are approached to the conductor because of the rare of oxygen molecular in TiO₂ films. As the oxygen flow rate is more than 15 sccm, the inductance of TiO₂ films will be decreased with increasing the oxygen flow rate. The cause of decrease of inductance is due to the increase of capacitance effect.

The annealing effect of TiO₂ films at annealing temperature of 450°C and annealing time of 30 minutes is shown in Fig. 3. The inductance of TiO₂ film grown at higher and lower oxygen flow rate is seriously influenced by annealing process. In the Fig. 3, the inductance of TiO₂ film is increased twice or three times obviously. The reason is that the TiO₂ film is formed the image part of impedance value at these ranges, which can be applied in sensor with capacitance type or inductance type.
compound will decrease the institute impurity and titanium-rich effects for a long annealing time at the growth condition of oxygen flow rate of 15 sccm or 25 sccm.

Table I shows the results of inductance effect on the TiO₂ film to apply it in biosensor devices. It’s demonstrated that the inductance is with maximum and optimum at oxygen flow rate of 15 sccm. The inductance of TiO₂ films is increased as the annealing time is increased, because of well anatasé structure of annealed TiO₂ films.

TABLE I

CHARACTERISTICS OF INDUCTANCE OF TiO₂ FILMS AT THE ANNEALING ENVIRONMENT WITH VARIOUS FLOW RATES OF OXYGEN SOURCE AND ANNEALING TIME (THE UNIT OF INDUCTANCE IS μH PER SAMPLE AREA OF 2CM²)

<table>
<thead>
<tr>
<th>O₂ flow rate (sccm)</th>
<th>5 (sccm)</th>
<th>15 (sccm)</th>
<th>25 (sccm)</th>
<th>35 (sccm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>4.0</td>
<td>5.1</td>
<td>4.3</td>
<td>3.7</td>
</tr>
<tr>
<td>30 min</td>
<td>8.5</td>
<td>12.0</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>60 min</td>
<td>7.0</td>
<td>13.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The measurements of the inductances were completed by using the LCR instrument as shown in Table I. It was clearly that the different between with high and low flow rate or annealing time. The measured result is obviously for the inductances which has the reduction in the environment of without annealing time. We believe that the oxygen molecular was absorbed by the titanium molecular to form the TiO₂ thin film. The absorption of oxygen molecular will have influenced for the dielectrics of the TiO₂ film. Hence, it changes the capacitances of TiO₂ film. Therefore, we suggest that the TiO₂ thin film has a ability as humidity sensor.

IV. CONCLUSION

In this paper, the oxygen flow rate during growth of titanium dioxide is controlled by mass flow controller in DC plasma sputtering growth system. The impedance of TiO₂ films for inductance effect is studied. The annealing time is the more, the inductance of TiO₂ film is the more. The growth condition of optimum and maximum inductance for TiO₂ film to as sensing device is oxygen flow rate of 15 sccm. The large inductance of TiO₂ film will be adopted to fabricate the biosensor to obtain the high sensitivity of biosensor.

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REFERENCES


Chih-Chin Yang was born in Taipei, Taiwan, Republic of China, in 1962. He received the B.S. degree, in electrical engineering from Feng-Chia University, Taiwan, in 1985. In 1988, he received the M.S. degree in electronic engineering from Chung-Yuan Christian University, Taiwan. He has been engaged in research of single crystal growth and study of semiconductor material and devices. In 1996, he received the Ph.D degree in Electrical Engineering from National Sun Yat-sen University, Kaohsiung, Taiwan. He has been engaged in research of gallium aluminium arsenic thin film growth and studies of microwave and resonant tunneling devices.

From 1985 to 1986, he joined the Foster Electronic Corporation, Kaohsiung, Taiwan, where he was worked on the design and study of loudspeaker. After receiving his M.S. degree, he was an Instructor in the Department of Mechanical Engineering at the National Sun Yat-sen University, Kaohsiung, Taiwan, from 1988 to 1990. After receiving his Ph.D degree, he was a Associate Professor in the Department of Electronic Communication Engineering at the National Peng-hu Institute of Technology, Peng-hu, Taiwan, from 1997 to 1999. In 1997, he was a Dean of office of Business Affairs in National Peng-hu Institute of Technology, Peng-Hu, Taiwan. He is currently a Associate Professor and Director in the Department of Microelectronic Engineering at the National Kaohsiung Marine University, Kaohsiung, Taiwan, from 2002. He has been engaged in research of semiconductor devices and materials, bio-sensors, annealing in semiconductor material, optimize model of semiconductor manufacturing process, infrared light detector, divided frequency and multi-value circuits. He has published many papers in SCI Journal and international conference from 1994 to now.

He had passed person qualified of the National Senior and Special Examination in civil service of electronic engineering in 1992. After passing the person qualified, he was employed in electronic communication engineering by Fisheries Administration of Council of Agriculture, in Executive Yuan of Republic of China government.

Lan Hui Huang received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan. He has been engaged in research of titanium dioxide device growth

Bo Shum Chen received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan. He has been engaged in research of titanium dioxide thin film in simulation of semiconductor structure

Jia Liang Ke received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan. He has been engaged in research of titanium dioxide thin film for theory analysis.

Chung Lun Tsai is currently a graduated student in the Department of Microelectronic Engineering at the National Kaohsiung Marine University, Kaohsiung, Taiwan, from 2008.