1. Introduction
Resistive random access memory (RRAM) device has been considered as a promising candidate to replace the present flash memory for next generation nonvolatile memory applications. However, there are large variations in switching parameters. Therefore, several techniques including modifying interface by active top electrode [1], lowering effective film thickness by embedded metal technology [2], reducing active device area by plug-bottom electrode [3], stabilize local oxygen migrations by inserting IrO2 buffer layer [4], creating locally strong electric field by process control [5], and reducing the effective film thickness by Ni migration [6] were proposed to improve the resistive switching performance. In this paper, we used nanosphere (NS) lithography to modify Pt bottom electrode with Au nanodots (Au:Pt) and fabricated the Pt/ZrO2/Au:Pt device.

2. Experimental details
Fig. 1 depicted the process of the Pt/ZrO2/Au:Pt device fabrication procedures. First, the polystyrene NSs pattern was ranged on the Pt/Ti/SiO2/Si substrate immersed with DI water to form the mask. After slowly lifting up the substrate from the solution, depositing Au metal and then, removing NSs mask, the Au nanodots formed on the Pt bottom electrode. In Fig. 2, Au nanodots prepared by the NS lithography process was checked by SEM investigation. Sequentially, fabricating the ZrO2 film on the modified bottom electrode based on our previous study [1]. Finally, after depositing and patterning the Pt top electrode, the Pt/ZrO2/Au:Pt device completed.

3. Results and discussion
Fig. 3 shows the typical resistive switching I-V curves of the Pt/ZrO2/Pt and the Pt/ZrO2/Au:Pt devices and the resistive switching behavior are reproducible. The retention characteristics of the Pt/ZrO2/Au:Pt device measured at room temperature (RT) and 150 °C as shown in the inset of Fig. 3, and there is no data loss appeared.

Fig. 4 demonstrates the statistics of the resistive switching parameters in the Pt/ZrO2/Pt and the Pt/ZrO2/Au:Pt devices, respectively. The Pt/ZrO2/Au:Pt device exhibits lower variations in Ron, Roff, Von, and Voff compared with the Pt/ZrO2/Pt device. As a result, the Pt/ZrO2/Au:Pt shows more stable resistive switching. According to the previous studies [1-6], the resistive switching mechanism is controlled by the formation and rupture of conducting filaments. The conducting filaments in the Pt/ZrO2/Au:Pt device are believed to be easily induced near the Au nanodots on the Pt bottom electrode, where the electric field across the ZrO2 film is strongest. Hence, the conducting filaments are confined here, causing less operation variations.

Table 1 shows the results of the changes in Ron, Roff, Von, Voff, and Ratio among the current reported methods to suppress the resistive switching operation variation. There are common phenomena observed: (i) a decrease in operation voltage; (ii) a decrease in Ron; (iii) a general increase in Roff; (iv) a total decrease in resistance ratio. Based on the above phenomena, it indicates that the effective resistive switching region is reduced and confined, further leading to lower operation voltage required. Hence, the resistive switching variations are restrained. The stability of the resistive switching device is more significant than the resistance ratio; in spite of the decrease in the resistance ratio, it still provides an enough memory margin for RRAM application.

4. Conclusions
In this study, Pt bottom electrode modification with Au nanodots is proposed to suppress the variations in switching parameters of the ZrO2 memory device. The retention property is also stable at RT and 150 °C. The Pt/ZrO2/Au:Pt device shows a promising potential for next generation nonvolatile memory application.

Acknowledgments
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References
Fig. 1 Schematic of the Pt/ZrO$_2$/Au:Pt device fabrication procedures. (a) Before depositing Au metal, polystyrene NSs patterning to form the mask. (b) After depositing Au metal and then, removing NSs mask, the Au nanodots formed on the Pt bottom electrode. (c) Stacking ZrO$_2$ film on the modified bottom electrode. (d) The Pt/ZrO$_2$/Au:Pt device completed finally.

Fig. 2 SEM image of Au nanodots prepared by the NS lithography process.

Fig. 3 Typical resistive switching I-V curves of the Pt/ZrO$_2$/Pt and the Pt/ZrO$_2$/Au:Pt devices. Retention characteristics of the Pt/ZrO$_2$/Au:Pt device measured at RT and 150 °C as shown in the inset.

Fig. 4 Statistics of the resistive switching parameters in the Pt/ZrO$_2$/Pt and the Pt/ZrO$_2$/Au:Pt devices, respectively. R$_{on}$ and R$_{off}$ measured at 0.3V for both devices.

Table 1 The summaries of the changes in R$_{on}$, R$_{off}$, V$_{on}$, V$_{off}$, and Ratio among the solutions to suppress the resistive switching operation variation.

<table>
<thead>
<tr>
<th>Solutions</th>
<th>Device structures</th>
<th>R$_{on}$</th>
<th>R$_{off}$</th>
<th>V$_{on}$</th>
<th>V$_{off}$</th>
<th>Ratio</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using Au nanodots</td>
<td>Ti/ZrO$_2$/Au:Pt</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>This work</td>
</tr>
<tr>
<td>Using Ti top electrode</td>
<td>Ti/ZrO$_2$/Pt</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>[1]</td>
</tr>
<tr>
<td>Embedding Cr layer</td>
<td>Al/SZO/Cr/SZO/LNO/Pt</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>[2]</td>
</tr>
<tr>
<td>Inserting IrO$_2$ buffer layers</td>
<td>Pt/IrO$_2$/NiO/IrO$_2$/Pt</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>[4]</td>
</tr>
<tr>
<td>Process control</td>
<td>Pt/NiO/Pt</td>
<td>→</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>[5]</td>
</tr>
<tr>
<td>Alloy electrodes</td>
<td>Ni$<em>{0.82}$Pt$</em>{0.17}$/NiO/ Ni$<em>{0.82}$Pt$</em>{0.17}$</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>[6]</td>
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